CITY OF SUMAS WELLHEAD PROTECTION PLAN

PREPARED FOR:

City of Sumas, Washington

PREPARED BY:

ASSOCIATED EARTH SCIENCES, INC

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Bellingham, Washington

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FORWARD

The City of Sumas Wellhead Protection Plan was funded by the Washington State Department of Ecology and the City of Sumas. The plan was developed in accordance with the guidelines presented in Washington State's Department of Health guidance document *Washington State Wellhead Protection Program*. The plan is divided into six major sections structured in the same general order as the Department of Health's guidance document:

Introduction
Delineation of Wellhead Zones of Contribution
Inventory of Potential Contaminant Sources
Management Options
Spill Response
Contingency Planning

Wellhead delineation was carried out by Converse Consultants NW and Associated Earth Sciences, Inc. After closure of Converse's Seattle office in February 1995, the personnel working on the project moved to Associated Earth Sciences, essentially intact, and completed the work under subcontract to Converse. The inventory, spill response, and contingency planning sections were prepared by Water Resources Consulting LLC under the direction of Mr. Peter Willing. Ground water management options were developed and reported by Horsley & Witten, Inc. under the direction of Mr. Jon D. Witten, AICP. Overall management of the Wellhead Protection Plan was performed by Converse/Associated Earth Sciences under direction of Mr. Erick Miller. Mr. David Davidson managed the project on behalf of the City of Sumas. In addition to administrative project oversight, Mr. Davidson was responsible for establishing the Ground Water Advisory Committee (GWAC), organizing and moderating the GWAC meetings, and preparation of the Introduction to the ground water management plan.

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EXECUTIVE SUMMARY

The Safe Drinking Water Act (SDWA) of 1986 and amendments established a requirement that ground water dependent public water systems implement a wellhead protection program. The Washington State Department of Health has a mandatory wellhead protection program that implements the SDWA 1986 amendments. The City of Sumas, bearing in mind its dependence on ground water and water quality changes in that ground water, in 1993 applied for funding from the Washington State Department of Ecology (Ecology) to carry out a wellhead protection program. Funding from the Centennial Clean Water Fund was approved in 1993, and consulting services were engaged to carry out the program in early 1994. The first task of the program is the delineation of the wellhead zone of contribution. The second task is the inventory of potential contaminant sources within the delineated wellhead protection zone. The third task is the development of management options for the wellhead area.

DELINEATION SUMMARY

The City of Sumas, Washington owns and operates two well fields, the May Road well field and Sumas well field, located in Whatcom County, Washington. The well fields are located approximately 3,000 and 600 feet, respectively, south of the international border with British Columbia, Canada. Time-related capture zones were delineated for each of these well fields.

The principal tasks performed in the delineation were development of a hydrogeologic conceptual model, numerical ground water modeling, and evaluation of time-related capture zones using numerical particle tracking methods. A hydrogeologic conceptual model for the Sumas area was developed based on existing literature and data from the U.S. Geological Survey (USGS) Lynden-Everson-Nooksack-Sumas (LENS) study.

The study area is divided into four physiographic regions: the Sumas River valley; an upland, morainal region characterized by hummocky topography and ice contact deposits; a broad, undulating upland outwash plain that extends into British Columbia; and an area of lineated topography in the southwest portion of the project area.

Three important hydrostratigraphic units are present in the study area. The Everson glaciomarine drift underlies most of the project area. The Everson glaciomarine drift is predominantly clay and forms the base of the flow system penetrated by the City of Sumas wells. The Sumas outwash is an extensive water-bearing unit in the project area and is penetrated by the City of Sumas wells. This unit is predominantly sand and gravel and was modeled as the bottom layer of the flow system. An overlying confining unit is comprised of ice marginal deposits/till/Sumas Valley lacustrine deposits. These latter units are considered collectively in the model because they form a continuous confining layer in the vicinity of the Sumas well fields.

Three aquifer regions were identified based on physiographic position.

> An unconfined aquifer in the upland Sumas sand and gravel outwash;
> a transition zone along the escarpment at the east edge of the upland area where flow through the Sumas outwash becomes confined; and,

a sand and gravel aquifer in the Sumas River Valley, confined by the Sumas Valley lacustrine deposits.

Ground water flow in the upland unconfined aquifer is radially south and eastward. Within the escarpment area west of Sumas, the ground water flow direction is predominantly east with a much steeper gradient. The ground water flow direction becomes northeast within the Sumas Valley confined aquifer.

A three-dimensional model for the site was developed for simulation of the steady-state ground water flow conditions in the vicinity of the Sumas and May Road well fields. Two geologic layers of variable thickness were included in the model. The top layer represents the confining unit comprised of Sumas Valley lacustrine silts and clays, ice marginal/till deposits and peat. This unit pinches out in the upland area. The bottom layer represents the Sumas outwash sand and gravel.

Constant head boundary conditions were assigned to all four boundaries of the bottom layer. The boundaries were located at a significant distance from the well field to minimize boundary effects on the modeled flow field.

Hydraulic conductivity values input into the model were based on pump test data and regional trends defined by specific capacity information obtained from driller's well logs. Recharge estimates for input into the model were based on existing literature and water balances performed for the upland region and the Sumas Valley.

The USGS finite difference model, MODFLOW (McDonald and Harbaugh, 1988), was used for the simulation of ground water flow in three dimensions. The particle tracking program, PATH3D, distributed by S.S. Papadopulos & Associates, was used for the simulation of movement and travel times of fluid particles in a steady-state three-dimensional flow field.

Results of the capture zone analysis indicate a capture zone extending to the northwest to the tributaries of Fishtrap Creek west of the town of Clearbrook, British Columbia. Travel times at the upstream boundary are approximately 20 years. A dispersion zone was calculated for the delineated capture zone based on average ground water flow velocity and estimates of transverse dispersivity for glacial outwash aquifer obtained from the literature. Including dispersion in the zone of contribution to the wells laterally expands the capture zones 420 feet at one year and 1,300 feet at the 10-year travel time.

INVENTORY OF POTENTIAL CONTAMINANT SOURCES

The report ranks ten categories of potential contaminant sources as to priority for management action. The most conspicuous of these are the following:

Application of poultry manure to raspberry fields: Raspberry culture is by far the largest acreage land use in the capture zone of both Sumas well fields. Raspberry plants consume a relatively modest amount of nitrogen, but the prevailing practice is to fertilize them with poultry manure far in excess of crop requirements. The excess has nowhere to go but into the ground, and contributes to elevated ground water nitrate levels.

Gravel mining and processing: Gravel mining can cause groundwater turbidity plumes, and fuel or oil can leak from equipment used in extracting or processing gravel. There are seven gravel pits or quarries within the 10-year travel time of the Sumas wells. The existing pits are all in Canada, and all beyond 5 years' time of travel to the wells. There are two proposals for new pits on the United States side of the border, within the 1- to 2-year time of travel zone.

Fuel storage tanks: Both above-ground and below-ground gasoline and diesel fuel tanks are susceptible to leaks and spills. Fuels are relatively high hazard contaminants, containing benzene and other volatiles with known health risks in drinking water. The exact number of storage tanks is not known and needs further inventory work.

Second priority was assigned to:

Unprotected wells: There are hundreds of wells in the zone of contribution to the Sumas wells, many of which have gone out of use but have never been properly capped. Each well is a potential conduit through which contaminants can inadvertently or purposefully be introduced into the aquifer.

Other lower priority activities and contaminant sources are:

Household hazardous wastes: Use of potential contaminants is associated with single-family suburban dwellings. A variety of lawn and automobile care products can find their way to the aquifer from such areas.

On-site waste disposal systems: There are 296 known on-site waste systems in the inventory, 120 of which are in the 10-year time of travel zone. All but two or three are beyond the 2-year time of travel. The Canadian municipalities (formerly Matsqui and Abbotsford, now combined) have detailed design and construction requirements applying to new systems and many existing ones. Current studies indicate that bacterial contamination attenuates rapidly with distance, well within 6 months' travel time. Viruses may survive somewhat longer distances. On-site systems can be contaminated by household chemicals: paint, solvents, cleaning agents, pesticides, oil, etc.

Agriculture other than raspberries: Most areas that are suitable to berry culture have been taken over for that purpose because of high prices. There are approximately fifteen identifiable parcels in non-berry agriculture.

Industrial and commercial facilities: There is industrial and commercial development north and east of the Abbotsford Airport, which is in the 15- to 20-year travel times.

Storm water management: This is not an issue in the capture zone at present, though it could become one where urbanization takes place and contaminated impervious surfaces replace relatively clean, vegetated, porous ones. Currently, there is hardly any surface runoff; the rainfall infiltrates directly into the aquifer.

MANAGEMENT OPTIONS

The City of Sumas shares the responsibility to protect and manage the Abbotsford-Sumas Aquifer with Whatcom County, the City of Abbotsford, B.C. and the Province of British Columbia. The challenge before the City is clear to protect its limited drinking water supply from a variety of known and well documented threats. Experience in the northwest, as well as throughout the United States and Canada, dictates that the cost of removing contaminants from ground water is so expensive that it is often cheaper to develop a new water supply, if possible, than to attempt to clean one that is contaminated. In Sumas, however, while the cost of new supply development may be cheaper than remediation, the overriding factor is that there is no evidence that easily obtained clean supplies are available.

Common sense dictates that if the responsible parties do not actively take steps to protect the Abbotsford-Sumas Aquifer, the ground water will become *more* contaminated in the near future.

As a result of the information gathered and analyzed during the course of the wellhead protection study, in conjunction with the abundant documentation of the significance of the Abbotsford-Sumas Aquifer, the following series of management options is recommended.

Legislative. Canadian officials indicate that no comprehensive ground water legislation has been enacted in British Columbia. In the absence of such legislation, their ability to control land-use over the aquifer is hampered. Certain provincial agencies have attempted to enact the necessary legislation, but the efforts have not yet succeeded. The City of Sumas should support the agencies' efforts by asking legislators and ministers to enact appropriate legislation.

Non-regulatory. The City should undertake a number of programs designed to educate farmers and homeowners who live and work over the aquifer. The programs include:

Roadside signs reminding drivers of the existence of the aquifer and displaying a phone number to contact in case of a hazardous material spill.
Posters and brochures designed to heighten homeowners' awareness of the aquifer and to educate them about steps they can take to protect water quality, such as proper maintenance of septic systems, proper disposal of household hazardous wastes, and closure of abandoned wells.
Workshops designed to heighten farmers' awareness of the aquifer and their knowledge of best agricultural practices.

Regulatory. The City should pursue amendments of the zoning regulations adopted by Whatcom County and the City of Abbotsford. The recommended amendments include:

Revision of agricultural zoning to limit the number of animal equivalents per acre, to establish performance standards for nutrient loading to the ground water, and to delete certain conditional uses (e.g., multi-family residences, landing strips, transitory solid waste facilities, commercial gravel extraction and processing) within wellhead protection areas.

Revision of clustering regulations such that clustering occurs outside wellhead areas.

Revision of density-transfer regulations such that density is not transferred into wellhead areas.

Revision of industrial zoning (in Abbotsford) to eliminate various uses threatening to ground water (e.g., processing, refining, mixing or bulk storage of petroleum) within wellhead protection areas.

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1.0 INTRODUCTION

Sumas is a small city (population 900) adjacent to the Canadian border in Whatcom County, Washington. Sumas operates two well fields from which water is provided to city residents as well as 1,400 other people living within a 25-square-mile area south of town, including the residents of the City of Nooksack. The well fields are located approximately 3,000 and 600 feet, respectively, south of the international border with British Columbia, Canada.

Sumas's water is a major regional resource and also a source of local pride. The well fields are situated at the foot of an upland region that stretches north into Canada. Rainwater recharges an aquifer underlying the upland, and ground water is naturally discharged at the foot of the upland in a series of springs. Sumas's drinking water was drawn directly from a spring until midway through the century, but a number of wells have been developed since then. All the wells exhibit artesian flow. The city has monitored water quality for many years, and no treatment of the water has ever been necessary. People throughout the region are pleased to drink Sumas well water.

There has been an increased focus on quality of ground water since reauthorization of the federal Safe Drinking Water Act (SDWA) in 1986. That act established new monitoring requirements to be phased in over a period of years, as well as a requirement that ground water-dependent water systems create a wellhead protection program. This heightened focus on water quality caused city officials to realize the seriousness of one lingering issue the presence of nitrate in the city's water. The SDWA specifies a maximum contaminant level of 10 milligrams per liter (mg/l) for nitrate within drinking water. Any concentration less than 2 mg/l is considered to be a natural background amount. At Sumas's two well fields, nitrate concentrations are well above background levels, varying between 2.5 mg/l and 13.5 mg/l depending upon the season and the well field. One well field is consistently above the maximum of 10 mg/l and is therefore used only for industrial processes. The second field, used for all potable water, has nitrate levels that fluctuate between 2.5 mg/l and 7 mg/l.

Nitrate is a common contaminant throughout the upland aquifer adjacent to Sumas. Nitrate concentrations as high as 30 mg/l can be found in some wells. The upland is prime agricultural land, and the source of the nitrate is animal waste generated at dairy farms and poultry farms that is then spread as fertilizer for various crops. Nitrogen from the animal waste can be flushed easily from the surface down to the water table. In other regions of the aquifer, contamination from agricultural pesticides and herbicides is also a serious problem.

The upland region is known as the Abbotsford-Sumas aquifer, and the aquifer is used as a drinking water supply both north and south of the Canadian border. The greatest use of the aquifer is within Abbotsford, B.C., where as many as 90,000 people drink the ground water at certain times of the year. Sumas's water system is the largest system tapping the aquifer within the United States.

Concerns about degradation of water quality within the aquifer led to the creation in 1992 of the Abbotsford-Sumas Aquifer International Task Force, a collaborative effort of the State of Washington and the Province of British Columbia. Sumas's mayor sits as a member of the Task Force. The Task Force has completed an information-gathering effort and is now beginning to recommend plans of action.

In light of the SDWA's requirement that Sumas create a wellhead protection plan, and in concert with the Task Force's efforts to deal with the aquifer, Sumas launched its own planning effort in 1993. The city sought a grant from the Washington State Department of Ecology Centennial Clean Water Fund in early 1993. The grant was awarded in late 1993, and selection of a consultant team was complete by the spring of 1994. Development of the plan was complete by the fall of 1995. Washington State Department of Ecology formally approved the plan in December 1995. The letter of acceptance is presented in Appendix C.

The plan describes the methods and results of the capture zone delineation for the Sumas and May Road well fields, results of the contaminant source inventory within the delineated wellhead protection zone, and management options for protection of the capture zone. This work was performed as part of the wellhead protection program for the City of Sumas, Washington, United States of America. Section 1428 of the 1986 Amendments to the federal Safe Drinking Water Act mandates that every state develop a wellhead protection program. In Washington state, the Department of Health is lead agency for program development and administration. The objective of the program is to prevent contamination of ground water used by public water systems.

1.1 GROUND WATER ADVISORY COMMITTEE

A plan is worthless unless it suggests a plan of action that has a chance of success. Given that the aquifer spans municipal jurisdictions in two countries, the advice of officials from other jurisdictions was seen as crucial to development of the plan. A Ground Water Advisory Committee (GWAC) was formed at the onset of the planning effort and met regularly throughout plan development. Members of the GWAC were chosen to represent the various stakeholders involved with the aquifer (farmers, gravel miners, water consumers) as well as the various jurisdictions controlling land use (Province of British Columbia, Whatcom County, City of Sumas, City of Abbotsford, B.C.) The GWAC consisted of the following people:

Ground Water Advisory Committee
City of Sumas Wellhead Protection Program

Steven Koehler	Citizen of Sumas
Pierson Dykstra	Dairy farmer and president of the Sumas Rural Water Association
Sue Blake	Water resource manager for Whatcom County
Gordon Scott	Land-use planner for Whatcom County
Alvin Starkenburg	Member of Whatcom County Council and owner of a gravel mining business
David Ernst	Member of the Whatcom County Planning Commission
Jim Lamson	Citizen of Abbotsford, B.C.
Mike Quinn	Member of the Sumas City Council
Robert Mitchell	Mayor of the City of Sumas
Lawrence Silvis	Utilities superintendent of the City of Sumas
Peter Andzans	Environmental manager of the City of Abbotsford, B.C.
Brad Whittaker	Coordinator of Project Enviro-Health in Abbotsford, B.C.
Ron Bertrand	Manager of the soils and engineering branch of the British Columbia Ministry of Agriculture, Fisheries and Food
Kevin Chipperfield	Coordinator of the Sustainable Poultry Farming Group in Clayburn, B.C.
Brad Boyes	Councillor of the City of Abbotsford, B.C.
Ken Funk	Councillor of the City of Abbotsford, B.C.
David Davidson	Project manager for the City of Sumas

The City of Sumas gratefully acknowledges the efforts of the committee members.

The committee met six times during development of this plan in order to review data generated by the consultants and to provide advice about appropriate plans of action. The meeting dates and general topics of discussion were as follows:

Ground Water Advisory Committee
Meeting Dates and Topics

May 13, 1994	Introductory meeting and description of program phases
July 21, 1994	Delineation of recharge area
September 22, 1994	Inventory of land uses in recharge area
January 12, 1995	Options for management of recharge area
March 2, 1995	Continued discussion of management options
June 22, 1995	Refinement of delineation, Continued discussion of management options, Spill-response plan and contingency water supply plan

The majority of the members of the GWAC have endorsed the management actions proposed in the plan, although certain proposals have not received universal support.

This report is divided into two sections. This first section presents the capture zone delineation. The second section presents an inventory of land use and potential sources of ground water contamination within the capture zone.

2.0 DELINEATION

2.1 INTRODUCTION

The principal tasks performed in delineation of the Sumas wellhead protection area were development of a hydrogeologic database and conceptual model, numerical ground water modeling, and evaluation of time-related capture zones using numerical particle tracking methods. A hydrogeologic conceptual model of the Sumas area was developed based on existing literature and data from the USGS Lynden-Nooksack-Everson-Sumas (LENS) study. Based on this conceptual model, the wellhead protection zone was delineated by first simulating the ground water flow field using the USGS numerical flow model, MODFLOW. The particle tracking program PATH3D, developed by S.S. Papadopulos & Associates of Bethesda, Maryland, was then used for simulation of movement and travel times of fluid particles in steady-state three-dimensional flow.

This work was performed in accordance with our March 7, 1994 scope of work. Results of the delineation were presented at a July 21, 1994 meeting of the Sumas Ground Water Advisory Committee (GWAC).

2.2 CONCEPTUAL HYDROGEOLOGIC MODEL

2.2.1 **Data Sources/Previous Investigations**

The hydrogeologic conceptual model was based on a review of geologic and hydrogeologic reports from Canadian and United States sources. Geologic mapping of the study area was obtained from Easterbrook (1976) (U.S. portion) and Armstrong (1976) (Canadian portion). Geologic history of the study area was compiled from Easterbrook (1969, undated field trip guide), Armstrong et al. (1965), and Armstrong (1978). Basic well log data was compiled from Washington State Department of Ecology (Whatcom County well logs) in Bellevue, Washington and the USGS in Tacoma (Canadian well logs).

Hydrogeologic investigations by USGS (unpublished data), Kahle (1990), Creahan (1988), Gibbons and Culhane (1994), Liebscher et al. (1992), Garland and Erickson (1994), Callan (1971a and 1971b), Lindsay (1988), and Golder Associates (1987 and 1992) were used to obtain detailed aquifer information. The most important source of basic data including well locations, elevations, and water level measurements was the USGS Lynden-Everson-Nooksack-Sumas (LENS) study. Kahle (1990) also provided detailed information on well locations, elevations and water levels in much of the Whatcom County portion of the study area.

Detailed water level and well information were also obtained from Garland and Erickson (1994) as part of a ground water quality survey near the Edaleen Dairy. Data on spring discharge into Johnson Creek and water balance estimates were obtained from Gibbons and Culhane (1994). Interpreted ground water flow direction and basic ground water level data in the vicinity east of Judson Lake were obtained from Golder Associates (1992).

Hydraulic data specific to the Sumas and May Road well fields was obtained from pump test data provided by Golder Associates (1987) and Robinson and Noble (1992a, 1992b, and 1992c). Existing pumping rate data and appropriated water right data were provided by the City of Sumas.

Interpreted ground water flow directions in the Canadian portion of the study area were obtained from Liebscher et al. (1992). Aquifer hydraulic constants were obtained from pump test data by Callan (1971a and 1971b) at the Fraser Valley trout hatchery wells. Pumping rates of the District of Matsqui wells, City of Abbotsford wells, and trout hatchery wells were obtained from discussions with the local purveyors.

2.2.2 Physiography

Four physiographic regions have been recognized in the project area (Figure 2-2-2) (Kahle, 1990). The Sumas River occupies a broad, flat valley oriented approximately northeast-southwest. Immediately adjacent to the valley is an upland, morainal region characterized by hummocky topography and ice contact deposits. Northwest of this area, the hummocky topography gives way to an undulating upland region extending well into British Columbia. An upland area of lineated topography lies in the southwest portion of the project area.

2.2.3 Geology

Geologic conditions in the study area consist of a sequence of unconsolidated glacial deposits associated with the Fraser glaciation, which occurred from approximately 25,000 to 10,000 years before present (ybp). A summary of the depositional history of the area is presented below.

The Fraser glaciation is the last major glacial episode in which glaciers occupied southwestern British Columbia and western Washington. Three major ice advances and one interglacial period are associated with the Fraser glaciation. From oldest to youngest these are:

Evans Creek Stade
Vashon Stade
Everson Interstade
Sumas Stade

A generalized geologic map of the study area is presented in Figure 2-2-1. A geologic cross section through the Sumas well field is shown in Figure 2-2-2.

During the early portion of the Fraser glaciation, alpine glaciers grew and advanced down-valley. This advance is believed to have occurred approximately 21,500 and 18,000 ybp. This ice advance, termed the Evans Creek Stade, was greatest in the valleys to the north and decreased to the south. Thus, in the Skagit Valley, ice reached the mouth of the valley, while at Mt. Rainier the ice remained relatively far upvalley. No deposits of the Evans Creek Stade have been mapped in the Sumas area, although the climatic changes associated with this glaciation may have had an impact on deposition in the project area.

The major advance of continental glacial ice, known as the Vashon Stade of the Fraser glaciation, reached the Seattle area about 16,000 ybp. As the ice sheet advanced southward, the Strait of Juan de Fuca became blocked by ice, forming a large glacial lake in the area of modern-day Puget Sound. Drainage from the Cascade and Olympic Mountains transported sediment into the lake and deposited the coarser material in deltaic fans along the lake margin, while the distal portions of the fan and into the lake were blanketed by silts and clays referred to as the Lawton clay.

Coarse material was deposited near the advancing glacier face. The succession of sand and gravel deposits laid down by the advancing ice, termed the Esperance sand in the U.S. and the Quadra sand in Canada, was deposited between 26,000 and 18,000 ybp. At its maximum extent, about 14,000 ybp, the ice had advanced about 50 miles south of Seattle. The succession of deposits laid down by the advancing glacier were, in turn, overridden by ice and blanketed by till. Vashon till caps most of the Puget Lowland today. There are no exposures of Lawton clay, Esperance sand, or Vashon till in the study area, although the Vashon till and Esperance sand likely underlie the project area at depth. The ice retreated from the Seattle area about 12,000 to 13,000 ybp and deposited recessional outwash, which collected in valleys and swales.

Glaciomarine and marine deposits accumulated in the lowlands of western Washington and British Columbia during the interglacial period referred to as the Everson Interstade. The Everson Interstade was marked by an invasion of the sea approximately 13,000 ybp and ended with advance of the Sumas ice about 11,000 ybp. Glaciomarine drift deposited in a marine environment is typically an unstratified, pebbly, sandy silt and silty clay derived from rock debris melting out of the floating ice. In the Canadian literature, the deposits associated with the Everson Interstade are referred to as the Fort Langley formation.

Fence diagrams by Halstead (1986) show the Everson glaciomarine drift to be a continuous layer underlying the Sumas outwash in the study area. Similar interpretations are presented in cross sections by Armstrong (1976). Glaciomarine drift is exposed in a large upland area in the northwest portion of the project area, west of the town of Clearbrook, British Columbia (Figure 2-2-1). Everson glaciomarine drift is exposed in the region of lineated topography located southwest of the project area (Figure 2-2-1). This area has been interpreted as estuarine deposits equivalent with Sumas Stade by Easterbrook. Based on stratigraphic relationships (i.e., position beneath Sumas sand and gravel outwash), Kahle (1990) favors an interpretation of materials in this area as a stratigraphic equivalent of the Everson glaciomarine drift.

In the project area, the Everson Interstade ended with the re-advancement of the continental glacial ice during the climatic episode termed the Sumas Stade. The re-advance of the ice has been dated at approximately 10,000 to 11,000 ybp. The advancing and later retreating ice lobe deposited outwash over a wide portion of the study area, referred to as Sumas outwash. The advance and recessional outwash of the Sumas Stade are not differentiated in this investigation, consistent with most mapping of this unit. The outwash deposits form a broad upland area extending northwestward from the Nooksack and Sumas River flood plains (Figure 2-2-1). The outwash is cobble-boulder gravel near the Canadian border and grades southwestward to sand near Lynden. Near the Abbotsford Airport, measured sections reported by Armstrong (1978) indicate the glaciofluvial sediments of the Sumas outwash are pebble to boulder gravel and sandy gravel.

Former meltwater channels within the outwash were later filled with peat, such as at Pangborn Bog and the surrounding vicinity. Glacial till and other ice contact deposits were deposited and are found as lenses within the Sumas outwash and as a cap to the outwash in the morainal region (Figure 2-2-1).

A sandy, silty clay layer occupies the Sumas River Valley. The origin of this unit is somewhat uncertain. Easterbrook mapped this unit as alluvium. However, Kahle (1990) favors a lacustrine origin for this unit based on its location within a moraine-encircled region, suggesting the outlet to this region may have once been dammed by morainal deposits. Well log data suggests this unit thickens to the northeast.

2.2.4 **Hydrogeology**

Using available information, well locations were plotted on the USGS 7.5-minute topographic map and Environment Canada map converted to the same scale. Well locations and elevations, water level data and other pertinent information were tabulated from well data obtained from the USGS LENS study, Kahle (1990), and Ecology for the project vicinity. The tabulated well data is presented in Appendix A and the well locations are shown in Figure 2-2-3. Wells that were only located to the nearest 40-acre subsection based on Ecology well log designation are indicated in the comments column. Locations of other wells were field-located by USGS or Kahle (1990).

The following identifier format was used for U.S. wells and is consistent with the LENS study: T40N R4E-5P1. In this example, the well is located in Township 40 North, Range 4 East, Section 5 and subsection P. The final "1" indicates this is the first well in this 40-acre subsection. Appendix A, Table A-1 presents the location key for the letter designation identifying a particular 40-acre subsection.

The following identifier format was used for Canadian wells and is consistent with the designation used in the LENS study: 092G.9.1.3.3-2. The Canadian well location system is based on successive quartering. In this example, 092 indicates the British Columbia Geographic Map System 1:250,000 map number; the number 9 indicates the 1:20,000 scale map derived from the breakdown of the 1:250,000 scale map into 100 equal parts; number 1 indicates the southwest quarter within this map; number 3 indicates the northwest quarter within the southwest quarter; the second number 3 indicates the southwest quarter within the southwest quarter. The 2 indicates this is the second well in the database within this quarter. Table A-1 presents the British Columbia Geographic System.

2.2.4.1 Hydrostratigraphic Units

A hydrostratigraphic unit is a geologic formation or part of formation, or a group of formations in which there are similar hydrologic characteristics such as porosity and permeability, allowing for grouping into aquifers or confining layers.

Three hydrostratigraphic units are of importance in the hydrogeologic conceptual model. These units include the Everson glaciomarine drift, Sumas outwash, and ice marginal/till/Sumas Valley lacustrine deposits.

2.2.4.1.1 Everson Glaciomarine Drift

The Everson glaciomarine drift underlies the Sumas outwash throughout the study area except in the area of lineated topography, southwest of Sumas where it is exposed at the surface. The distribution of this deposit is based on constructed fence diagrams by Halstead (1986) and structure contour maps by Kahle (1990). Kahle reports the thickness of the glaciomarine drift ranges from 20 to over 95 feet. The unit is predominantly clay and forms a major confining unit in the study area. The top of the Everson glaciomarine drift is considered the bottom of the flow system penetrated by the Sumas well field.

2.2.4.1.2 Sumas Outwash

The Sumas outwash is an extensive water-bearing unit in the project area. Thickness of this predominantly sand and gravel unit reportedly ranges from 70 to over 200 feet. Till and ice marginal deposits occur as lenses throughout the Sumas outwash, although as discussed above, they appear to occur less frequently to the west. The lenses of the ice contact deposits have lower permeability than the surrounding material. The lenses do not appear to have any significant effect on water levels, indicating that good hydraulic communication exists in aquifer material lying above and below the ice contact lenses. Sand and gravel deposits that underlie the Sumas Valley lacustrine deposits are considered part of the Sumas outwash in this investigation, because of their textural similarity. However, several well logs for wells completed within the Sumas Valley indicated the presence of wood, while no wood was identified in well logs for the upland region.

2.2.4.1.3 Ice Marginal/Till/Sumas Valley Lacustrine Deposits

The ice contact deposits including the glacial till and ice marginal deposits of the Sumas Stade are considered to be semi-confining to confining units. These deposits are typically poorly sorted and dense. The ice marginal, till, and Sumas Valley lacustrine deposits are considered collectively because they form a continuous confining unit in the area of the Sumas and May Road well fields. Isolated lenses of glacial till and ice marginal deposits within the Sumas outwash were interpreted on cross sections by Halstead (1986) and are indicated on some of the Canadian well logs. Fence diagrams by Halstead (1986) also indicate the ice contact/till lenses occur less frequently to the west, where the underlying glaciolacustrine deposits are interpreted to be overlain by a uniform blanket of outwash.

Thickness of this hydrostratigraphic unit is variable. The ice contact deposits in the vicinity of the Sumas and May Road well fields are approximately 20 to 25 feet thick. At the Sumas well field, a peat deposit 30 feet thick was penetrated during the drilling. The thickness of the lacustrine deposits ranges from approximately 15 feet adjacent to the valley margin and increases to 56 feet (well 9.2.2.1.03) where the Sumas River crosses the Canadian border.

2.2.4.2 Aquifer Regions

Three aquifer regions were identified in this investigation based on physiographic position. Although the aquifers are discussed in terms of their physiographic position, ground water flow is hydraulically continuous between the three areas. The three areas are:

> an unconfined aquifer in the upland Sumas sand and gravel outwash;
>
> a transition zone along the escarpment at the east edge of the upland area where the flow through the Sumas outwash becomes confined beneath the till/ice marginal deposits, and;
>
> a sand and gravel aquifer, presumably Sumas outwash, in the Sumas River Valley confined by the Sumas Valley lacustrine deposits.

The locations of these areas are shown in Figure 2-4-4.

2.2.4.3 Ground Water Flow

Ground water flow in the upland unconfined aquifer is radially south and eastward at a gradient of approximately 0.002 ft/ft. Within the escarpment area west of Sumas, the ground water flow direction is predominantly to the east at a relatively steep gradient of 0.01 ft/ft. Ground water flow direction turns to the northeast in the Sumas Valley confined aquifer where it parallels the Sumas River. The gradient in the Sumas Valley confined aquifer is approximately 0.001 ft/ft. Ground water flow is further described in Section 2.3.2. The interpolated potentiometric surface for the Sumas outwash is presented in Figure 2-4-6.

2.2.4.4 Ground Water Recharge/Discharge

Ground water recharge occurs predominantly in the upland area through precipitation. Precipitation on the clay uplands, north of the aquifer, runs off into local ditches and Fishtrap Creek, which then flows south across the aquifer. Recharge of the aquifer occurs through the unlined drainage ditches as water is lost into the relatively permeable sand and gravels. Fishtrap Creek seasonally is a losing stream, recharging the ground water system during the winter months when water levels in the creek are higher than the water table. The situation reverses from approximately March-September when water levels in the creek are less than the water table. The clay uplands act as a surface water and ground water divide. North of this divide, flow is into the Fraser River basin.

Recharge rates in the upland outwash area and the Sumas Valley region were estimated at 30 and 6 inches, respectively, based on water balance calculations performed for these areas. The water balances are presented in Tables 2-2-1 and 2-2-2. Water balance input parameters are discussed in Section 2.4.1.4.

Ground water discharge from the upland area occurs through numerous springs located along the escarpment at the east edge of the transition zone, including springs at both the Sumas and May Road well fields. Spring flow at the Abbotsford trout hatchery during the dry season in 1967 was measured at approximately 9 cubic feet per second (cfs) over a length of 5,000 feet, prior to development of the well field (Callan, 1971a). Gibbons and Culhane (1994) report that spring flows emanating along the U.S. portion of the escarpment totaled approximately 10 cfs at the end of the dry season in 1993. Spring flow from this area provides base flow to Johnson Creek.

Gibbons and Culhane (1994) estimate approximately one-third of the discharge from the upland unconfined aquifer occurs as underflow into the Sumas Valley confined aquifer. Water levels in the Sumas Valley confined aquifer suggest this aquifer discharges into the Sumas River.

2.2.4.5 Hydraulic Parameters

Hydraulic conductivity values for the study area ranged from less than 10 ft/day to over 3,000 ft/day based on specific capacity information provided on driller's logs. Hydraulic conductivity estimates of 250 to 600 ft/day were obtained for the transition zone based on pump test data from the May Road well field, Sumas well field, and the Fraser Valley trout hatchery wells.

Specific capacity data for the upland unconfined aquifer suggest hydraulic conductivity values similar to those measured in the transition zone. However, no pump test data were available from wells in the upland unconfined aquifer. Geologic descriptions of the aquifer in this region suggest a greater hydraulic conductivity in the upland area then in the transition zone.

Hydraulic conductivity trends based on specific capacity information indicate the Sumas Valley aquifer has the greatest hydraulic conductivity in the study area. No pump test data was available for wells completed in the Sumas Valley aquifer.

2.3 GROUND WATER USE

Several large municipal wells serve the City of Abbotsford, British Columbia, the District of Matsqui, British Columbia, and the City of Sumas, Washington. The City of Abbotsford has four well fields located between Huntingdon and Abbotsford. Three of these well fields are operational with water use ranging from 500 gallons per minute (gpm) to 1,435 gpm. The fourth well field has been tested at 2,000 gpm, but was not in service at the time of this investigation. The Fraser Valley trout hatchery well field is located in the same vicinity with water use ranging from minimum flows of 1,800 gpm to a maximum continuous pumping rate of 2,600 gpm.

The District of Matsqui has five large capacity wells, which are used for backup purposes during the summer months. Use of these wells typically is for a one-month period, but during the summer of 1994, they were used for a three-month period. Two of these wells, Townline # 1 and #2, are located immediately north of the Abbotsford Airport. These wells have pumping rates of 685 and 468 gpm. Lucerne Food operates a large capacity (961 gpm) well immediately north of the Townline wells. Three wells (Marshall #1 through #3) are located at the south end of the town of Clearbrook. These wells have a combined pumping rate of 3,038 gpm.

The City of Sumas owns and operates the May Road well field and the Sumas well field. The Sumas well field consists of five wells with total depths ranging from 57 to 79.5 feet below ground surface. Wells 1 through 3 gravity-feed to the city booster pump facility. The water supplies the City of Nooksack and the Nooksack Rural Water Association. Wells 4 and 5 feed the City of Sumas and the Sumas Rural Water Association. Current water use for the Sumas well field is 42,000,000 cubic ft/annually or an average of 598 gpm. Full appropriation level for this well field is 2,250 gpm.

The May Road well field has three wells varying in depth from 53.7 to 70.5 feet. Wells 1 and 3 are connected to the distribution system, but only Well 3 is currently operational. This well pumps at 500 gpm and a portion of this water (approximately 100 gpm) replenishes a nearby stream that flows into Johnson Creek. The remainder of the water (approximately 400 gpm) is used at a local cogeneration plant. This well field has had a history of nitrate levels consistently exceeding the Washington State Department of Health standard of 10 parts per million (ppm). However, nitrate levels appear to be decreasing over time. Full appropriation level for the May Road well field is 1,660 gpm.

In addition to the municipal and trout hatchery well fields described, one other well producing greater than 500 gpm is located in the project area south of the Abbotsford Airport (Liebscher et al., 1992). This well is used for agricultural purposes. Several smaller capacity irrigation and industrial wells are located in the project area, as well as numerous domestic wells.

2.4 GROUND WATER MODEL

2.4.1 **Model Configuration**

Based on the regional flow field described in the conceptual model above, a three-dimensional model for the site was developed for the simulation of the steady-state ground water flow conditions in the vicinity of the Sumas and May Road well fields. The model domain was oriented approximately at an angle of 41 degrees clockwise with respect to the east-west direction, such that the two opposite model boundaries are generally parallel to the regional ground water flow direction (Figure 2-4-1). A length of 35,600 feet was selected for the model domain in the regional flow direction (northeast and southwest) based on the location of the upstream ground water divide and the downstream Sumas Valley. The length of the domain in the perpendicular direction was selected to be 25,500 feet based on the location of the ground water divides and bedrock outcrops along the lateral boundaries and the probable zone of influence of the extraction wells. The model layers were discretized by a variably-spaced finite difference grid consisting of 106 rows and 115 columns (Figure 2-4-1). The grid line spacing varied from 150 feet to 600 feet in the regional flow direction (x) and from 150 to 500 feet in the perpendicular direction (y). The region of minimum spacing was centered around the Sumas and May Road well fields.

2.4.1.1 Geologic Layers and Hydraulic Conductivities

Two geologic layers of variable thickness were included in the model as shown in Figures 1-4-2 and 2-4-3. The top layer is present in the transition zone and the Sumas Valley. It includes the confining unit comprised of Sumas Valley lacustrine silts and clays, ice marginal/till deposits and peat. This top unit pinches out in the upland area consistent with the surficial geologic maps and well log data. The confining layer was divided into two hydraulic conductivity zones (Figure 2-4-4). A zone in the Sumas Valley area was assigned a very low hydraulic conductivity (0.64 ft/day), which is consistent with the silt and clay deposits of the valley. The transition zone was given a slightly higher conductivity value for the ice marginal/till deposits of the upland area, based on geologic descriptions.

The bottom layer represents the Sumas outwash sand and gravel. The bottom of this layer is defined by the top of the Everson glaciomarine silts and clays and is consistent with the previous interpretations by Kahle (1990). This layer was divided into four hydraulic conductivity zones, as shown in Figure 2-4-5: the upland unconfined area, the upstream transition zone, the downstream transition zone, and the Sumas Valley confined aquifer. Hydraulic conductivity trends in these zones were consistent with those determined from specific capacity data presented on well logs and the transmissivity trends presented by Gibbons and Culhane (1994). Hydraulic conductivity values modeled in the transition zone were slightly less than the values determined from the pump test data within the transition zone.

The anisotropy ratio of the hydraulic conductivities in two perpendicular directions in areal plane was maintained at unity for both model layers. The ratio of vertical hydraulic conductivity to horizontal hydraulic conductivity was maintained at 100 for both layers. This value is considered reasonable for layered, heterogeneous systems (Freeze and Cherry, 1979).

2.4.1.2 Measured Ground Water Levels for Sumas Outwash Layer

Measured ground water elevation data within the model domain were compiled from various sources including the USGS LENS study. The most complete seasonal data set, inclusive of U.S. and Canadian wells, was data for May/June 1990 obtained as part of the LENS study. Measured values at selected locations were used for the calibration of the ground water flow model. This water level data set was also used to develop a potentiometric surface for the Sumas outwash (bottom) layer. Calibration data points were restricted to those wells with May/June 1990 water level data, known elevations and locations. Based on the measured water level elevations, the method of Kriging was used to interpolate values of water level elevation at all grid nodes of the model domain. Figure 2-4-6 shows the contours for the interpolated potentiometric surface with the location of the measured data points. This potentiometric surface was used to specify head values at the constant head cells for both model layers.

2.4.1.3 Boundary Conditions

Constant head boundary conditions were assigned to all four boundaries of the bottom layer. The boundaries were located at a significant distance from the well field to minimize boundary effects on the modeled flow field. The head values were specified by the interpolated ground water elevations obtained from the measured data as described above. The boundaries are listed below:

Southwest Downstream Boundary. Head values were specified by the interpolated ground water elevations. Contours of ground water elevation in this area are consistent with previous interpretations by Liebscher et al. (1992), Creahan (1988), and Kahle (1990).

Northwest Upstream Boundary. Head values were specified by the ground water elevation near Fishtrap Creek south of Highway 1 and at an interpreted ground water divide north of Highway 1. Fishtrap Creek passes beneath Highway 1, southwest of Clearview. North of this point, the creek rises up into the clay uplands, and ground water levels measured in wells near the creek suggest the creek is no longer in direct communication with the ground water aquifer, i.e., ground water levels are significantly lower than creek elevation. This interpretation is consistent with other studies such as Gibbons and Culhane (1994), which delineate a similar aquifer boundary, and Liebscher et al. (1992), who describe hydraulic communication between Fishtrap Creek and the aquifer.

Northeast Lateral Boundary. The constant head boundary condition was defined by the ground water level contours, which is consistent with other studies such as potentiometric surfaces developed by Liebscher et al. (1992).

Southeast Boundary. The constant head boundary was assigned with head values specified based on ground water level contours. Ground water level contours are consistent with Kahle (1990) and Gibbons and Culhane (1994).

For the top layer, a no-flow boundary condition was specified for the upstream boundary and both lateral boundaries. A constant head boundary condition was specified for the downstream boundary with the head values the same as that of the bottom layer. The contact surface between the Sumas outwash layer and the underlying Everson glaciomarine drift was assumed to be a no-flow boundary surface.

2.4.1.4 Recharge

The model domain was divided into two recharge zones, as shown in Figure 2-4-7. The downstream zone included the transition zone and the valley area. Forty-six inches of mean annual precipitation was estimated for this zone based on climate data from Clearbrook weather station in Whatcom County. A relatively high runoff coefficient for this area was obtained from tables by Lu et al. (1985) based on soil type and slope. Evapotranspiration and soil moisture conditions were obtained from estimates by Gibbons and Culhane (1994). Results of the water balance indicated approximately 9 inches of recharge in the Sumas Valley through infiltrating precipitation. During the model calibration process, a relatively low recharge intensity (6 inches) was specified for this zone, suggesting a higher runoff coefficient or less precipitation.

The upstream recharge zone included the upland area. A mean annual precipitation of 58 inches is reported for the Abbotsford Airport by Callan (1971a) and Kohut et al. (1989). Other input parameters were obtained from the same source as for the upstream recharge zone. The water balance shown in Table 2-2-2 is for 1990 precipitation data presented by Liebscher et al. (1992). During 1990, precipitation was approximately 10 inches above the mean and this is reflected in the calculated recharge estimate. Callan (1971b) estimated 24 inches of recharge for the upland area. A relatively high value of 30 inches was used in the model based on the mean annual precipitation and the water balance shown in Table 2-2-2. A relatively low runoff coefficient was selected for this zone. The absence of surface water drainage features in this area is consistent with this selection.

2.4.2 Numerical Simulation Models

The USGS finite difference model, MODFLOW (McDonald and Harbaugh, 1988), was used for the simulation of ground water flow in three dimensions. The particle tracking program, PATH3D, distributed by S.S. Papadopulos & Associates of Bethesda, Maryland, was used for the simulation of movement and travel times of fluid particles in a steady-state three-dimensional flow field. The computed pathlines provide a visual description of the ground water flow regime. PATH3D computes the linear seepage velocity of flow using the hydraulic head solution predicted by MODFLOW and the specified effective porosities of various geologic units. Consequently, the particle tracking simulations represent the steady-state movement of a conservative, non-reactive constituent in ground water.

2.4.3 Model Calibration

The model described above was used to perform the simulation of ground water flow pattern at the site. All simulations were performed in the steady-state mode, that is the temporal variations of various hydrologic elements (such as recharge rate, well extraction rate, and specified heads) were not considered in the simulations, instead time-averaged values of these quantities were input or predicted. This was done primarily because of the lack of adequate data (such as the storage coefficients of geologic units and seasonal variation of recharge rates and extraction rates) required for a transient simulation, which generates time-dependent results.

Since the only complete seasonal water level data set, inclusive of U.S. and Canadian wells, was available for May/June 1990, the ground water model was calibrated against this data set, with appropriate recharge intensities applied to the top active model cells. Hydrographs for the Abbotsford aquifer reported in Liebscher et al. (1992), for example, indicate the May/June water levels represent an average condition. Selected data points were eliminated from the May/June 1990 data set that were either very closely spaced (redundant points) and/or showed unusual variation with respect to the neighboring data points.

Multiple water level measurements were available for some wells in the study area. Water level measurements from these wells indicate 5 to 10 feet seasonal fluctuation in the upland unconfined aquifer and 2 to 4 feet seasonal fluctuation in the transition zone and Sumas Valley.

Calibration runs were carried out by varying the horizontal hydraulic conductivity of various geologic units and recharge rates of the upland and valley topographical areas. Initial model runs were performed with the hydraulic conductivity estimates determined from pump tests, reported in the literature or estimated from other relevant hydraulic properties. These estimates were refined during the calibration process to achieve the best agreement between the measured water level elevations and the model predicted hydraulic heads for the Sumas outwash layer. Recharge rates were also varied within a small range, while maintaining the same hydraulic conductivity values for various geologic units. The hydraulic conductivity values used for various geologic units for the final calibrated model are shown in Figures 2-4-4 and 2-4-5. The recharge rates for the final calibrated model is shown in Figure 2-4-7.

Table 2-4-1 compares the measured heads and the heads simulated by the final calibration run. Figures 2-4-8 and 2-4-9 show the contours of the potentiometric surfaces for top and bottom model layers, respectively. The values shown inside boxes in Figure 2-4-9 represent the distribution of the difference between the predicted and measured heads; where a positive value indicates overprediction and a negative value underprediction. No reliable head data were available for the top model layer for such a comparison. Therefore, the difference between the predicted and measured heads are not shown for the top layer (Figure 2-4-8). The distribution of the difference between the simulated heads for the bottom layer is presented in Figure 2-4-10.

Considering the regional model domain, the overall target for calibration was set at 5 feet. However, better calibration was expected in the Sumas outwash deposits of the upland area where the gradient is relatively flat. In the transition zones, a less exact calibration match was expected where the gradients are much steeper. The overall root mean square (RMS) of the difference between predicted heads and measured heads was 8.57 feet, with the greatest differences occurring in the steep gradients within the transition zone where gradients are steep. This difference is reflected in Figure 2-4-10, which shows contours of the difference between simulated and measured head.

2.4.4 **Delineation of Capture Zones**

The particle tracking program, PATH3D, distributed by S.S. Papadopulos & Associates, was used to simulate the paths and travel times of fluid particles in a steady-state, three-dimensional flow field. In PATH3D simulation, the paths of particles may be tracked either in forward tracking mode or backward tracking mode. In forward tracking mode, a particle originating at any point in the flow domain will be removed from the model at one of the fluid sinks present in the domain. In backward tracking mode, a particle originates at one of the sinks (such as extraction wells) in the flow domain and travels backward in time until it encounters one of the sources present inside the domain or the edge of the flow domain where it is removed from the model. Ten existing extraction well fields were incorporated into the final calibrated model. These include:

District of Matsqui Townline wells 1 and 2 (TL1 and TL2)
District of Matsqui Marshall well field (MRS)
Lucerne Foods Ltd. Well (LUC)
three well fields from the city of Abbotsford (AW1, AW2, and AW3);
Fraser valley trout hatchery wells (FHW);
Sumas well field pumping at current use rates and fully appropriated rates (SWF); and
May Road well field pumping at existing and fully appropriated rates (MRD).

A three-month withdrawal period was conservatively assumed for the District of Matsqui wells and the Lucerne Foods Ltd. well. The three-month withdrawal was then averaged over a year period to determine the flow rate for input into the steady-state model.

Simulations for the capture zone were performed for the Sumas and May Road well fields in backward particle tracking mode. A particle was placed at the center of each of the eight cells adjacent to the cell representing the extraction well field. Paths of these particles as they travelled back in time were computed by PATH3D. A value of 30 percent was assigned to the effective porosity for all geologic units in the PATH3D simulations. A forward particle tracking simulation was run to verify that particles in cells beyond the eight adjacent cells were not included in the capture zone.

PATH3D computes three components (in x, y, and z directions) of the linear seepage velocity of flow using the hydraulic head solution predicted by MODFLOW, the specified boundary conditions used in MODFLOW simulation, and the specified effective porosities of various geologic units. When a particle migrates into, or located in, a cell containing the water table, PATH3D includes the effect of net recharge rate at the water table (recharge and evapotranspiration) in the computation of the vertical component (in z direction) of the seepage velocity. Since most of the areas of the bottom model layer in the upland areas are unconfined and the recharge rate for the upland areas was relatively large, the vertical seepage velocity component in the water table cells in the upland areas was also large compared to the horizontal velocity components. Because of the large vertical velocity component, most of the particles travelling backward in time from the Sumas and May Road well fields were being removed from the model at the water table near the central region of the upland area.

Since recharge is a seasonal occurrence and in order to obtain a more realistic result, recharge was eliminated from the PATH3D simulation, which caused the particles from both well fields to migrate through the upland areas to the upstream model boundary. Figures 2-4-10 and 2-4-11 show the capture zones for Sumas and May Road well fields for the existing and the maximum extraction rates, respectively. The extraction rates of various wells used in the simulations are shown on the same figures. Points locating the distance travelled in 0.5, 1, 2, 5, 10, and 20 years are shown on the pathlines.

2.4.5 Delineation of Dispersion Zone

Dispersion is the process causing ground water flow to deviate from ideal linear streamlines computed in conventional ground water hydraulic modeling. Dispersion occurs because ground water flow deviates around individual grains and larger scale features such as bedding planes and depositional structures. Because of dispersion, the zone of contribution to a well or well field is wider than is indicated by the hydraulic model. However, contaminants originating outside the hydraulically-defined capture zone will be more dilute than those originating inside that zone.

The mathematical formulation for dispersion is complex. Precise analysis requires computer modeling and assumptions regarding the nature of the contaminant source. However, the additional lateral zone of contribution extent (measured from each side of the hydraulic capture zone) due to dispersion can be approximated as three standard deviations of the concentration distribution (Freeze and Cherry, 1979).

$$3\sigma = \sqrt{2Dt}$$

where D is the coefficient of transverse hydrodynamic dispersion, which in turn is the product of the transverse dispersivity and the ground water flow velocity; and t is the time of travel.

For the Sumas well field case, the average ground water flow velocity is approximately 1,600 feet/year and the transverse dispersivity is estimated at about 55 feet, based on an average of 3 values determined for glacial outwash at similar spatial scales (Gelhar et al., 1992). This gives an estimated coefficient of transverse hydrodynamic dispersion of 88,000 ft^2/yr.

For a ground water travel time of 1 year, the lateral extension on either side of the hydraulic capture zone accounting for dispersion would be approximately 420 feet. Calculations were made for other travel times and the resulting zone of contribution due to dispersion was overlaid on the capture zone map shown in Figure 2-4-12.

TABLE 2-2-1

WATER BALANCE -1990 for UPLAND REGION
WELL HEAD PROTECTION PROGRAM
CITY OF SUMAS

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL TOTALS (INCHES)
1.PRECIP. (inches)	10.2	7.87	4.3	3.54	2.76	4.33	0.78	1.38	0.98	7.48	15.7	10.8	70.11
2.RUNOFF COEFFICIENT	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
3.RUNOFF (inches)	1.02	0.79	0.43	0.35	0.28	0.43	0.08	0.14	0.10	0.75	1.57	1.08	7.01
4.INFILTRATION (I, inches)	9.18	7.08	3.87	3.19	2.48	3.90	0.70	1.24	0.88	6.73	14.13	9.72	63.10
5.St (SOIL MOISTURE STORAGE)	8.62	8.62	8.62	8.62	8.30	7.10	4.86	3.86	4.01	7.08	8.62	8.62	2.70
6.dSt(CHANGE IN STORAGE)	0	0	0	0	-0.32	-1.25	-2.08	-1.14	0.16	3.11	1.54	0.00	0.01
7.ACTUAL EVAPOTRANSPIRATION	0.28	0.63	1.18	1.92	3.15	3.78	3.62	2.98	2.87	1.73	0.78	0.38	23.29
8.PERC	8.90	6.45	2.69	1.27	0.00	0.00	0.00	0.00	0.00	0.00	11.80	9.33	38.80

NOTES:
1. PRECIP= Precipitation measured at Abbotsford Airport (Reported in Liebscher and others, 1992).
2. RUNOFF COEFFICIENT = Obtained from published tables (Lu et. al., 1985) for cover crop with 0-2% slopes with sandy loam
3. RUNOFF (Ro) = RUNOFF COEFFICIENTxPRECIP
4. INFILTRATION (I) = PRECIP - RUNOFF
5. St= Soil moisture obtained from Gibbons and Culhane, 1994 (based on soil data from USDA Whatcom County Soil Survey).
6. dSt (change in soil moisture storage) = storage from this month - storage from previous month
7. ACTUAL EVAPOTRANSPIRATION=obtained from Gibbons and Culhane, 1994 based on temperature data measured at Clearbrook weather station and computer program WATBUG.
8. PERC=Moisture available for percolation to groundwater= for positive dSt = I-AET-dSt. For negative dSt = 0.

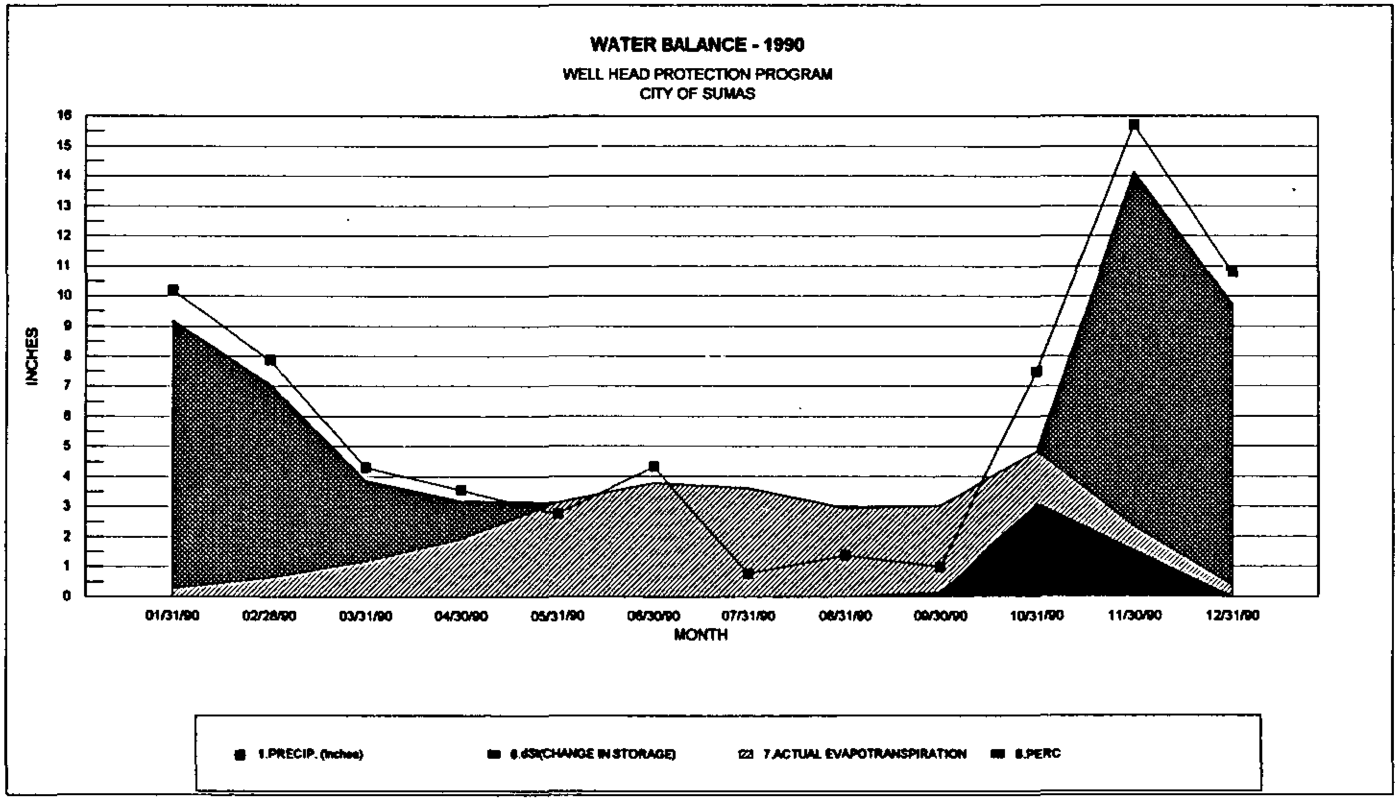


TABLE 2-2-2

WATER BALANCE -30 YEAR MEAN for SUMAS VALLEY REGION
WELL HEAD PROTECTION PROGRAM
CITY OF SUMAS

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL TOTALS (INCHES)
1.PRECIP. (inches)	5.6	4.6	4.13	3.38	2.83	2.55	1.49	1.81	3.03	4.83	5.86	5.98	46.09
2.RUNOFF COEFFICIENT	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
3.RUNOFF (inches)	2.80	2.30	2.07	1.69	1.42	1.28	0.75	0.91	1.52	2.42	2.93	2.99	23.05
4.INFILTRATION (I, inches)	2.80	2.30	2.07	1.69	1.42	1.28	0.75	0.91	1.52	2.42	2.93	2.99	23.05
5.St (SOIL MOISTURE STORAGE)	6.56	6.56	6.56	6.56	6.23	4.09	2.36	1.57	1.73	4.84	6.56	6.56	2.70
6.dSt(CHANGE IN STORAGE)	0	0	0	0	-0.31	-1.18	-1.73	-0.79	0.16	3.11	0.71	0.00	-0.03
7.ACTUAL EVAPOTRANSPIRATION	0.28	0.63	1.18	1.93	3.14	3.70	3.22	2.59	2.87	1.73	0.79	0.39	22.45
8.PERC	2.52	1.67	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	2.60	9.11

NOTES:
1. PRECIP= Precipitation measured at Clearbrook Weather Station
2. RUNOFF COEFFICIENT = Obtained from published tables (Lu et. al., 1986) for cultivated land, moderate permeability. (loam), <2% slopes.
3. RUNOFF (Ro) = RUNOFF COEFFICIENTxPRECIP
4. INFILTRATION (I) = PRECIP - RUNOFF
5. St= Soil moisture obtained from Gibbons and Culhane, 1994 (based on soil data from USDA Whatcom County Soil Survey).
6. dSt (change in soil moisture storage) = storage from this month - storage from previous month
7. ACTUAL EVAPOTRANSPIRATION=obtained from Gibbons and Culhane, 1994 based on temperature data measured at Clearbrook weather station and computer program WATBUG.
8. PERC=Moisture available for percolation to groundwater= for postive dSt = I-AET-dSt. For negative dSt = 0.

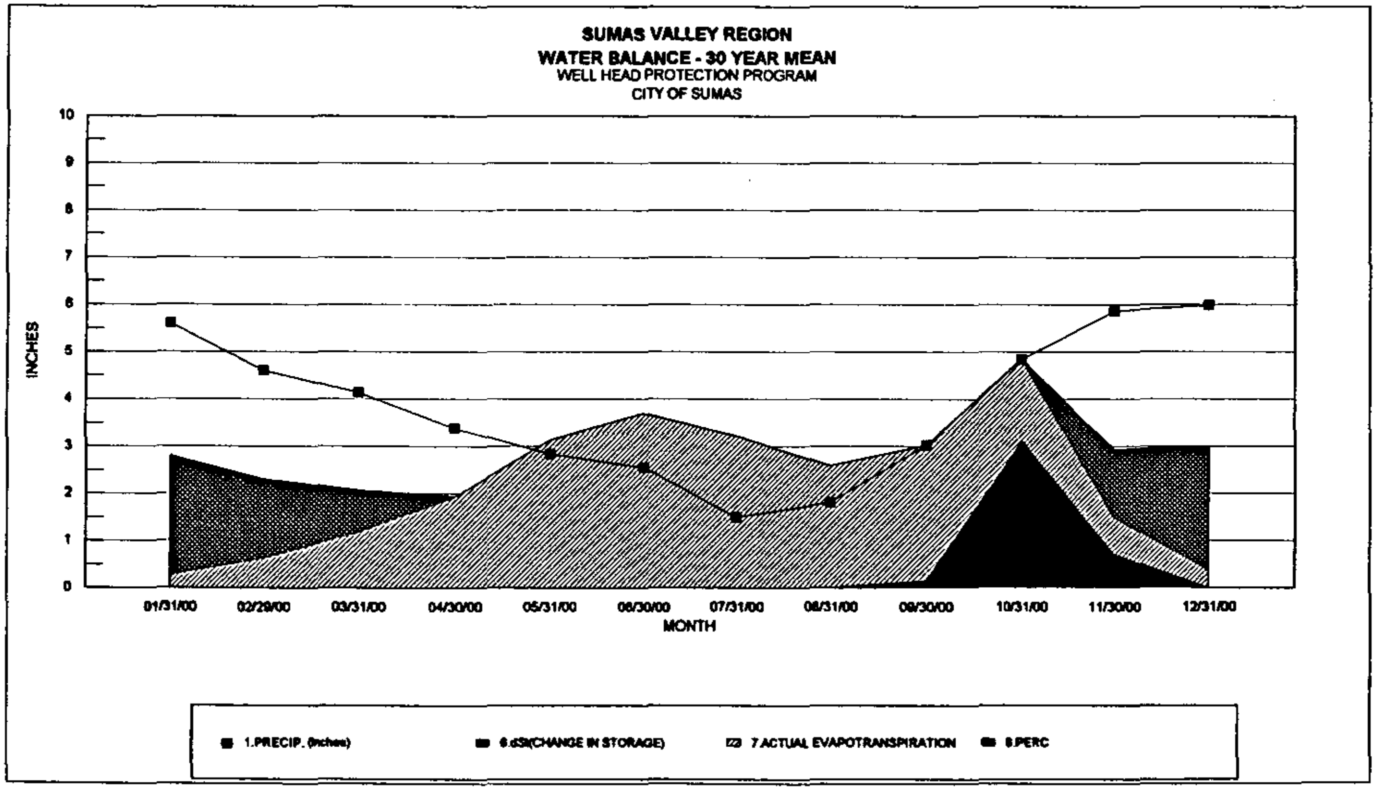


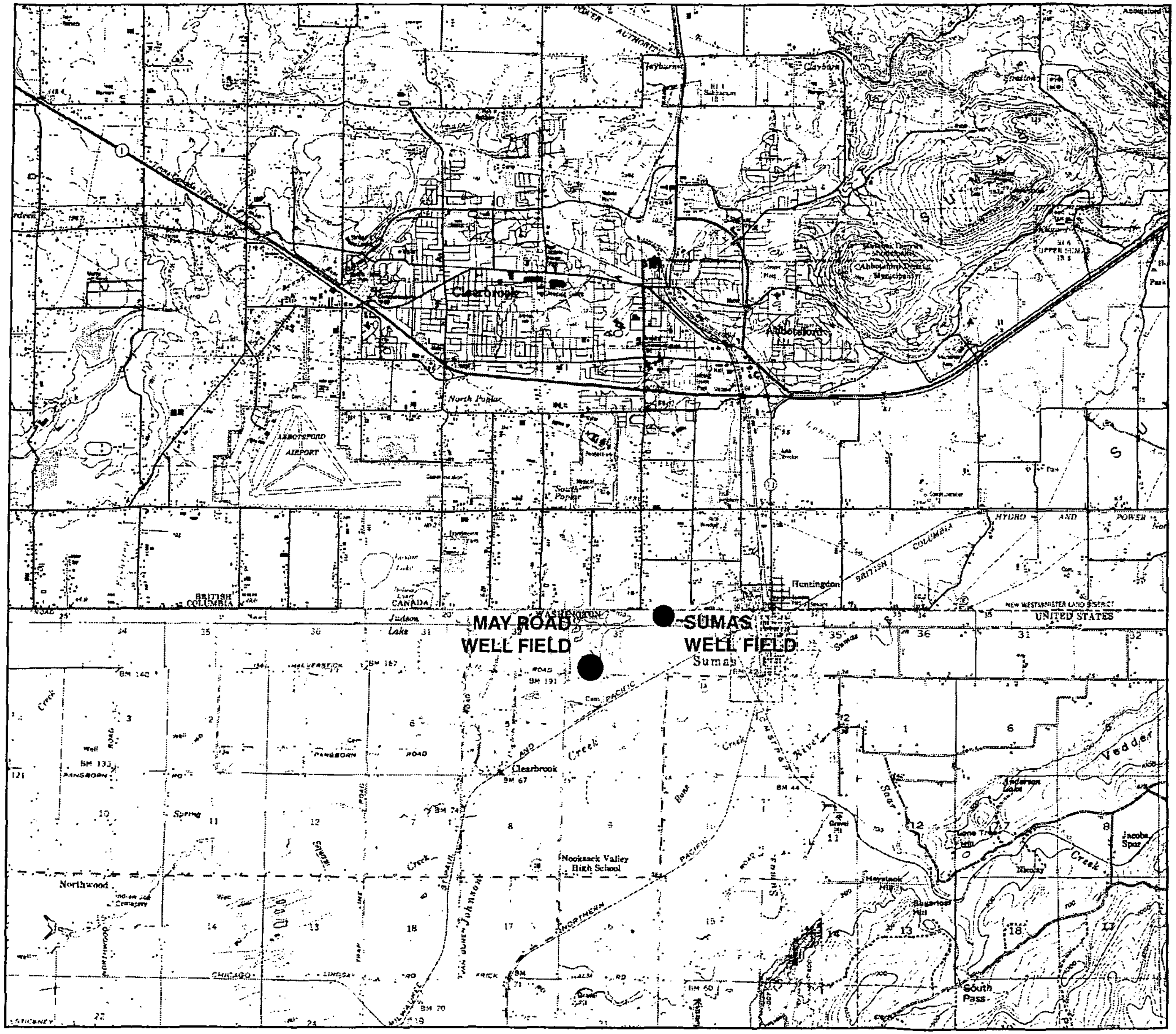
TABLE 2-4-1

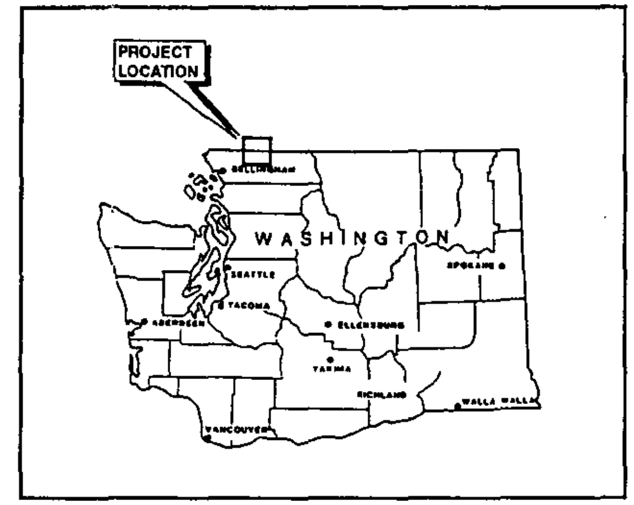
94-35515-21 CITY OF SUMAS

MODELING OF GROUNDWATER FLOW FOR SUMAS AND MAY ROAD WELL FIELDS

SUMMARY OF SIMULATED AND MEASURED WATER LEVELS

WELL NAME	SIMULATED WATER LEVEL ELEVATION IN FEET	MEASURED WATER LEVEL ELEVATION IN FEET	DIFFERENCE BETWEEN SIMULATED AND MEASURED WATER LEVEL IN FEET	GEOLOGIC UNIT
T40NR4E-5D1	115.674	132.88	-17.2	Qso
T40NR4E-5D2	127.178	136.05	-8.9	Qso
T40NR4E-6B1	132.544	136.22	-3.7	Qso
T40NR4E-6K1	125.331	127.24	-1.9	Qso
T40NR4E-7G1	101.542	107.61	-6.1	Qso
T40NR4E-8A1	52.028	48.82	3.2	Qso
T40NR4E-8L1	56.814	52.63	4.2	Qso
T40NR4E-9Q1	48.906	52.13	-3.2	Qso
T40NR4E-10G1	40.470	38.26	2.2	Qso
T41NR3E-36J1	140.151	140.20	.0	Qso
T41NR4E-31J1	129.925	135.37	-5.4	Qso
T41NR4E-33H5	61.181	59.57	1.6	Qso
T41NR4E-33N7	88.769	90.50	-1.7	Qso
9.1.1.1-06	151.182	155.47	-4.3	Qso
9.1.1.1-99	144.940	144.40	.5	Qso
9.1.1.2-12	151.080	156.04	-5.0	Qso
9.1.1.2-29	145.439	151.46	-6.0	Qso
9.1.1.2-99	147.229	156.37	-9.1	Qso
9.1.1.4-19	156.598	159.70	-3.1	Qso
9.1.2.1-99	139.315	154.30	-15.0	Qso
9.1.2.2-32	103.257	104.89	-1.6	Qso
9.1.2.2-46	129.637	143.13	-13.5	Qso
9.1.2.3-69	148.164	155.89	-7.7	Qso
9.1.3.3-08	170.670	171.81	-1.1	Qso
9.1.3.4-26	170.021	162.95	7.1	Qso
9.1.3.4-34	166.706	164.58	2.1	Qso
9.2.1.2-98	40.951	26.37	14.6	Qso
9.2.1.3-47	92.824	116.38	-23.6	Qso
9.2.1.4-20	68.073	57.46	10.6	Qso
9.2.2.1-03	29.639	26.41	3.2	Qso
9.2.3.1-32	136.692	151.67	-15.0	Qso
9.3.1.2-23	177.230	176.79	.4	Qso
9.1.1.4-99	152.400	162.70	-10.3	Qso
Root mean square error:			8.57	





N

Scale

0 3000' 6000'

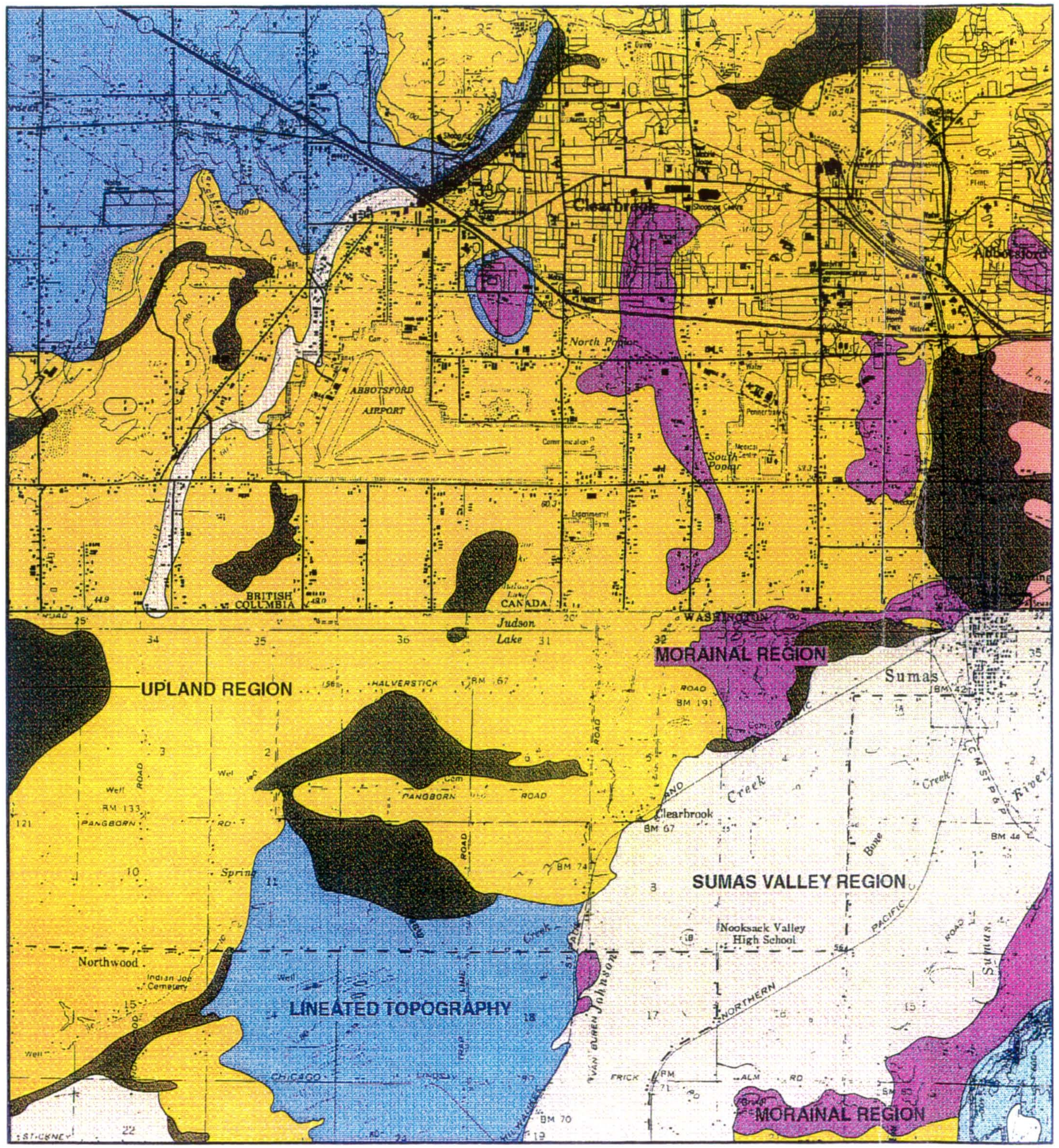
SOURCES

Van Zandt and Lynden, Washington Quadrangles.
15' Series (Topographic). U.S.G.S. 1951 and 1954.

Mission, 92 G/1, Edition 5. Energy, Mines and Resources, Canada. 1992.

PROJECT LOCATION MAP	
WELL HEAD PROTECTION PROGRAM Sumas, Washington for City of Sumas	Project No. **VB9504A** Figure No. **2-1-1**

ASSOCIATED EARTH SCIENCES, INC.



LEGEND:

POSTGLACIAL

- Qal — Alluvial Deposits; Sand, gravel, and silt includes Sumas Valley Clay
- Qp — Peat; Peat and organic silt
- Ql — Postglacial Lacustrine silts and clays

PLEISTOCENE

- Qso — Outwash Sand and Gravel; Includes till and ice contact deposits (Qs) north of border
- Qs — Till and Ice Contact Deposits
- Qsc — Silt and Clay; of Glaciomarine origin, Includes Badger Clay of Kahle, 1990
- Th — Bedrock; Tertiary, undifferentiated

Scale
0 3000' 6000'

N

SOURCES
Van Zandt and Lynden, Washington Quadrangles. 15' Series (Topographic). U.S.G.S. 1951 and 1954.

Mission, 92 G/1, Edition 5. Energy, Mines and Resources, Canada. 1992.

Geology from Armstrong, 1981 and Easterbrook, 1976.

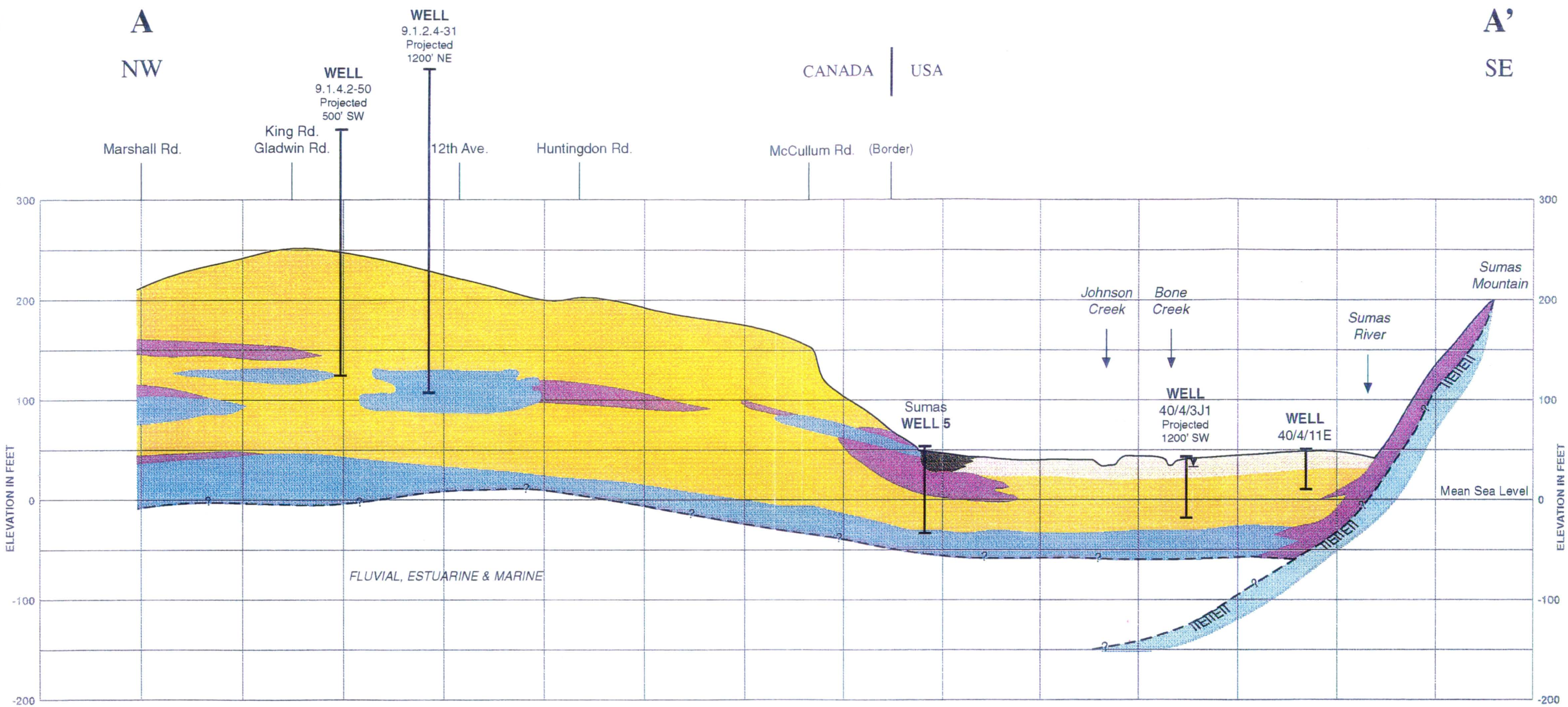
GEOLOGIC MAP

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. **VB9504A**

Figure No. **2-2-1**

ASSOCIATED EARTH SCIENCES, INC.

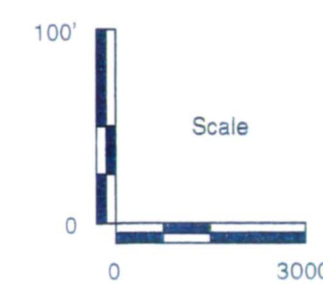


		Geologic Unit	Composition	Hydrological Characteristics
	Qp	Peat	Peat and organic silt	Semi-confining unit (Aquitard)
	Qsc	Sumas Valley Clay	Silt, clay, and sand interbeds	Confining unit (Aquitard)
	Qs	Ice Contact, Ice Marginal and Till	Sand and gravel interbedded with clay and till lenses	Semi-confining unit (Aquitard) with some interconnected permeable sand and gravel lenses and channels
	Qso	Sand and Gravel	Stratified sand and gravel outwash with some thin silt and clay interbeds	Unconfined and confined aquifer (Major Water Bearing Unit)
	Qsc	Glacio-Marine Drift (Includes Badger Clay)	Thick, interbedded silt and clay with some till-like diamicton horizons	Confining unit (Aquitard)
		Mixed Fluvial, Estuarine and Marine	Silt, clayey silt, and fine sand	Confined Aquifer (Extent and thickness unknown)
		Huntingdon Formation	Sandstone and siltstone	Hydrogeologic Boundary (Aquitard)

SOURCES

Halstead, E.G., 1979. *Well Location Map*, Township 16, Matsqui District Municipality, British Columbia. National Hydrology Research Institute.

Kahle, S.C., 1990. *Hydrostratigraphy and Groundwater Flow in the Sumas Area*, Whatcom County, Washington. Thesis, Western Washington University.



GEOLOGIC PROFILE A–A'

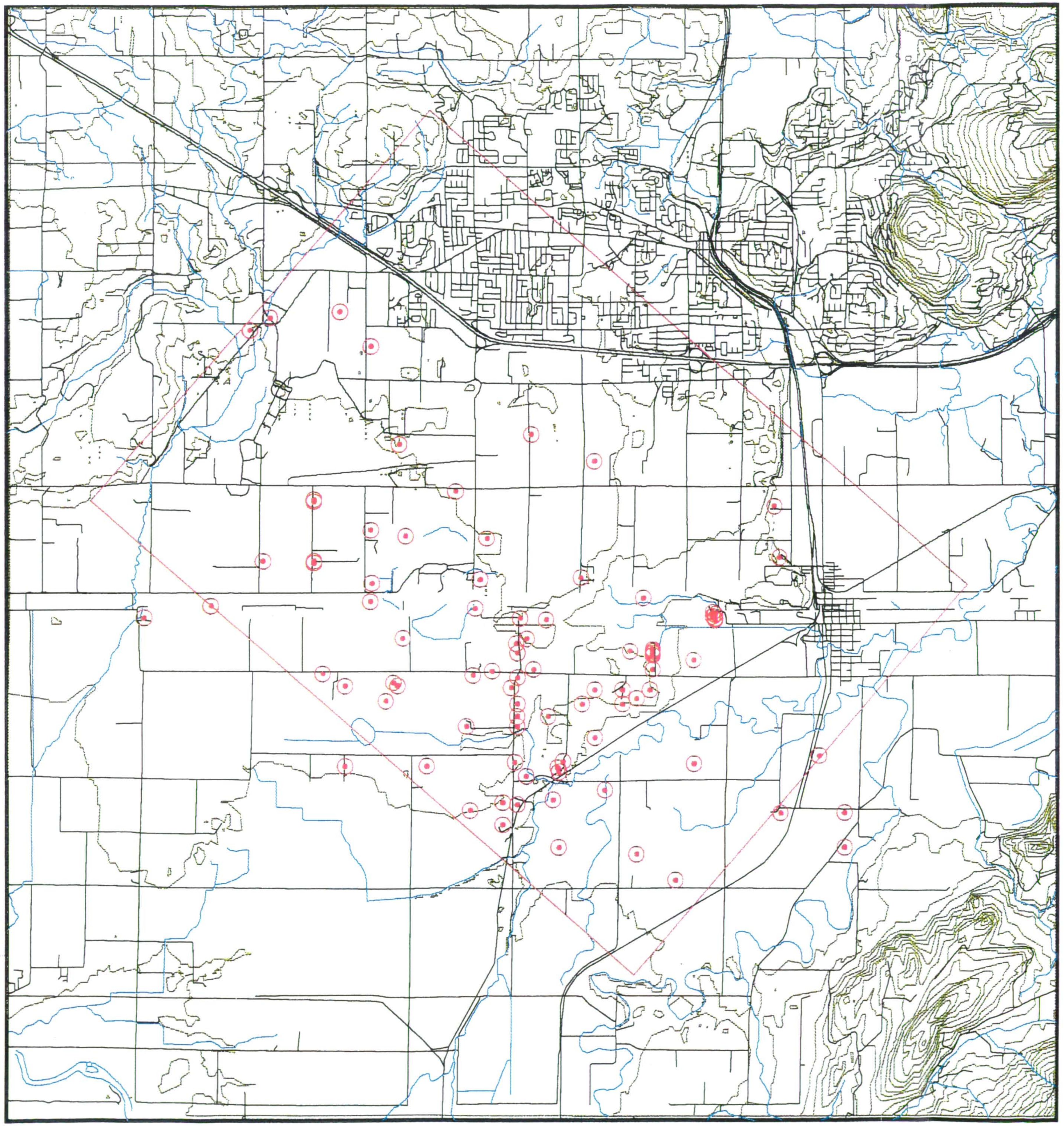
WELLHEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

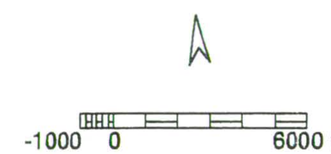
Project No. **VB9504A**

Figure No. **2-2-2**

ASSOCIATED EARTH SCIENCES, INC.

WELLS USED IN WHPA STUDY
LOCATION MAP





ASSOCIATED EARTH SCIENCES, INC.

Figure 2-2-3

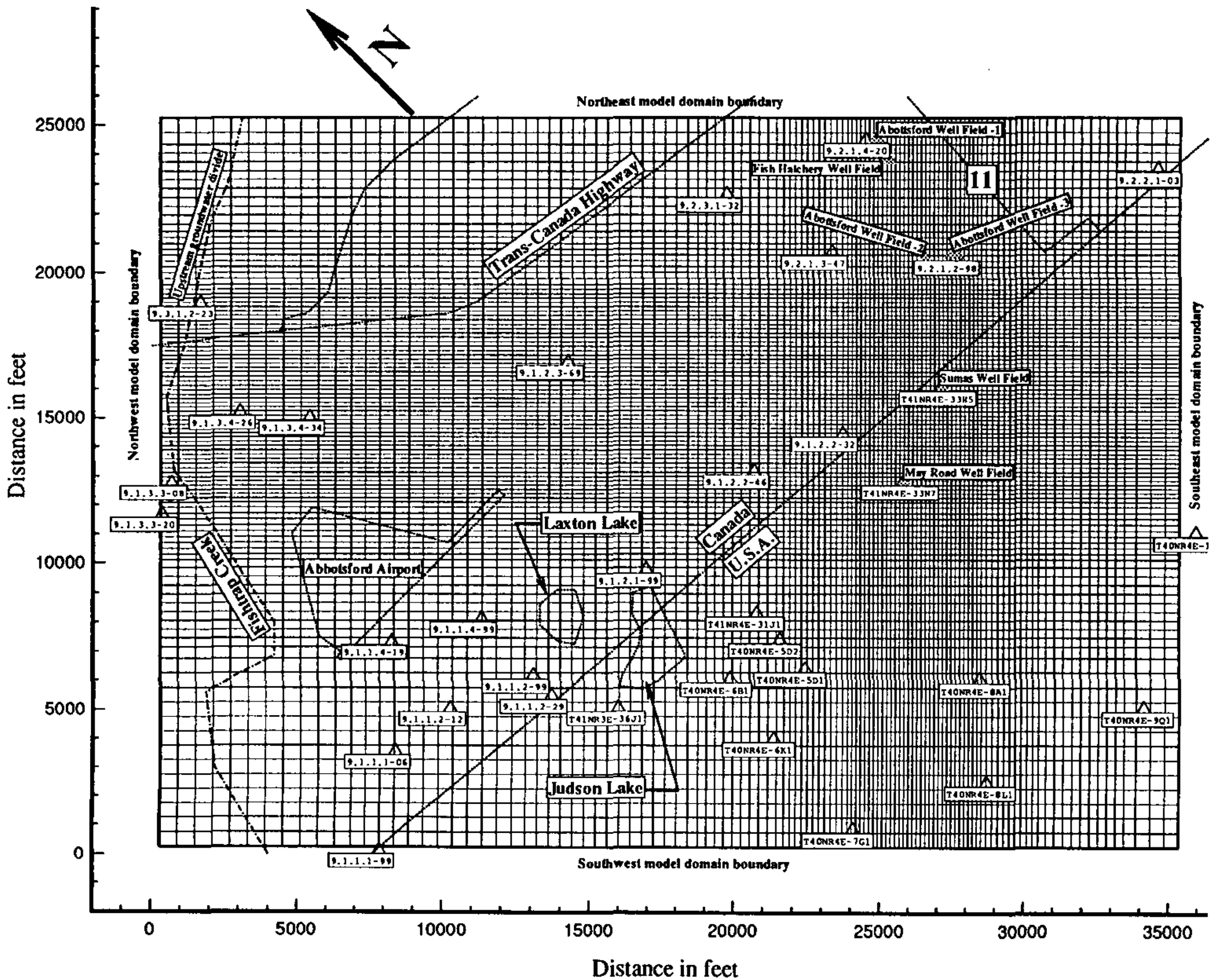


FIGURE 2-4-1 Finite-difference grid used to discretize project site within model domain. Also shown are well locations used in model calibration. Note: line spacings are variable - 150 to 600 feet along x-axis, 150 to 500 feet along y-axis.

coor1.int, gw-e7.trs 2d-grid.sty gw-e7-1b.tg, ups-bndy.tg, land-mrk.tg

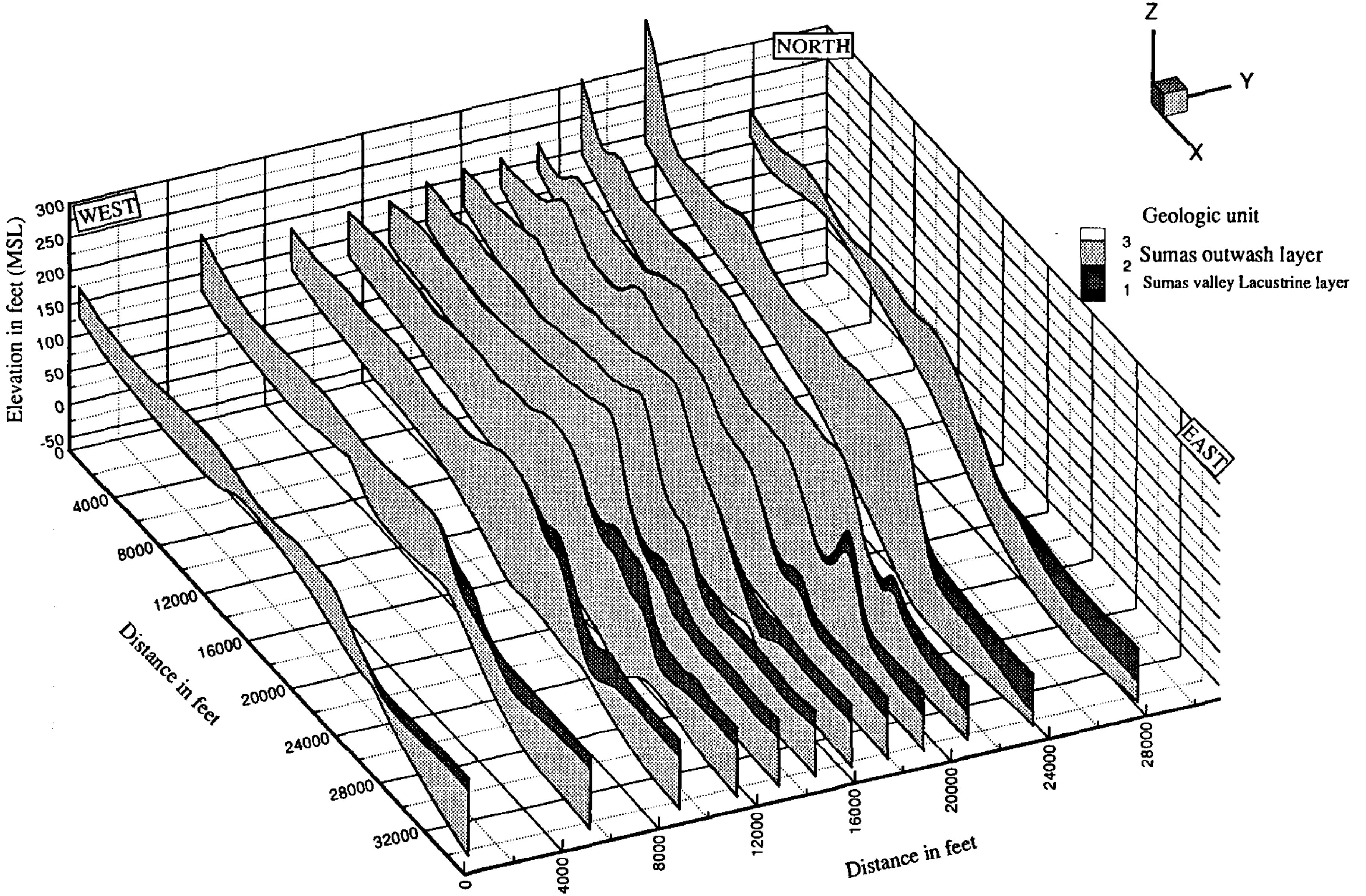


FIGURE 2-4-2 Traces of interpolated geologic contact surfaces in vertical cross-sections within model domain. Orthographic projection. Interpolation method: Kriging. Cross-sections shown for J=1,117,10.

surface.out, fn-diag.sty

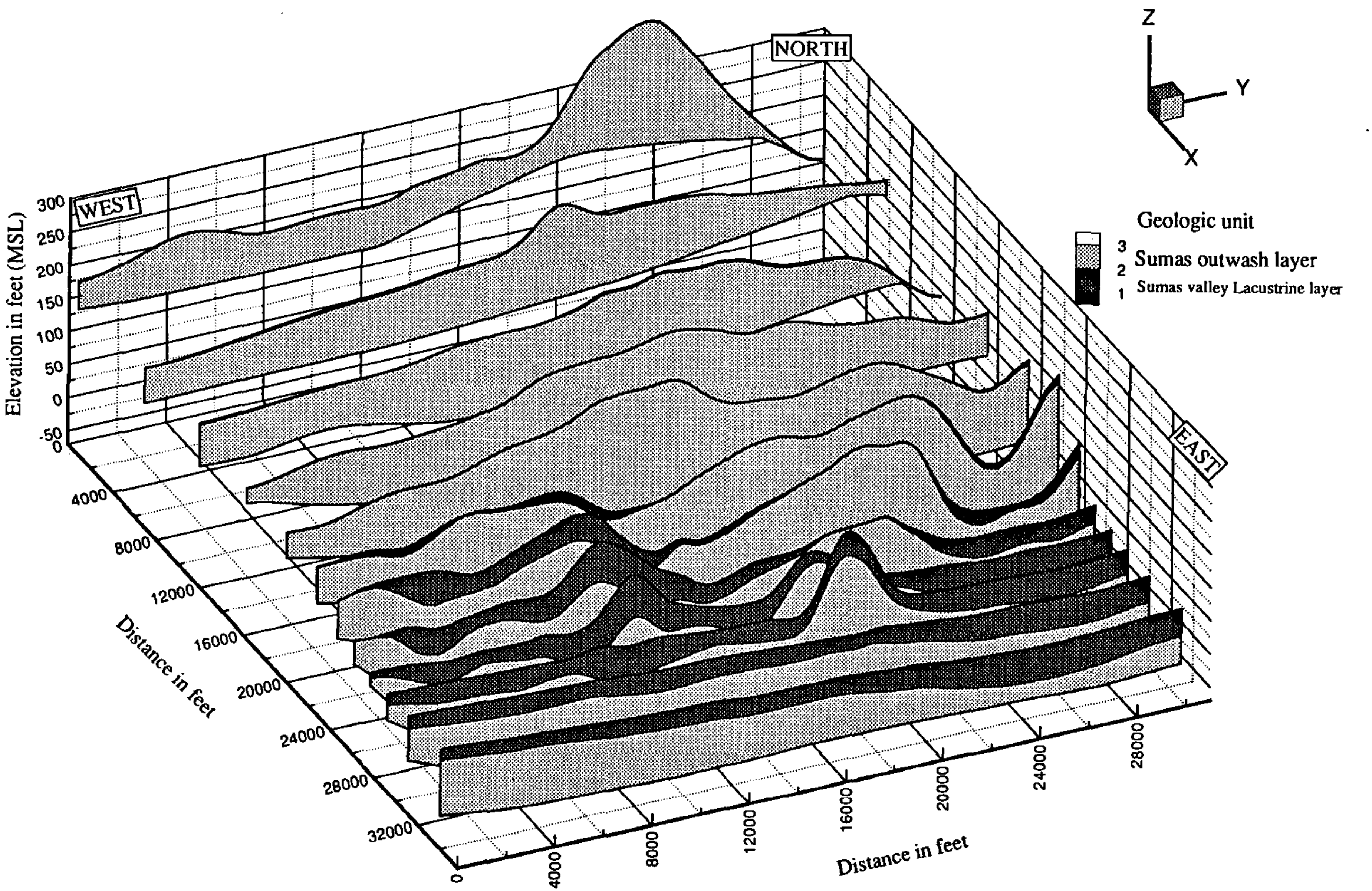


FIGURE 2-4-3 Traces of interpolated geologic contact surfaces in vertical cross-sections within model domain. Orthographic projection. Interpolation method: Kriging. Cross-sections shown for I=1,115,10.

surface.out. fn-diag.sty

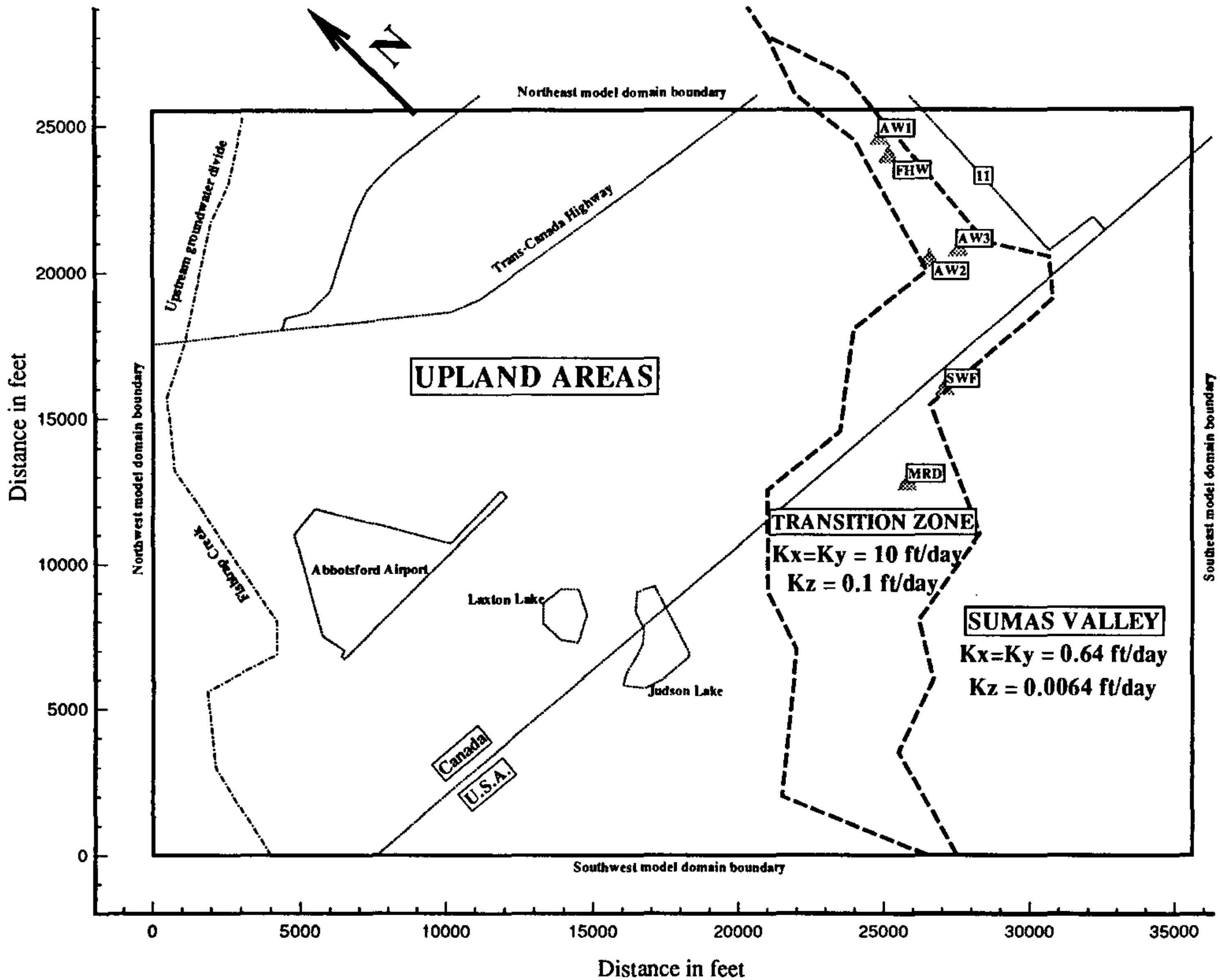


FIGURE 2-4-4 Distribution of hydraulic conductivities in top model layer.
Note: long-dashed lines represent conductivity zone boundaries.

coorl.int, gw-e7.trs, kx-lyl.sty, lmrk-wel.tg

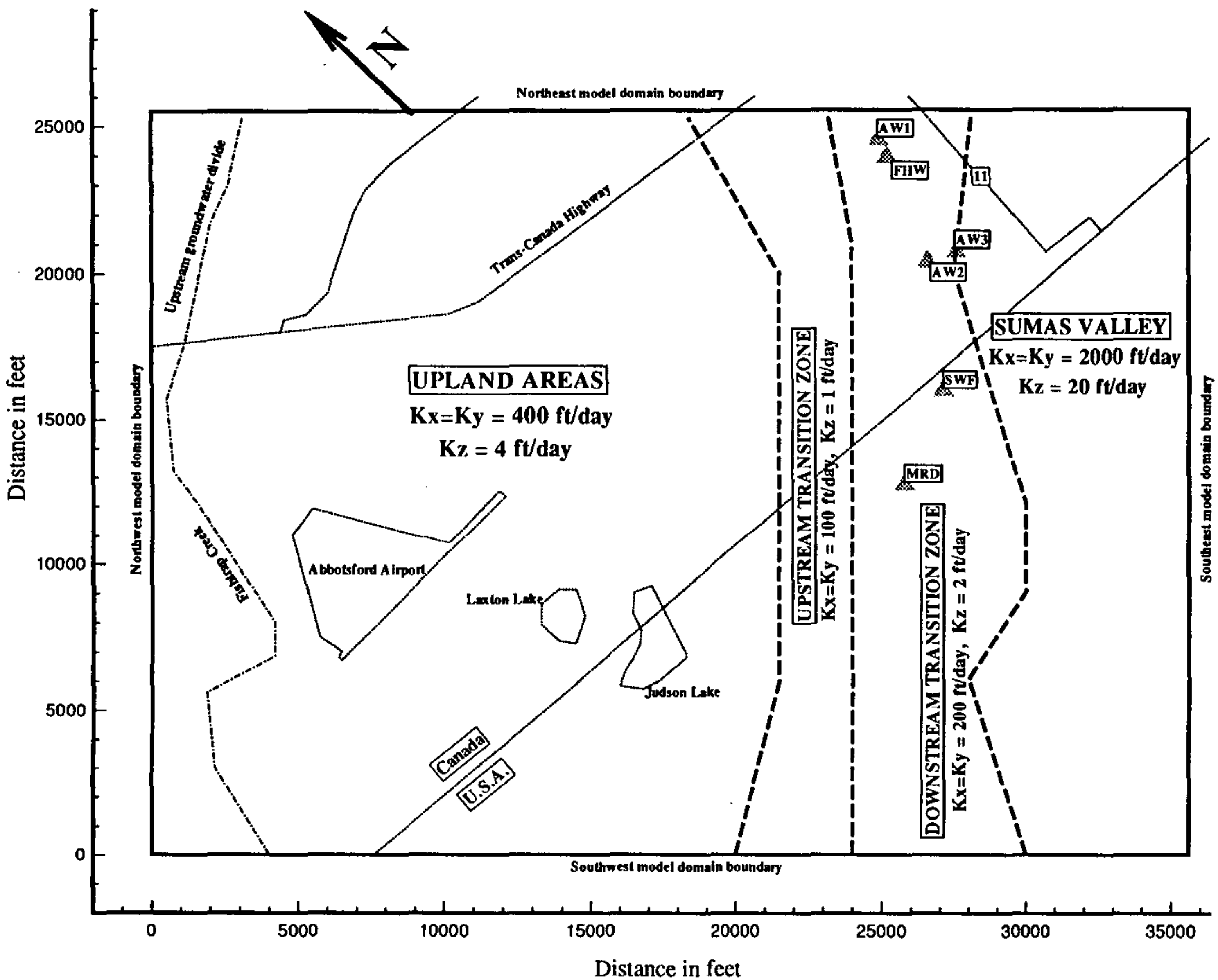


FIGURE 2-4-5 Distribution of hydraulic conductivities in bottom model layer.
Note: long-dashed lines represent conductivity zone boundaries.

coorl.int, gw-e7.trs, kx-ly2.sty, lmrk-wel.tg

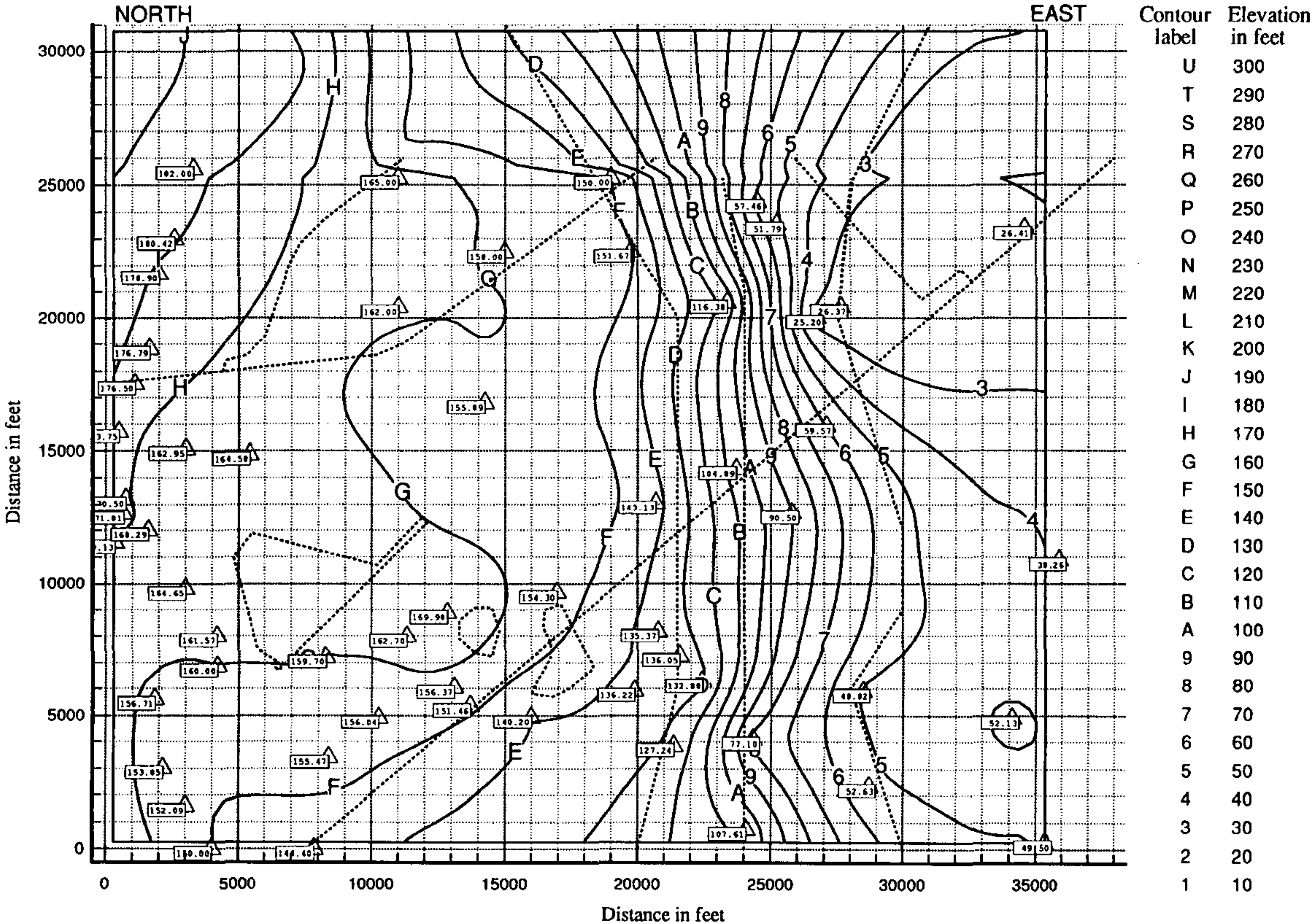


FIGURE 2-4-6 Contours of interpolated potentiometric surface for Sumas outwash layer based on measured May/June 1990 groundwater elevations. Interpolation based on nonuniformly spaced grid. Interpolation method: kriging. Elevation relative to mean sea level. Data points used for interpolation are shown with triangle symbol and water level elevation in feet.

gw-e6-k.out, gw-e6-wl.tg, ms-gw-cn.sty

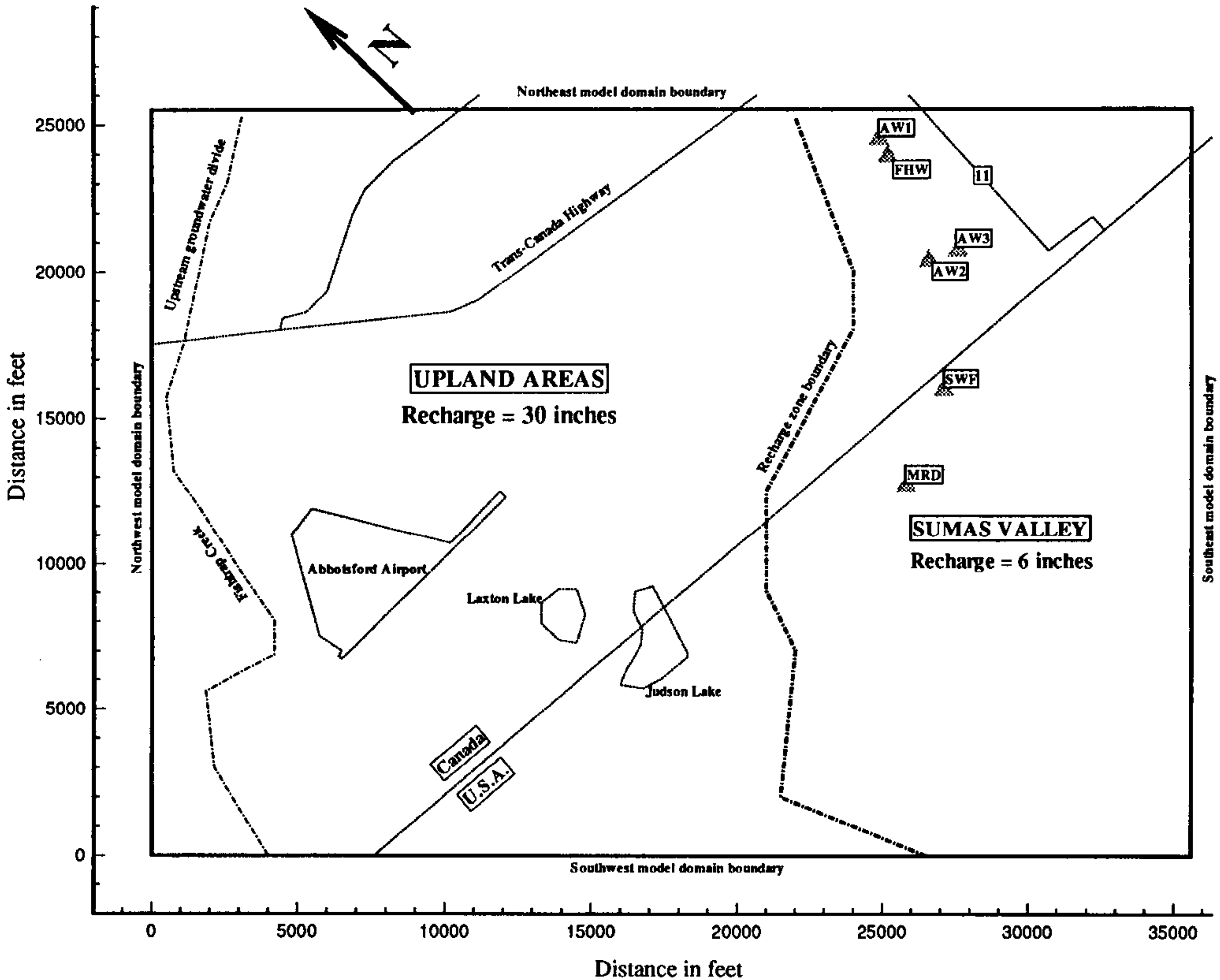
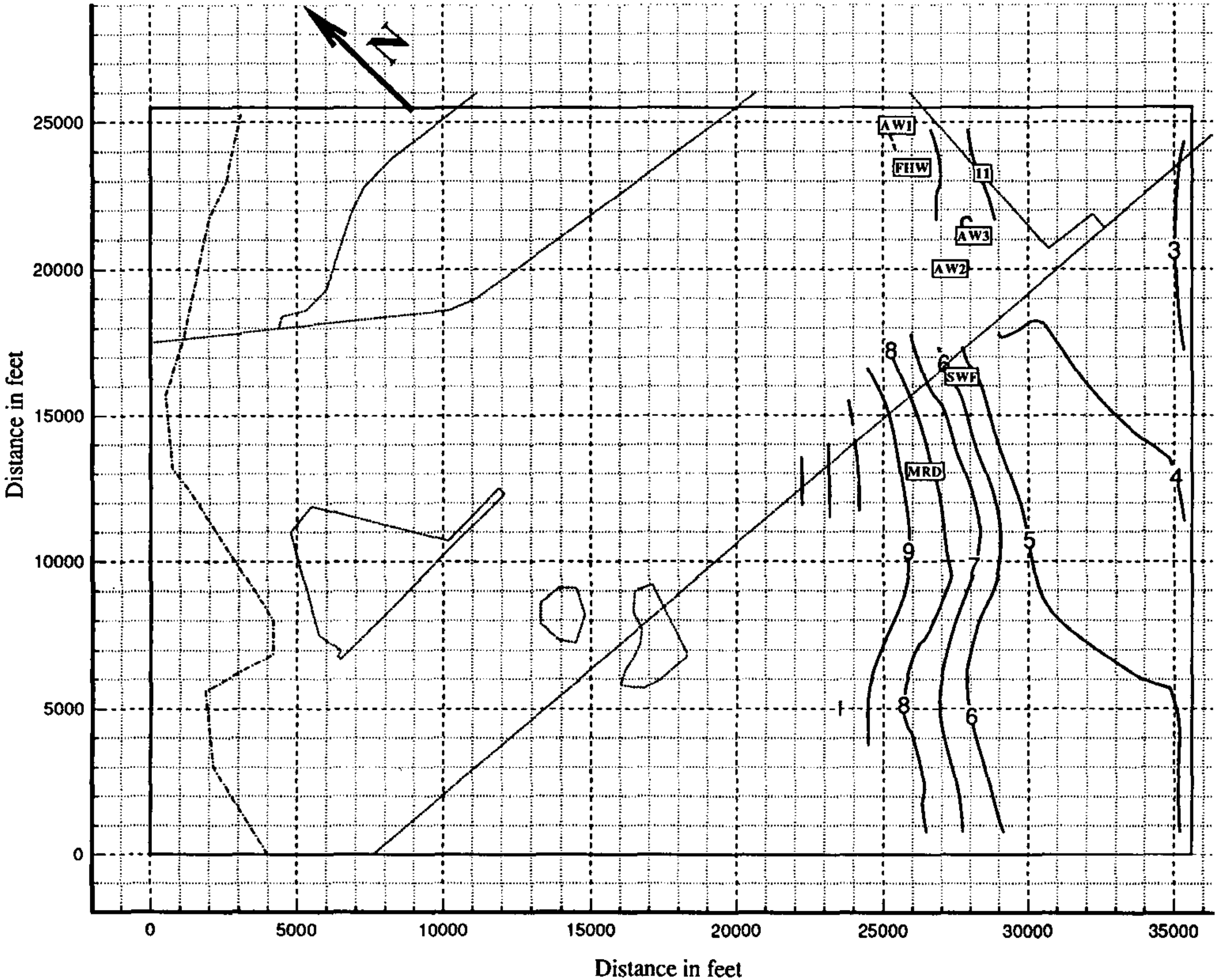


FIGURE 2-4-7 Distribution of recharge intensity applied to top active cells in model.
Note: long-dashed lines represent recharge zone boundaries.

coorl.int, gw-e7.trs, rch.sty, lmrk-wei.tg



Contour label	Elevation in feet
P	250
O	240
N	230
M	220
L	210
K	200
J	190
I	180
H	170
G	160
F	150
E	140
D	130
C	120
B	110
A	100
9	90
8	80
7	70
6	60
5	50
4	40
3	30
2	20
1	10

FIGURE 2-4-8 Contours of potentiometric surface for Ice Marginal/Till/Sumas Valley Lacustrine layer obtained from calibrated model. Elevation relative to mean sea level.

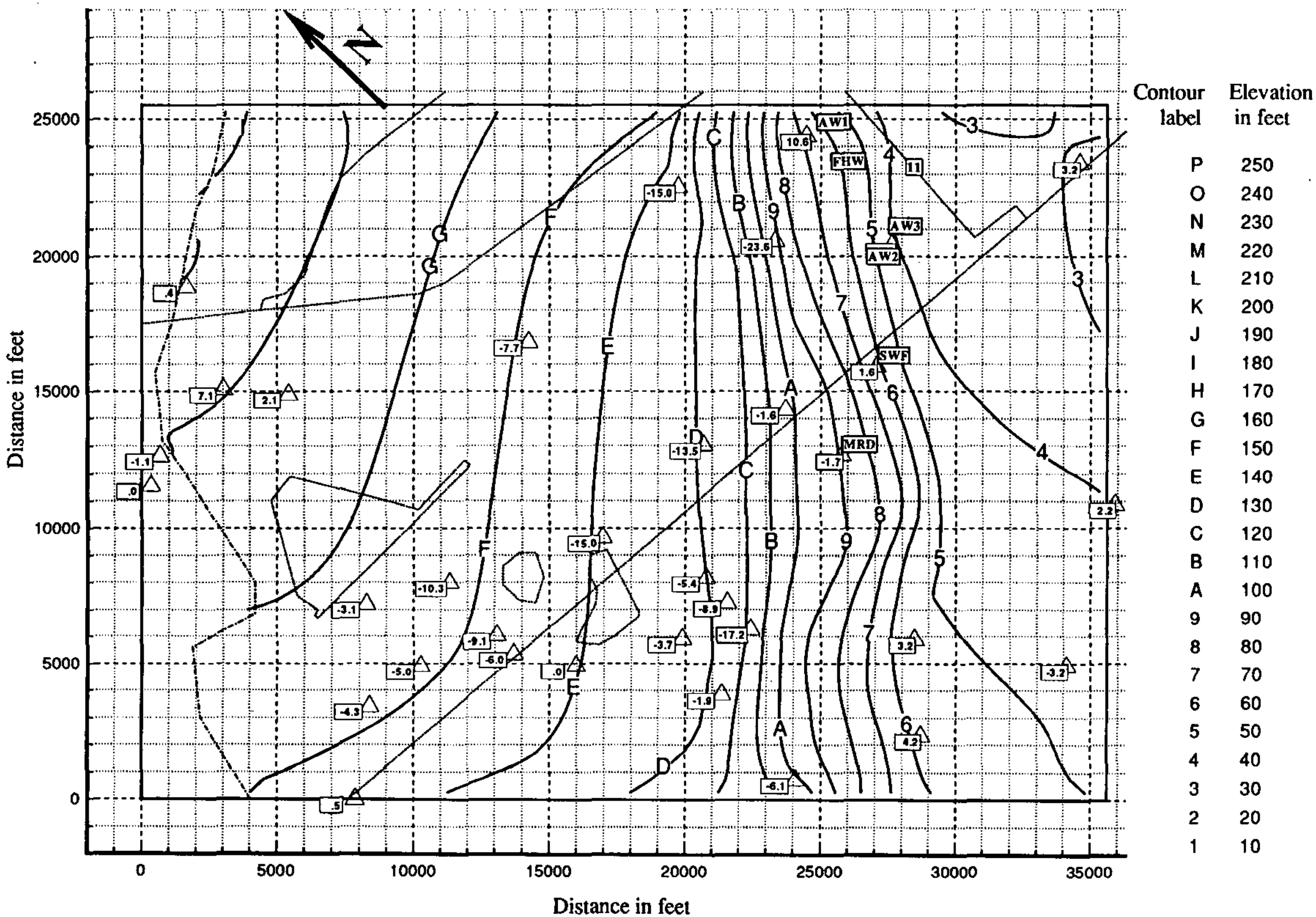


FIGURE 2-4-9 Contours of potentiometric surface for Sumas outwash layer obtained from calibrated model. Elevation relative to mean sea level.
Note: triangle symbol represents data point used for calibration, values inside box show difference between simulated and measured heads.

107-hed.tec, gw-e7.trs, hd-ly2.sty, gw-dh-12.tg

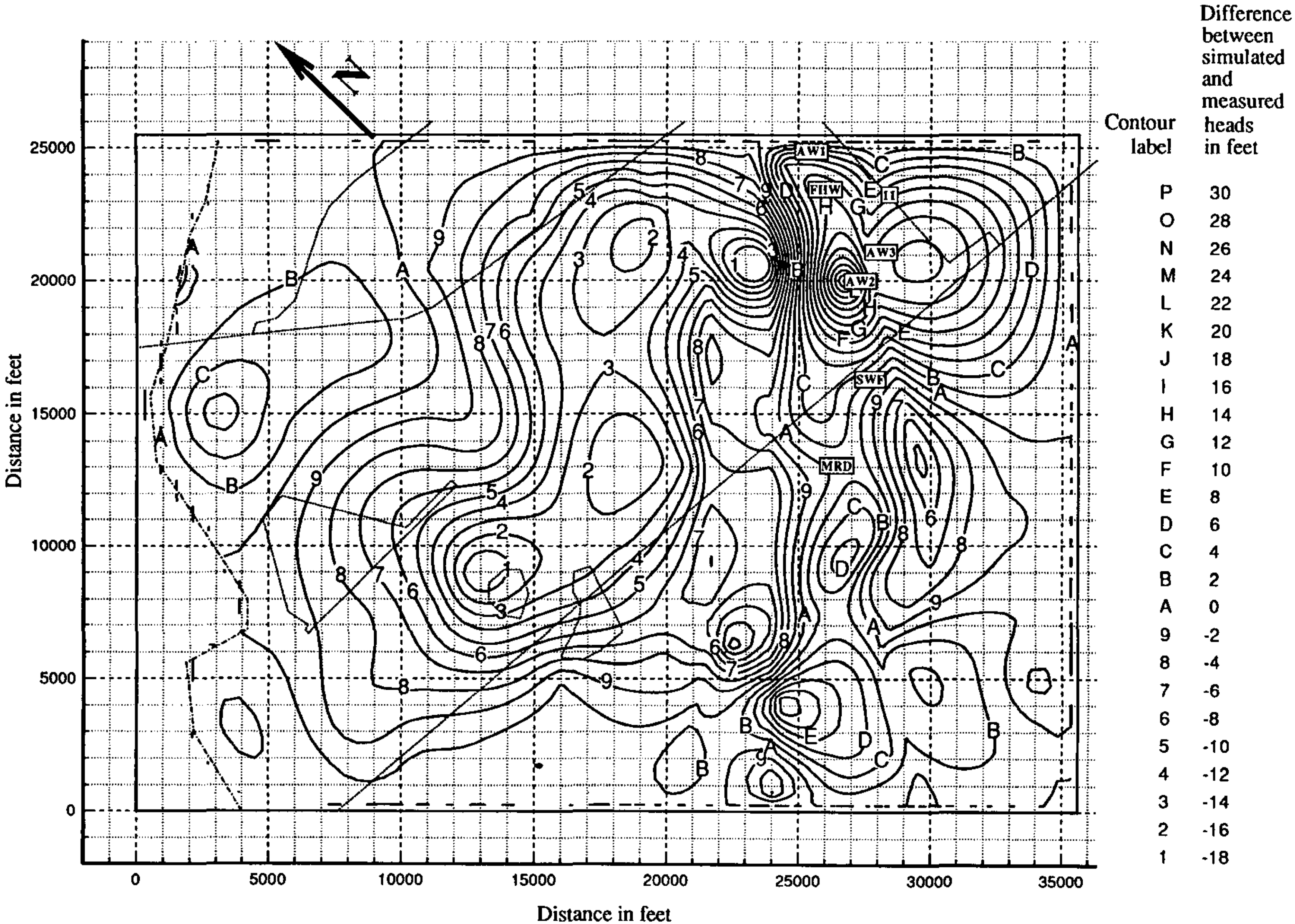
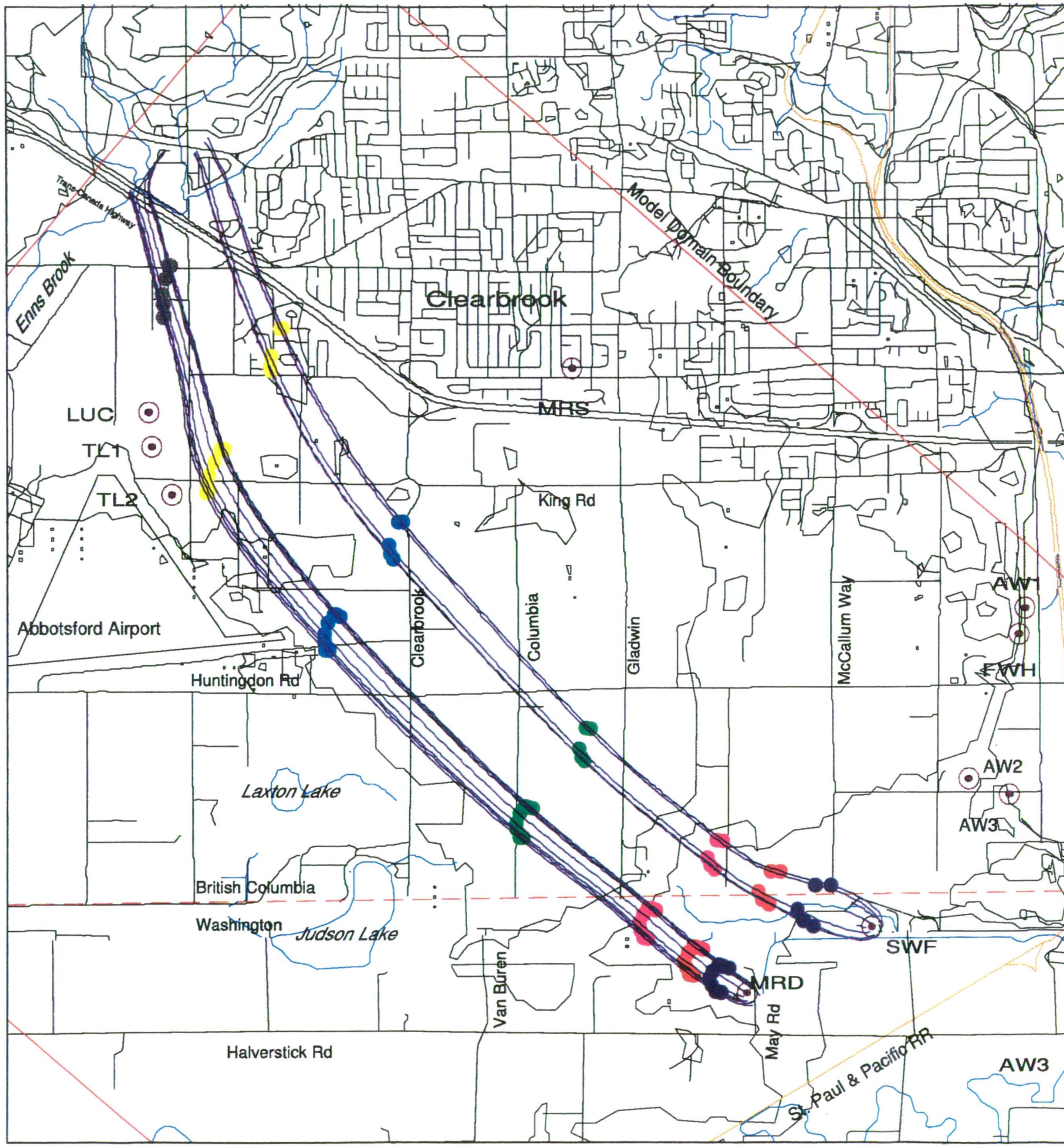


FIGURE 2-4-10 Contours of distribution of difference between simulated and measured heads for Sumas outwash layer obtained for calibrated model.

gwe6-107.hed, dh-ly2.sty



Legend

Travel Times (Years)

- 0.5
- 1.0
- 2.0
- 5.0
- 10.0
- 15.0
- 20.0

N

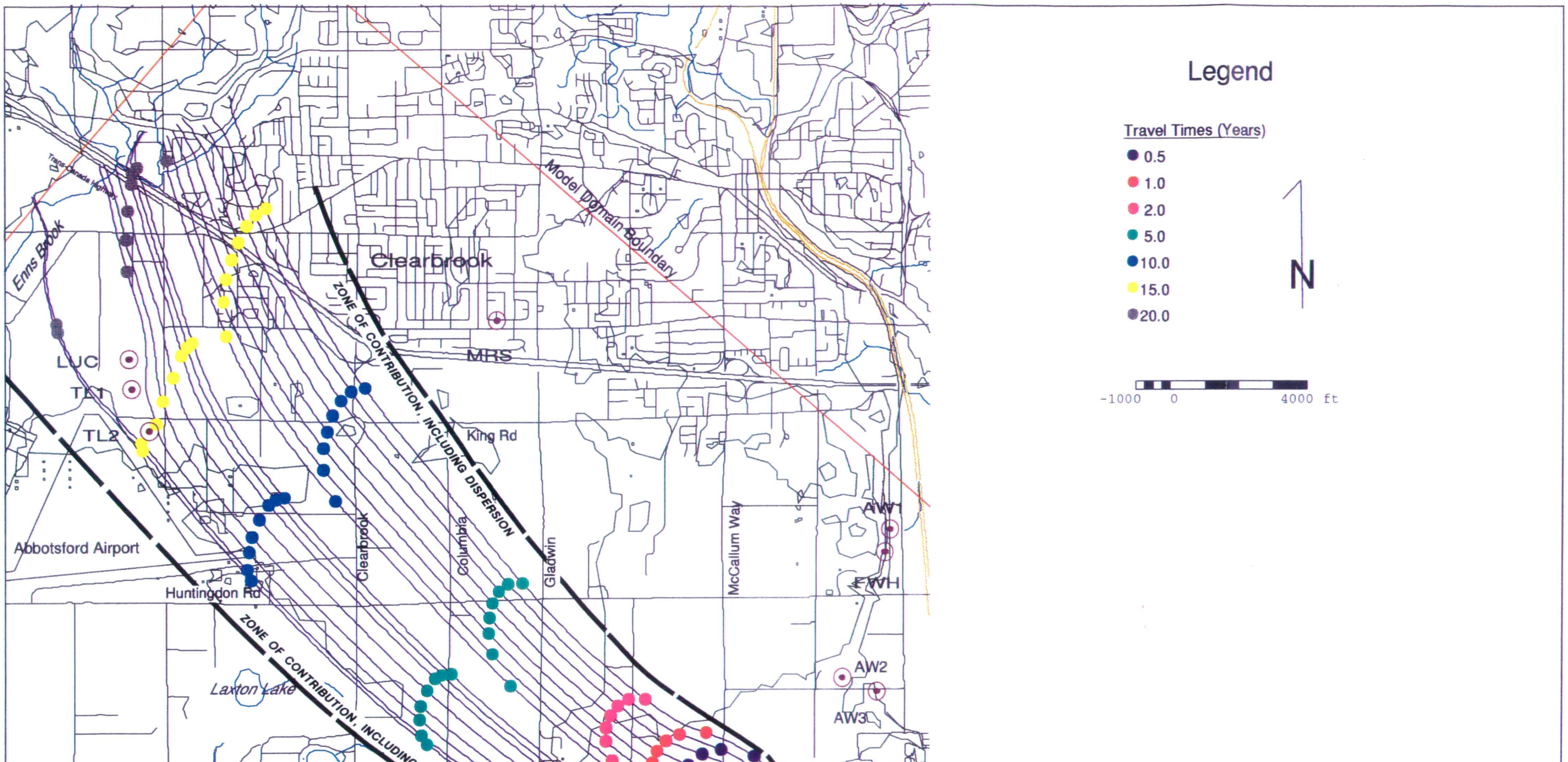
-1000 0 4000 ft

Note: Dispersion zone not shown.

CAPTURE ZONES - MAY RD AND SUMAS WELL FIELDS - CURRENT PUMPING RATES

WELL HEAD PROTECTION PROGRAM Sumas, Washington for City of Sumas	Project No. **VB9504A**
	Figure No. **2-4-11**

ASSOCIATED EARTH SCIENCES, INC.



CAPTURE ZONES - MAY RD AND SUMAS WELL FIELDS FULL WATER RIGHT PUMPING RATE

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. **VB9504A**

Figure No. **2-4-12**

ASSOCIATED EARTH SCIENCES, INC.

3.0 INVENTORY OF POTENTIAL SOURCES OF GROUND WATER CONTAMINATION

3.1 WELLHEAD PROTECTION INVENTORY METHODOLOGY

3.1.1 Introduction

The Abbotsford-Sumas Aquifer is a broad upland created by glacial deposition of sands and gravels from the North Cascades. It is some 250 square miles in extent, and it straddles the Canada-United States border. It is a highly prolific aquifer, and has been extensively utilized for ground water since modern settlement started to take place. The ground water from the aquifer is used more intensively on the Canadian side than on the American side. Public withdrawals from the aquifer, for example for fish hatchery and municipal purposes, total several thousands of gallons per day.

One of the key features of the contaminant source inventory for the City of Sumas wellhead program is that 90% of the recharge area is in Canada. This means that Sumas has a challenging problem all through its wellhead program: delineating an area of contribution; inventorying potential contaminant sources; and analyzing and proposing management methods all by "remote control" in a neighboring country. This report attempts to deal only with the second of these concerns.

Another feature of the inventory process is that it concentrates on the ten-year time of travel zone for a specific well or well field, as determined in the delineation phase. Ten years is a short time in the life of a public water supply, and it is generally accepted that potential contaminant sources beyond the ten-year time of travel can impact the well source. Prudent resource management requires that such sources be dealt with. However, the ten-year travel time has become the basis of the regulatory wellhead protection program (see WAC 246-290).

The Washington State Health Department in 1993 published a guidance document entitled "Inventory of Potential Contaminant Sources in Washington's Wellhead Protection Areas." The present inventory follows this document in its general outline, although the document lacks guidance in dealing with specific situations.

3.1.2 Inventory Forms and Data Collection

The source inventory for the Sumas wellhead area relied heavily on work carried out by Patrick Ryan for a Masters of Science Thesis at the University of British Columbia (Ryan, 1994). Ryan's principal interest was the relationship between land use and nitrate contamination in the Abbotsford-Sumas Aquifer. Inventory data collected by Ryan was not duplicated or redone, but it was supplemented with data on areas or land uses that Ryan did not collect. In some cases data was developed by Ryan that was not directly necessary for the wellhead protection inventory, but these data have been retained in the database because future uses of the information cannot be foreseen.

In May 1994 inventory data categories were developed to suit the particular setting of the source inventory for the City of Sumas. These were adapted from a Wellhead Protection Program carried out for the City of Everson, and from Ryan's 1994 work. Categories of potential contaminants were not included if they were not thought to be important features of the Sumas zone of contribution. For instance, initial land use information in the 10-year zone of contribution showed that there was no large-scale manufacturing activity in the zone. If the inventory is carried out and there is no data in a field for a certain activity, then the field is dropped from the discussion. A data collection plan was developed at this time.

The data categories used in the inventory are the following:

- Township North
- Range East
- Section
- Tax parcel no. ("X-Y")
- Canadian I.D. #
  - Lot #
  - Plan #
- Property Owner
  - Street Name
  - House Number
  - Telephone #
- Primary Land Use
- Secondary Land Use
- Water Source, primary
- Source, Additional
- Buildings
- Domestic/residential Waste
  - (Data for 3 time periods: pre 1969, 1970-81, 1982-92)
  - Tank Size/Field Size
  - Flow
- Solid Waste
- Primary Ag. Category
- Secondary Ag. Category
- Type of Crop
- No. of Cattle
- Primary Cultural Practice
- Secondary Cultural Practice
- Name of substance
- Hazardous Materials Transport
- Fuel Storage
- Secondary Fuel
- Chemical Storage
- Gravel Mining
- Comments

The inventory process covered existing data and information sources such as state databases, archival material, etc.; and then air photo information on land use, windshield surveys, and interviews by telephone and in person with residents of the lands in question.

The first step in gathering information was to access Provincial, state and local organizations and data bases they maintain. Some examples are the B.C. Ministry of Environment, the B.C. Sustainable Poultry Farming Group, the Washington Dept. of Ecology, Whatcom County Planning and Development Services, Whatcom County Health Department, Washington State University Cooperative Extension, and the U.S. Natural Resources Conservation Service (formerly known as the Soil Conservation Service).

The inventory of lands in the zone of contribution relied on air photo interpretation, County Assessor's records, and phone or direct interviews with land owners for determination of agricultural land uses. Detailed inventory data can be found in the computer data base. A summary of land use and associated potential ground water contaminants is presented in Table 3-1-1.

The next logical column in this table is a short list of the appropriate management options for each land use. Management options are described in a separate report under the Sumas Wellhead Protection Program.

3.1.3 Compiling and Analyzing Results

Ryan's inventory was supplemented in June 1994 by the efforts of Water Resources Consulting personnel. These efforts filled in some of the gaps in the information collected by the Ryan effort, and supplemented the geographic areas that were found to lie in the delineated zone of contribution but were not included in Ryan's original inventory.

The data was compiled in an electronic spreadsheet (Please see Appendix). A unique identifier for each land parcel in the Zone of Contribution to the wellhead was adopted, and data associated with each parcel was tabulated in the spreadsheet. There are 331 parcels in the spreadsheet, but a comprehensive inventory was not possible for all parcels. For instance, as can be seen from Figure 3-2-8, which shows wells only up to 1957, a systematic inventory of wells would take a substantial additional effort. Activities were summed to show totals. A given land parcel is likely to have more than one land use associated with it, especially in agriculture; the primary land use is the one shown in the summary.

The land use summary shows a general break-down of land uses for all 331 parcels. The water source summary is only a small portion of the total picture. The domestic waste summary gives a detailed and systematic picture, largely because of the work done by Ryan (1994). The agricultural land use summary is fairly complete because land use can be ascertained from a windshield survey. Fuel storage tanks are hard to see, and voluntary information is hard to get; therefore the summary information is accurate as far as it goes but is probably not complete. An inventory of agricultural practices was attempted, but the information derived was fragmentary. A more reasonable approach is to assume that a given crop is engaging in standard pest management practices for that crop.

3.2 CHARACTERIZATION OF POTENTIAL SOURCES

Predominant land uses in the wellhead zone of contribution are raspberry farming, poultry production, miscellaneous crop and livestock farming, gravel pits, and residences. Much of the large quantity of chicken manure generated in the zone of contribution is applied to crops in the zone. Poultry production and raspberry farming are treated in their own categories because both are so extensive. Figure 3-2-1 is a composite map showing distribution of major land uses relative to the zones of contribution based on current water withdrawal; Figure 3-2-2 is the same map showing the zones of contribution based on full future use of the City of Sumas' water right. There is some difference between the May Road well field and Sumas well field zones of contribution in regard to potential contaminant sources within the 1.year travel time. For instance, May Road has raspberries only beyond the 2-year travel time, but the Sumas well field has raspberry acreage within six months' travel time. In many cases there are some assumed relationships between land uses and associated potential contaminants. Some of the relationships can be appreciated by reference to the following table (Table 3-2-1), and by reference to the land use figures (nos. 3-2-1 through 3-2-8):

3.2.1 On-Site Sewage Disposal Systems

Septic tanks and leach fields are the predominant type of on-site waste disposal system in rural B.C. and Whatcom County. Figure 3-2-3 shows the distribution of septic tanks in the capture zone. They store and treat domestic waste from residences that are too far from a public sanitary sewer collector to be connected to it. Septic tanks, unlike underground fuel tanks, do not maintain a high degree of bacterial or viral contamination potential for years after use has been discontinued, so the old ones are not as great a concern as newer ones. Common household products contain a variety of volatile organic compounds (VOCs), however, which do accumulate at the site of disposal. VOCs show up in the ground water across the aquifer (Gartner Lee, 1993; Abbotsford-Sumas Aquifer International Task Force, 1993; Golder Associates, Inc., 1992); the source of these materials is not known.

Septic systems present three kinds of risk of contamination: bacterial and viral loading, nitrate, and unknown hazardous materials flushed down the line. The bacterial and viral loading is self-limiting in a properly designed and maintained system; after a time (longer for viruses) the organisms are not viable. Nitrate, on the other hand, is a mass loading problem. Although nitrogen metabolism in the soil is vastly complicated (for a graphical description, see Ryan, 1994 p. 33, 61), nitrates tend to accumulate in the soil or ground water rather than attenuate. Nitrate is of concern from a human health point of view because it causes methemoglobinemia ("blue baby syndrome") in infants, and also because it is an indicator of other possible water-borne pollutants.

Septic systems in the Abbotsford-Sumas aquifer have little fine-grained material near the surface, so there is little treatment of effluent before it reaches the water table.

3.2.2 Fuel Storage Tanks

Ground water contamination by fuel is a concern because it can force the shut-down of a public water supply. Medical evidence has implicated components of fuel (such as benzene, a confirmed human carcinogen) in human illness. Health effects range from acute symptoms such as nausea, dizziness, tremors and blindness, to lower level chronic effects including skin eruptions and central nervous system impairment (Pye et al., 1983).

The inventory effort was not able to collect systematic or comprehensive data on underground fuel tanks, and they are therefore not shown on a figure. Numerous above-ground fuel tanks can be observed in a windshield survey of the capture zone, however. In a few instances, owners informed the surveyors about tanks they have.

For the Washington State portion of the Zone of Contribution, the inventory surveyors contacted the Washington Department of Ecology for information in the state list of underground fuel storage tanks. The inventory has a lower capacity limit of 1,100 gallons. No tanks of greater capacity showed up in the inventory for the Sumas wellhead zone of contribution. The surveyors consulted the Whatcom County Office of Emergency Management list of hazardous chemicals developed pursuant to federal "right to know" requirements; this list also turned up no storage tanks.

Heating oil distributors who serve the Sumas area were contacted. They do not keep systematic records of kinds of storage tanks, and were reluctant to share what they perceive as private customer information. There is a need to provide information about the objectives of the inventory, explain the official local government mandate, and enlist the support of both fuel distributors and landowners. This process does not happen overnight, and it is to be expected that the first inventory attempt may meet with some resistance that can eventually be overcome by meaningful public involvement in the program.

3.2.3 Agriculture: Raspberries

To any casual observer of the landscape in the Sumas wellhead zone of contribution, raspberry farming is the dominant activity (see Figure 3-2-4). Raspberries account for over 60% of the area in the ten-year travel time of the Sumas and May Road wells. Berry culture also continues to expand. Raspberry culture is capital intensive, and intensive in terms of irrigation and chemical inputs. Raspberries are not gross consumers of nitrogen, but prevailing practice has been to spread poultry manure on berry crops considerably in excess of the agronomically optimal level of application. A typical application rate for raspberries is 50 lb/ac. of nitrogen (B.C. Ministry of Agriculture, Fish & Food, 1994 p. 39); for corn, a comparable application rate could be in excess of 170 lb/ac. (U.S. Soil Conservation Service, 1993 p. 11.28). The result is that high nitrate levels have been documented in wells for some years (Liebscher et al., 1992; Kohut et al., 1989; Ryan, 1994).

Because of U.S. state and federal requirements that insecticide and herbicide operators be licensed, U.S. farmers within the zone of contribution tend to rely on commercial distributor-applicators. Until recently, berry farmers in B.C. have applied their own pest control materials. Raspberries are among the most intensively sprayed of crops (Canadian Farm Worker's Union, 1990). In British Columbia, both the Ministry of Environment and the Workers Compensation Board now have requirements for training and certification of pesticide applicators. Ministry of Agriculture personnel estimate that over half of pesticide applicators have been through some level of training, but the exact numbers are not known. In 1992, requirements were adopted for certification for purchase and use of Restricted pesticides (such as organophosphorus materials). The Ministry of Environment currently is proposing extension of this requirement to a longer list of materials.

The Fraser Valley Ground Water / Drinking Water Study surveyed water quality in numerous locations in the Abbotsford-Sumas Aquifer. At least 15 different pesticides were found to occur in the study area (Gartner Lee, 1992).

3.2.4 Agriculture: Other Crops Besides Raspberries

Interspersed with raspberry and poultry operations are a number of dairy farms, orchards, pasture, etc., which are lumped together for the purposes of the inventory as "other crops." The distribution of these activities is shown on Figure 3-2-5.

Some agricultural land uses are highly compatible with wellhead protection areas because they preempt other uses with higher contamination potential, and entail application of few if any contaminants to the land. This would be true of grass pasture and hay land, provided nutrients are supplied at agronomically appropriate rates; i.e. at or below the seasonally varying rate of uptake by plants. This argues for some advantages to the continuation of agriculture in the capture zone, from a ground water protection point of view. Intensive crop agriculture may entail applications of chemicals that have disadvantages for ground water protection. It is hard to say categorically that agriculture is better than other land uses.

3.2.5 **Poultry Production**

Commercial poultry operations are spread out fairly evenly across the capture zone (see Figure 3-2-6). Typical operations consist of two to five long single-story buildings fifty feet apart, with tens of thousands of birds in each one. The average broiler operation has 32,000 birds at any given time. They make use of fairly small parcels of land, averaging 16 acres (6.5 ha) (Chipperfield, 1993). Virtually no operators own a sufficient land base to absorb the wastes they generate within their own operation. There are 40 poultry operations within the ten-year capture zone on the Canadian side of the border. These have not been surveyed as to their specialty in the poultry industry; we have assumed where better information is not available that these 40 operations are typical of the Fraser Valley poultry industry as a whole. Broiler chickens produce nitrogen at a rate of approximately 1.1 pound per thousand pounds of body weight per day; laying chickens, approximately 0.8 pound per thousand pounds per day. (These rates compare to a figure for humans of 0.2 pound per thousand pounds.) (See Soil Conservation Service, 1993.) Chipperfield (1993) estimates bird production for subareas of the Fraser Valley; we have used a proportion of his estimates for the area that contributes flow to the Sumas wells. Based on Chipperfield, there are approximately 1.1 million birds at any one time in the 10-year time of travel zone. Manure production from these birds is about 16,000 metric tons per year; this tonnage contains approximately 400 tons of nitrogen.

The public health significance of nitrate contamination of ground water is based on several concerns. One is that infant humans and young cattle are susceptible to methemoglobinemia when exposed to nitrate-containing drinking water. Another is that nitrogen has been implicated in the causation of human cancer and birth defects (Taylor, 1995). Long-standing risk assessment and rule-making has set the drinking water maximum contaminant level at 10 mg/l.

Livestock and agricultural waste can contribute to unsafe levels of nitrates in the aquifer recharge. There is a documented history of high nitrates in the zone of contribution to the Sumas wells, and strong evidence of its association with poultry production (Liebscher et al., 1992). Kohut et al. (1989) published isopleths of nitrate concentration for the Abbotsford upland. The Wellhead Protection source inventory focused on known sources of nitrates such as the poultry industry.

How the manure is handled obviously is a key determinant of the effect of the operation on ground water. Storage practices make considerable difference. Chipperfield reports that 65% of the stored manure from poultry operations was stored uncovered on the ground. Typical practice is to apply the manure to the nearest crop land, which tends to be raspberries. Ryan (1994) concludes that this source of nitrogen is by far the greatest source in the area, far ahead of septic systems and inorganic fertilizers.

3.2.6 Gravel Mining and Processing

The entire Abbotsford-Sumas Aquifer consists of glacial outwash deposits, sand and gravel beds that were left by meltwater as the ice retreated. These deposits have been mined for at least a generation on both sides of the border (see Figure 3-2-7). On the Canadian side, there are four gravel mines (referred to as quarries in Canada) within the ten-year capture zone, and three contiguous ones just beyond it to the north. Some of these mines or quarries are currently being worked, and some of them have fallen into disuse. On the U.S. side, there are no active gravel mines within the ten-year travel time; however, proposals are under consideration to expand gravel mining activities into deposits within the capture zone that have not been previously exploited. Columbia Aggregates, Inc. has proposed opening a gravel pit immediately west of the capture zone and shipping the gravel across the border to Canadian markets by conveyor belt. Starkenburg & Wiersma has an application to open a new gravel pit to the east of the proposed Columbia project, within the two-year capture zone.

Gravel processing is usually associated with the extraction process. It entails sorting, crushing, handling, and washing facilities. It often involves use of local ground water, and disposal of high-turbidity washings. A variety of machinery and associated fuels and lubricants is usually on site. Numerous examples of documented contaminant spills are contained in Mead (1995).

One of the concerns presented by gravel mines has been that it is very difficult to control illegal waste dumping after the economically available gravel has been mined out. The practice is particularly attractive for large waste that is expensive or difficult to dispose of, such as empty storage tanks or appliances. Documented cases are known on both sides of the border; the disused Whatcom County pit on the Halverstick Road is an example. The key issue is that it is difficult and expensive to control the access to an abandoned gravel pit so this does not happen. While gravel removal has been carried out without contaminating the ground water, it tends to increase the vulnerability of the aquifer by removing fine-grained material that may adsorb contaminants and by reducing the distance to the water table.

Figure 3-2-7 shows the locations of existing and proposed gravel mining activity in and near the capture zone.

3.2.7 Hazardous Waste Sites

There are no known hazardous waste sites or Superfund sites in the capture zone for the Sumas wells. This statement can be made with greater conviction on the U.S. side of the border, because the capture zone is smaller and the history of land use is better known.

3.2.8 Household Hazardous Materials

It is recognized that a typical household has a wide array of materials that could cause problems if improperly used, stored, or disposed of: cleaners, solvents, fuel, lubricants, paints, insecticides, medicines. The time and money available to carry out the inventory did not allow for a systematic residence survey to ascertain what potential ground water contaminants are in each household. Two further aspects of household wastes are that owners and habits change, and the whole problem can probably best be dealt with through area-wide information and materials disposal campaigns. There is no control over application rates for home lawn care chemicals; thus per acre application rates can be substantially higher than commercial rates.

3.2.9 Unprotected Wells

Wells that do not have adequate protection are a potential avenue for very rapid pollution of the aquifer, from materials that we can only guess at: batteries, oil, paint, fuel, pesticides, etc. It is an easy matter for an untended hole in the ground to be regarded as a convenient waste disposal site rather than a window into the water supply. The multitude of separate land ownerships and attitudes toward the problem tend to exacerbate it.

The water level over much of the recharge area in the Abbotsford-Sumas aquifer is shallow and has little impervious soil on top of it. Historically, residents of the upland area have been able to obtain an abundant water supply from wells less than 100' deep, and there is a dense pattern of wells throughout the recharge area (see Figure 3-2-8.) There has been an historical decline in water levels in these wells, and many users have switched over to municipal supplies (which ironically are dependent on the same aquifer). Some old wells have been abandoned; in other cases the old well has not been abandoned, and the owner has intentions of using it again in the future. Even for wells that are still in use, there may be no surface seal or other means of preventing contamination from entering the aquifer.

The inventory process was not able to systematically identify all unprotected wells in the area, or to reduce available data to mapped format. Figure 3-2-8 shows well locations in Canada as of the mid-1950's. It shows the prevalence and distribution of privately controlled wells, or windows of contaminant access, to the aquifer. Although there is no requirement that well drillers submit well specifications to the Provincial authorities, as there is in Washington, there is nevertheless a large body of information on existing wells. The B.C. Ministry of Environment maintains a database of wells for which voluntary logs have been submitted. These wells have not been plotted, but they are in machine-readable form and could be plotted.

3.2.10 Industrial and Commercial Facilities

The zone of contribution for the 10-year travel time does not contain significant manufacturing operations. One conspicuous commercial operation is an extensive greenhouse less than a mile north of the border.

3.2.11 Storm Water Management

Storm water handling facilities become important to ground water recharge when large amounts of impervious surface have been created over the recharge area. There are no storm drain systems within the 10-year capture zone, largely because storm runoff infiltrates rapidly into the fields and roadside ditches. There are storm drain systems over other parts of the Abbotsford-Sumas Aquifer, which would deserve attention if wellhead protection programs were instituted for the Canadian side. In these situations, it might make sense to route the storm runoff particularly the "first flush" of a storm away from the wellhead protection area and/or to surface drainages or grass-lined swales where some of the contaminants would be removed.

Storm drainage systems are not discussed further in the context of existing potential contaminant sources, but they could have significance in the future to the extent that urbanization of the Sumas zone of contribution takes place. If urbanization is accepted as a concept and long-range facility planning for it is feasible, it would be both possible and desirable to implement a storm water management program.

3.2.12 Linear Transportation Sources

There are no major transportation routes such as railroads, pipelines, or arterial highways through the Sumas wellhead protection area. There are secondary roads however, and some transport of fuels or other potential contaminants. A partial spill of a tanker load of gasoline could force an immediate shut-down of a nearby well. There is a low likelihood of this happening to the Sumas wells, because the roads within the 1.year time of travel are low usage dead-end roads where bulk materials transport is not common.

3.3 ASSESSMENT OF RISKS AND SOURCE PRIORITIZATION

After an inventory of potential ground water contaminant sources has been carried out, and before development of management options, an assessment of relative risk of the different potential contaminant sources identified in the inventory phase should be done. The relative risk assessment is an attempt to combine the judgments of a wide spectrum of individuals concerned with the problem, including trade groups, the consulting team, and knowledgeable residents of the community.

The significant categories of activity identified in the inventory that have potential to contaminate ground water in the Sumas wellhead protection area are the following:

Agriculture: raspberries
Agriculture: other crops
Poultry production
Gravel mining and processing
Fuel storage tanks
Unprotected wells
Household hazardous wastes
On-site sewage disposal systems
Storm water management
Industrial and commercial facilities

3.3.1 Contaminant Source Priority Setting Approach

The U.S. Environmental Protection Agency guidance document for wellhead protection risk assessment (1991) contains an elaborate methodology: characterization of each source by design, age, distance from the well, contaminants present, likelihood of release, likelihood of reaching the well, and attenuation before it gets there. The individual judgments are collated in an array of data sheets, worksheets, scoresheets, and a master matrix.

The EPA methodology is not being recommended for general application by the Washington Department of Health, and it is considered too detailed and laborious for small communities like Sumas. Consequently the method has not been applied here. The EPA guidance document is however useful for its suggestions as to how to conceptualize the problem.

The risk assessment method used by the consulting team consists of best professional judgment of the personnel who carried out the inventory (Table 3-3-1). A rationale for these judgments is provided below. We think it is important that the Sumas risk assessment method be simple enough to make intuitive sense to community residents; if they disagree with the judgments made, they can see where they came from and see how much difference an alternative judgment would make. There is inevitably an element of subjectivity in the judgments shown in the priority matrix, and the result is sensitive to assumptions. Which single source ranks as first priority is probably not as important as the management strategy suggested by the top three or four sources.

It is useful to distinguish between risk evaluation and priority setting. A higher risk may be perceived as acceptable on the grounds that it would be prohibitively expensive or difficult to eliminate; whereas a lower risk may be attractive for elimination because it lends itself to a simple or inexpensive solution.

Individual judgments were made for each activity in the list above, as to four criteria:

Design characteristics of source
Relative hazard
Geographical distribution
Manageability

Briefly, these mean the following:

Design characteristics of source: How inherently susceptible is the design of the activity in question to release of potential ground water contaminants? Are there inherent safeguards, or is the activity just an accident waiting for a time to happen? An example of the latter would be juvenile water skiers fueling a ski boat on a beach with a five gallon can.

Relative hazard: What is the relative toxicity of the contaminant in question; for example, chloride or sulfate would rate a 1 (relatively low), while gasoline would rate a 3.

Geographical distribution: How geographically widespread is the activity within the 10-year zone of contribution? If numerous sites are involved, the activity rates high; if few, it rates low.

Manageability: How difficult would it be for the City to influence the activity so as to minimize the threat it might pose to ground water? If the problem is relatively tractable, it would rate a 3, thus increasing its priority for action. The implied assumption is that doing the easiest things first would show the best return for our time and trouble.

Each criterion was scored a 1, 2, or 3; the scores were summed, and rank order established. The higher the total score, the higher priority the activity has for preventive action. The following section relates the individual judgments made for each activity.

3.3.2 PRIORITY CONTAMINANT SOURCES

The consulting team has made a trial application of this ranking system to the activities in the Sumas wellhead area. Several opinions on the trial ranking surfaced, and the consulting team subsequently modified its judgments to reflect these opinions.

Briefly, the activities rank as follows:

No. 1 priority:

- Poultry production
- Gravel mining
- Fuel storage tanks
- Agriculture: raspberries

No. 2 priority:

- Unprotected wells

No. 3 priority:

- On-site sewage disposal systems
- Household hazardous wastes
- Industrial and commercial facilities
- Agriculture: other crops

No. 4 priority:

- Storm water management

The priorities reached through this process should be reviewed to ensure that they represent the consensus judgments of the community and the consulting team. They should be revised as appropriate.

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TABLE 3-1-1
Summary of Land Use and Associated Potential Ground Water Contaminants in the Zone of Contribution
City of Sumas Wellhead Protection Plan

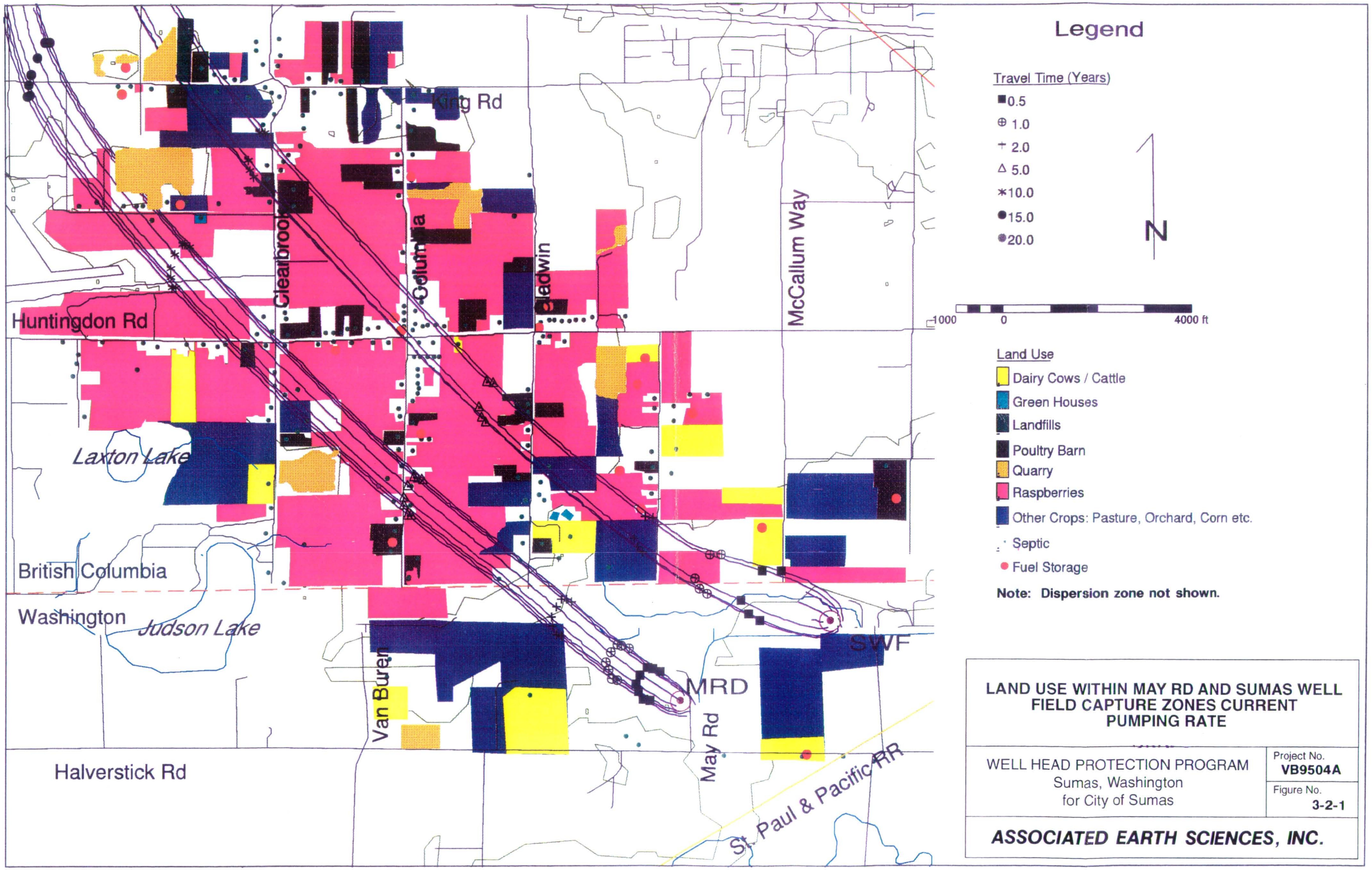
Land use	Contaminants	Relative Hazard	Travel time to wells	Prevalence in 10-year ZOC
Gravel mining and processing	fuel & lubricant spills; unauthorized dumping	high	5-10 year	four; others proposed
Fuel storage	diesel oil, gasoline	high	5-10 year	many & widely distributed
Unprotected wells	Unknown; wastes characteristic of homes and farms	high	5-10 year	many & widely distributed
Agriculture: Raspberries	Insecticides, Herbicides, Fungicides, Fertilizers	some high, some medium	5-10 year	all over
Agriculture: other	Variable	some high, some medium	0.5-10 year	relatively few; widely distributed
Poultry production	Manure: nitrate, bacteria, viruses; Disposal of dead birds: bacteria	Medium	2-10 year	many & widely distributed
Single family homes	household chemicals	medium	2-10 year	many & widely distributed
Storm water systems	road runoff: oil & grease, asbestos, heavy metals; acids, antifreeze	medium	2-10 year	No organized storm water systems in 10-year TOT
Industrial & commercial facilities	Dependent on specific manufacturing or processing activity.	Activity specific	2-10 year	One major facility (commercial greenhouse) in 10-year TOT

TABLE 3-2-1
Characteristics of Potential Contaminant Activities
City of Sumas Wellhead Protection Plan

Potential contaminant source	Design characteristics of source	Relative Hazard	Geographical distribution	Manageability
Household hazardous wastes	uncontrolled	potentially high; unknown	widespread, wherever single-family homes located	Not hard to do educational efforts, harder to achieve and show results. There are some management options in place.
On-site sewage disposal systems	regulated by County or Province; supposedly in shallow fine-grained material; good absorption characteristics	generally low, but contaminants not controlled	widespread outside of 1.year time of travel; none inside 1.yr time of travel	education; possible public maintenance scheme
Fuel storage tanks	susceptible to leakage or spillage	high	not completely known; suspected to be numerous and widespread	expensive; may be able to devise incentive or voluntary remediation program
Gravel mining/Quarries and processing	high susceptibility; removes all surface cover from water table	unknown; could be low if best management practices are followed, high if not followed	Locations distributed through the 10-year TOT zone; potential future expansion	high in the sense that proposed pits have not been permitted yet; low in the sense that enforcement is difficult.
Unprotected wells	high vulnerability; provides a window directly into water table	unknown contaminants; could pose severe hazard	apparently widespread throughout the wellhead area; fewer in the 1.year time of travel.	probably expensive to treat; could devise an incentive or voluntary remediation program
Industrial & Commercial facilities	Unified control of materials and activities	potentially high	one facility (greenhouse)	high, because of small number
Agriculture: Raspberries	Depends on chemical & fertilizer application practices. Design of farming activities inherently extensive.	variable; manure low, some chemicals higher	Many operations of varying sizes; largest land use in ZOC	low, given large number of operators and language barriers
Agriculture: Other crops	can be good if farm plans adopted; design of farming activities inherently extensive.	variable; manure low, some chemicals higher	relatively small number of operations, though each involves a lot of acreage	high, given small number of operators and availability of options
Poultry production	can be good if state of the art practices applied. Design of poultry barns inherently concentrated; it is obvious where they are, they are under cover, and can be mechanized.	Medium	large number of operations, with large animal biomass concentrated in small area. Each operation involves small acreage	high, given concentrated nature of the industry and logical character of some options.
Storm water management	high susceptibility; roadside ditches tend to route surface runoff directly into the aquifer	Medium; specific contaminants unknown	problem does not exist yet	surface drainage can be re-routed, for a price

TABLE 3-3-1
Priority Matrix
City of Sumas Wellhead Protection Plan

	Source design	Relative hazard	Geographic distribution	Manageability	Sum	Rank
Gravel mining and processing	2	3	2	3	10	1
Poultry production	2	2	3	3	10	1
Fuel storage tanks	3	3	2	2	10	1
Agriculture: Raspberries	3	2	3	2	10	1
Unprotected wells	3	2	3	1	9	2
Household hazardous wastes	2	2	2	2	8	3
On-site sewage disposal systems	2	2	2	2	8	3
Agriculture: other crops	2	2	2	2	8	3
Industrial and Commercial facilities	2	2	1	3	8	3
Storm water management	2	2	1	2	7	4



LAND USE WITHIN MAY RD AND SUMAS WELL FIELD CAPTURE ZONES CURRENT PUMPING RATE

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. VB9504A

Figure No. 3-2-1

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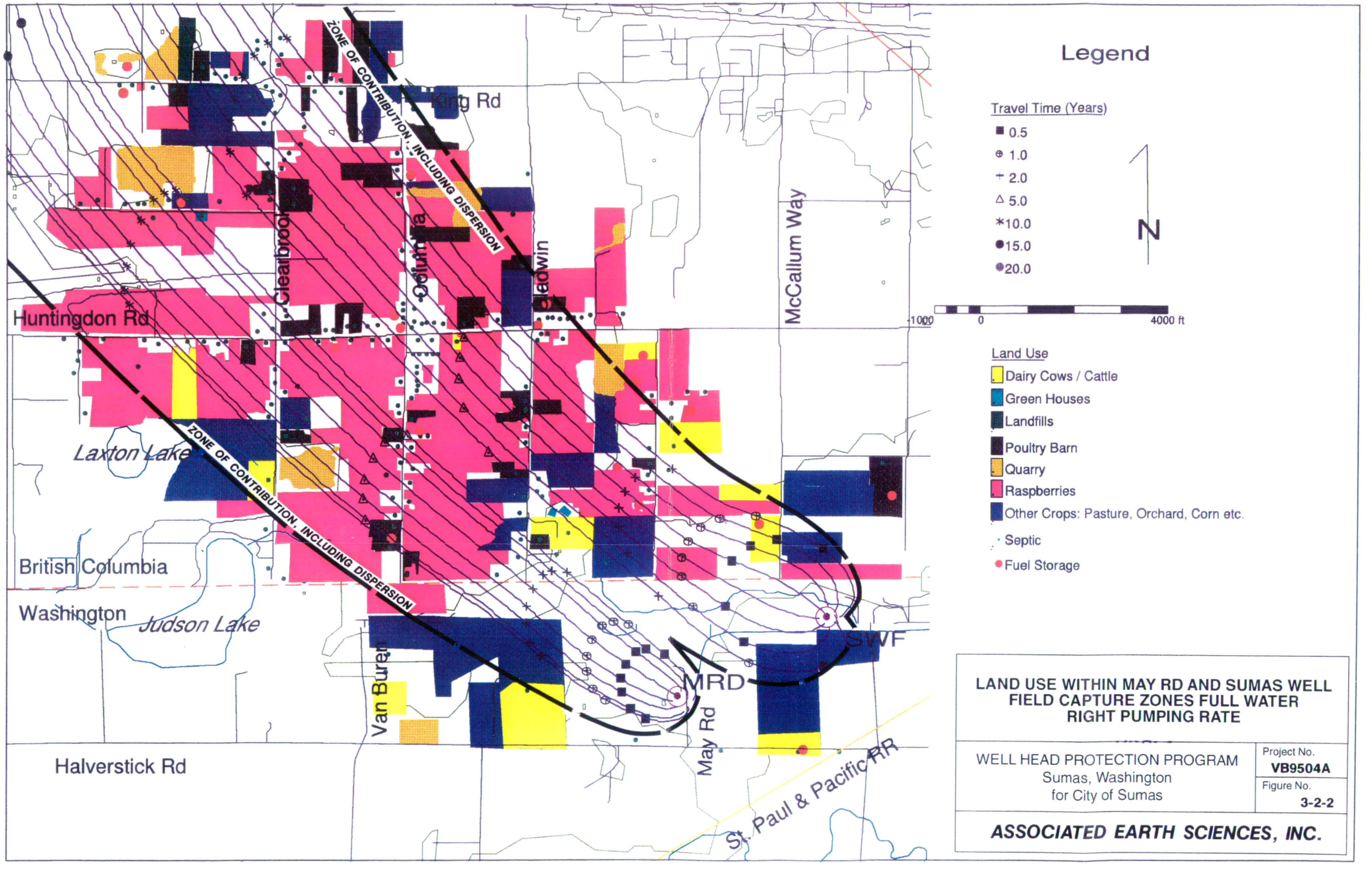

LAND USE WITHIN MAY RD AND SUMAS WELL FIELD CAPTURE ZONES FULL WATER RIGHT PUMPING RATE

WELL HEAD PROTECTION PROGRAM Sumas, Washington for City of Sumas	Project No. VB9504A Figure No. 3-2-2

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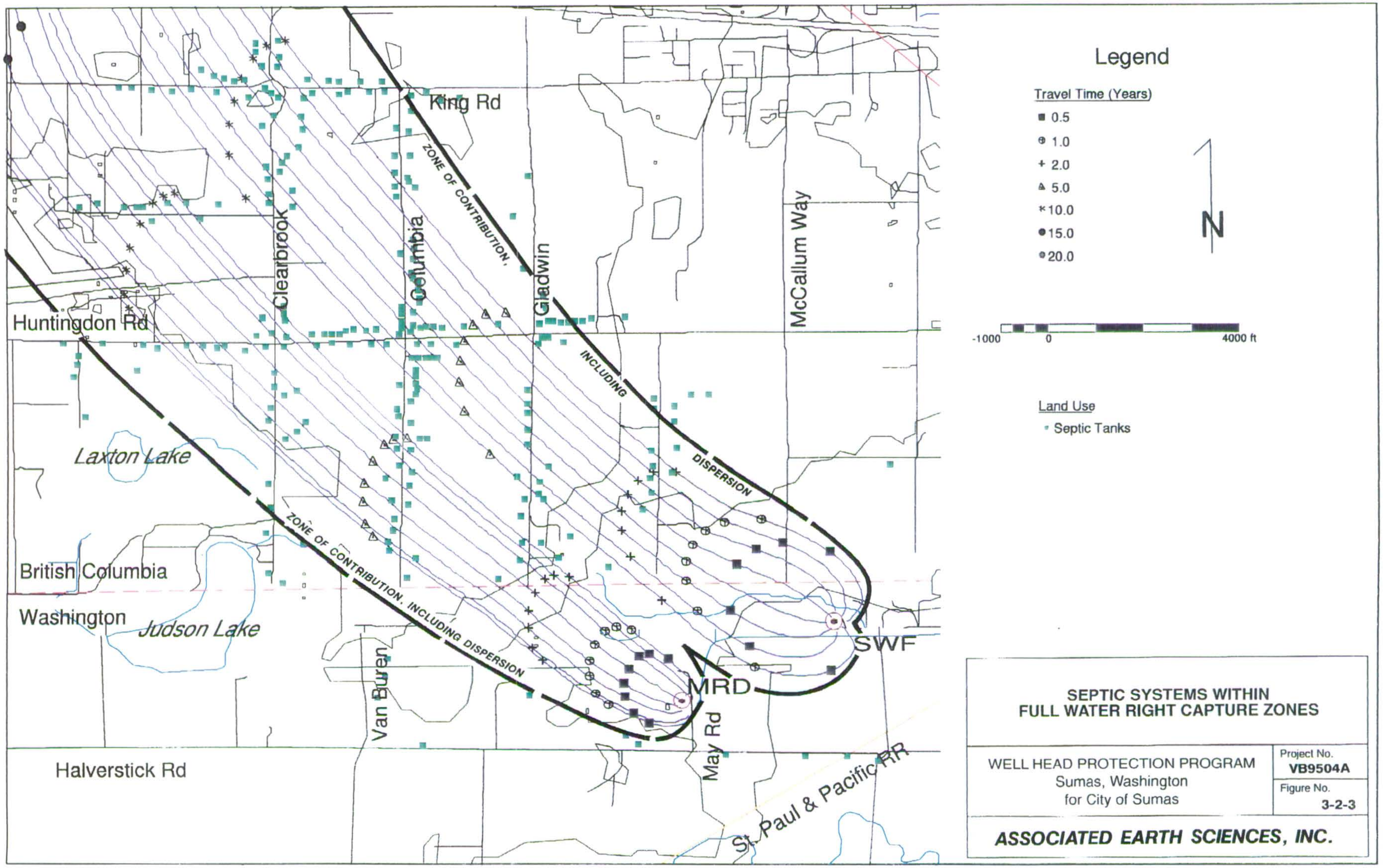

SEPTIC SYSTEMS WITHIN FULL WATER RIGHT CAPTURE ZONES

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. **VB9504A**

Figure No. **3-2-3**

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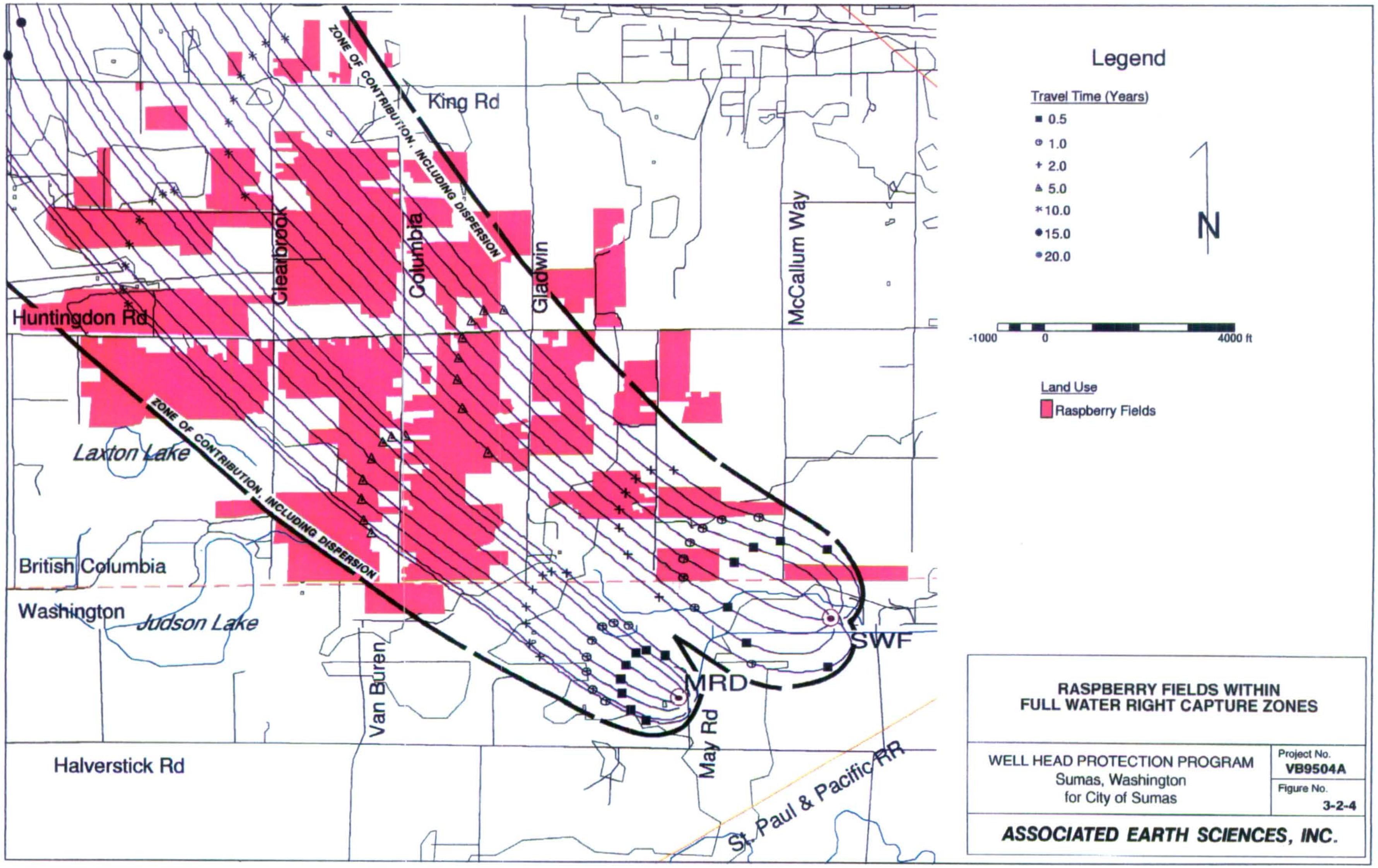

RASPBERRY FIELDS WITHIN FULL WATER RIGHT CAPTURE ZONES

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. **VB9504A**

Figure No. **3-2-4**

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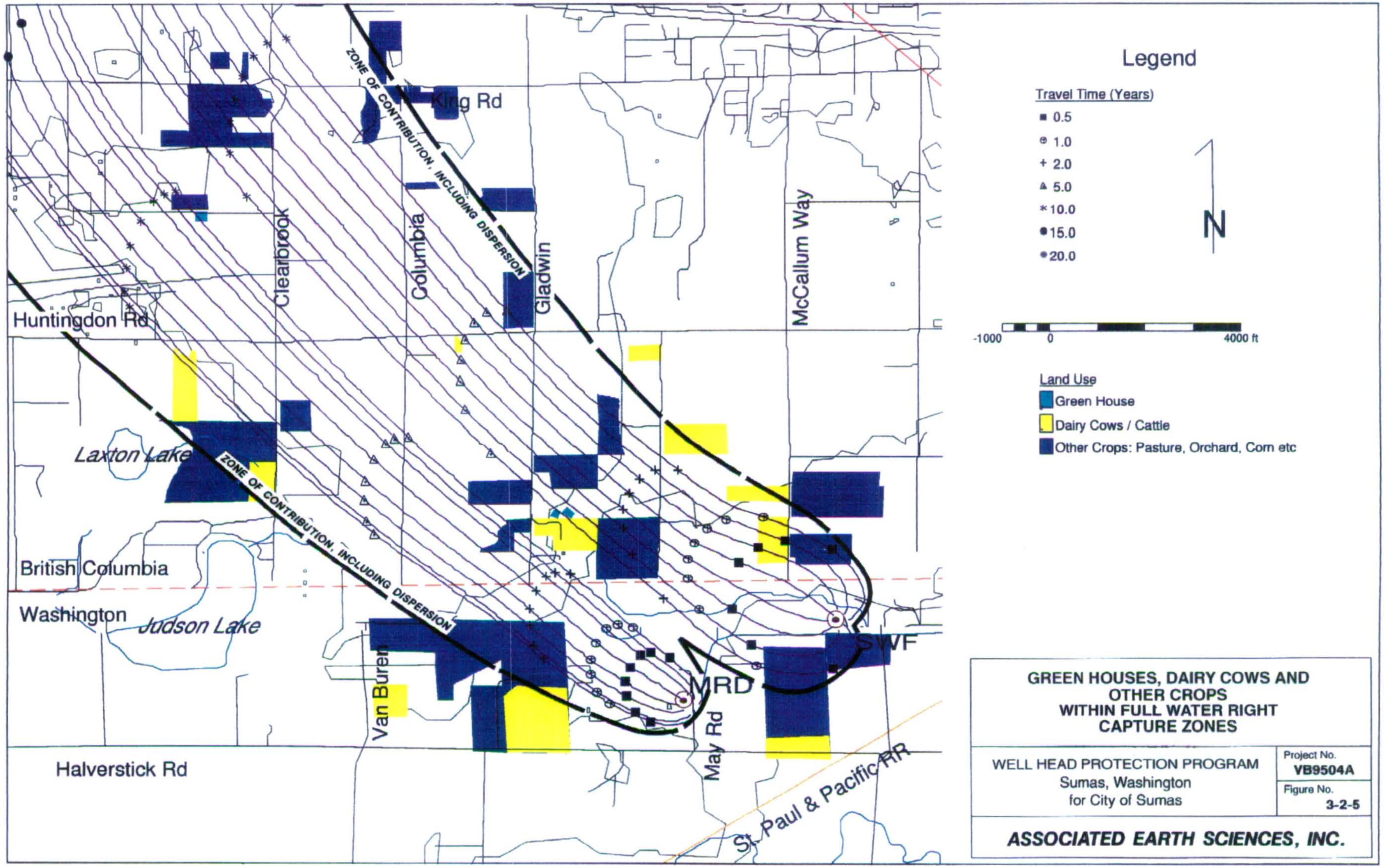

GREEN HOUSES, DAIRY COWS AND OTHER CROPS WITHIN FULL WATER RIGHT CAPTURE ZONES

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. VB9504A

Figure No. 3-2-5

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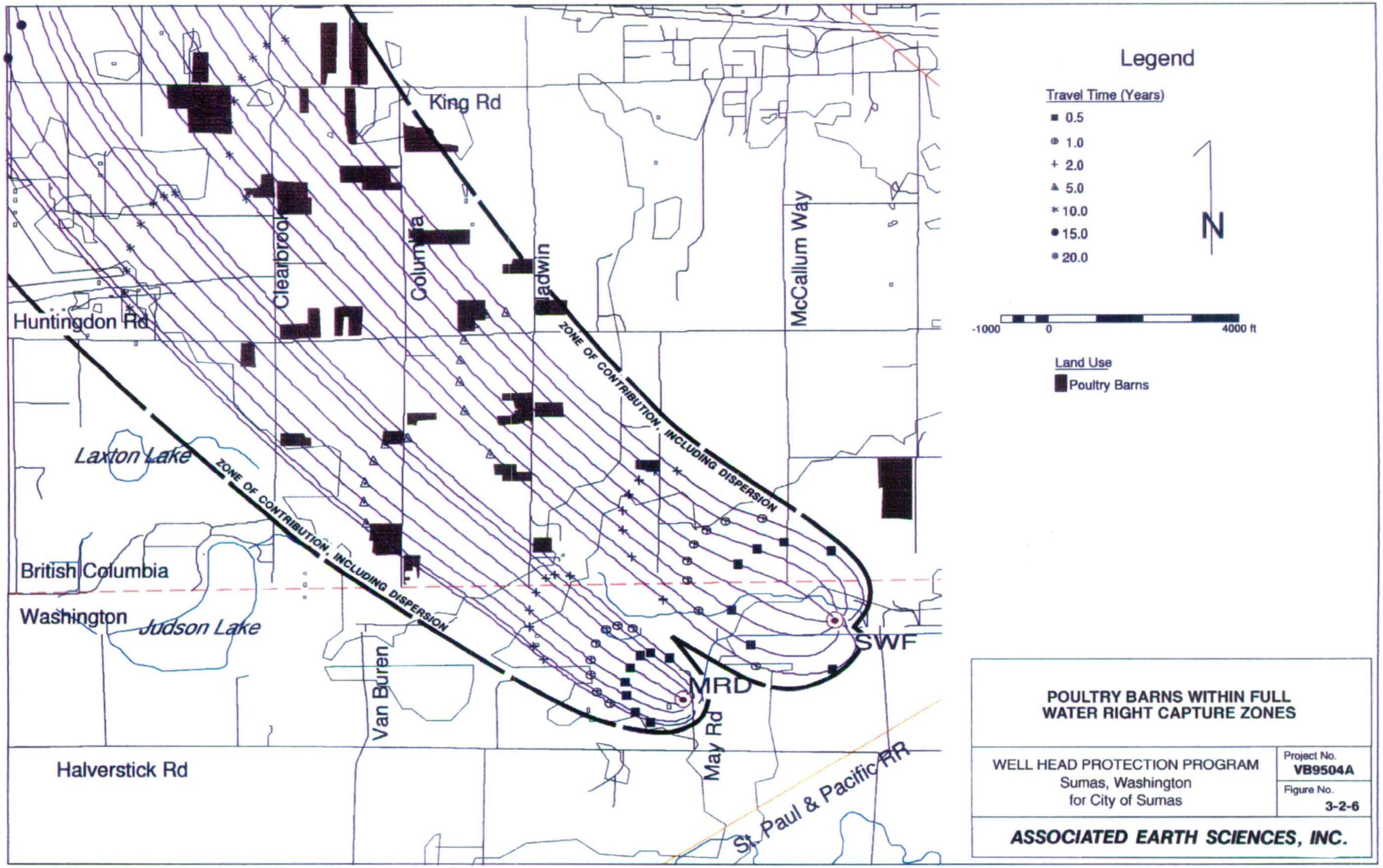

POULTRY BARNS WITHIN FULL WATER RIGHT CAPTURE ZONES

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. VB9504A

Figure No. 3-2-6

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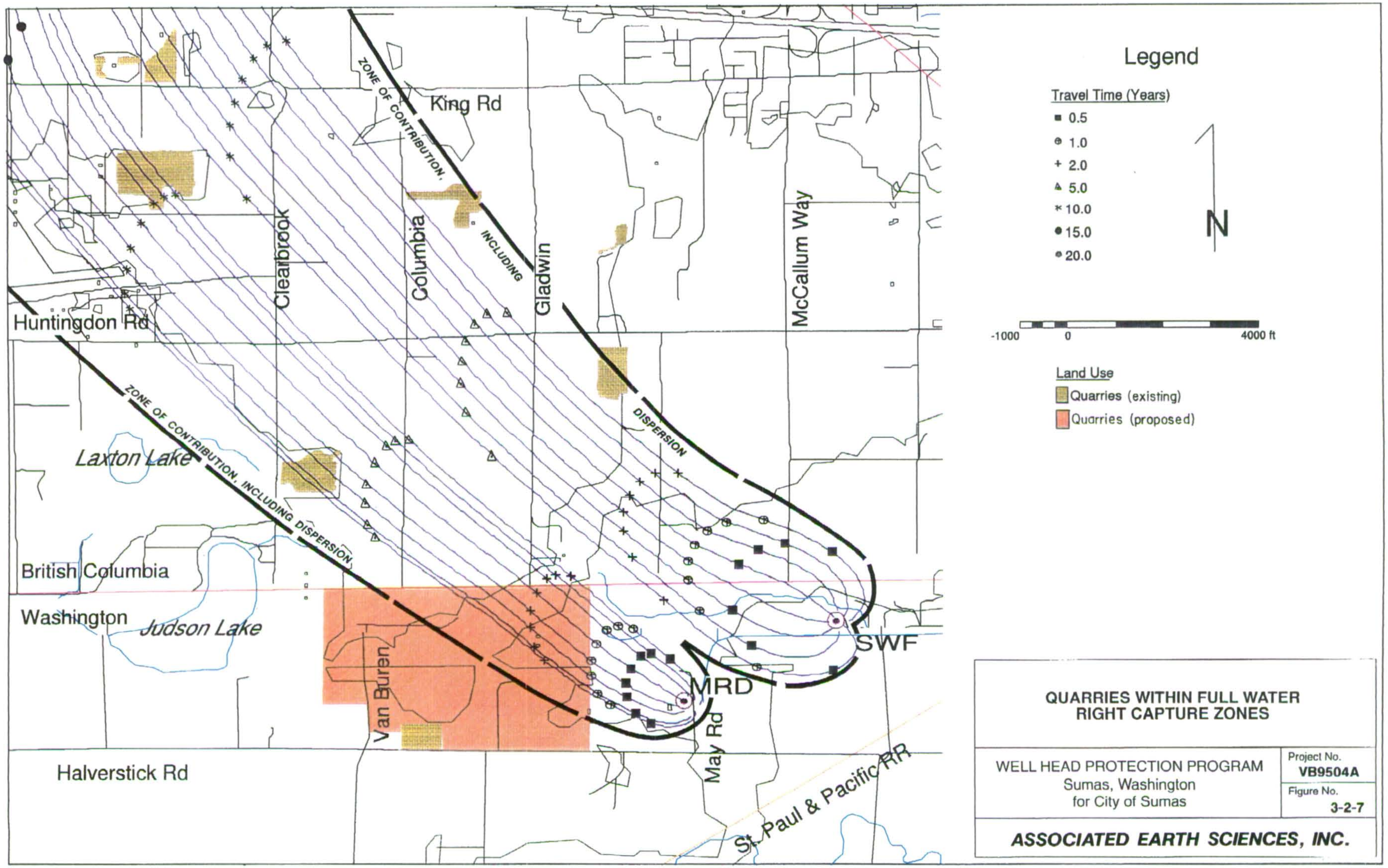

QUARRIES WITHIN FULL WATER RIGHT CAPTURE ZONES

WELL HEAD PROTECTION PROGRAM
Sumas, Washington
for City of Sumas

Project No. **VB9504A**

Figure No. **3-2-7**

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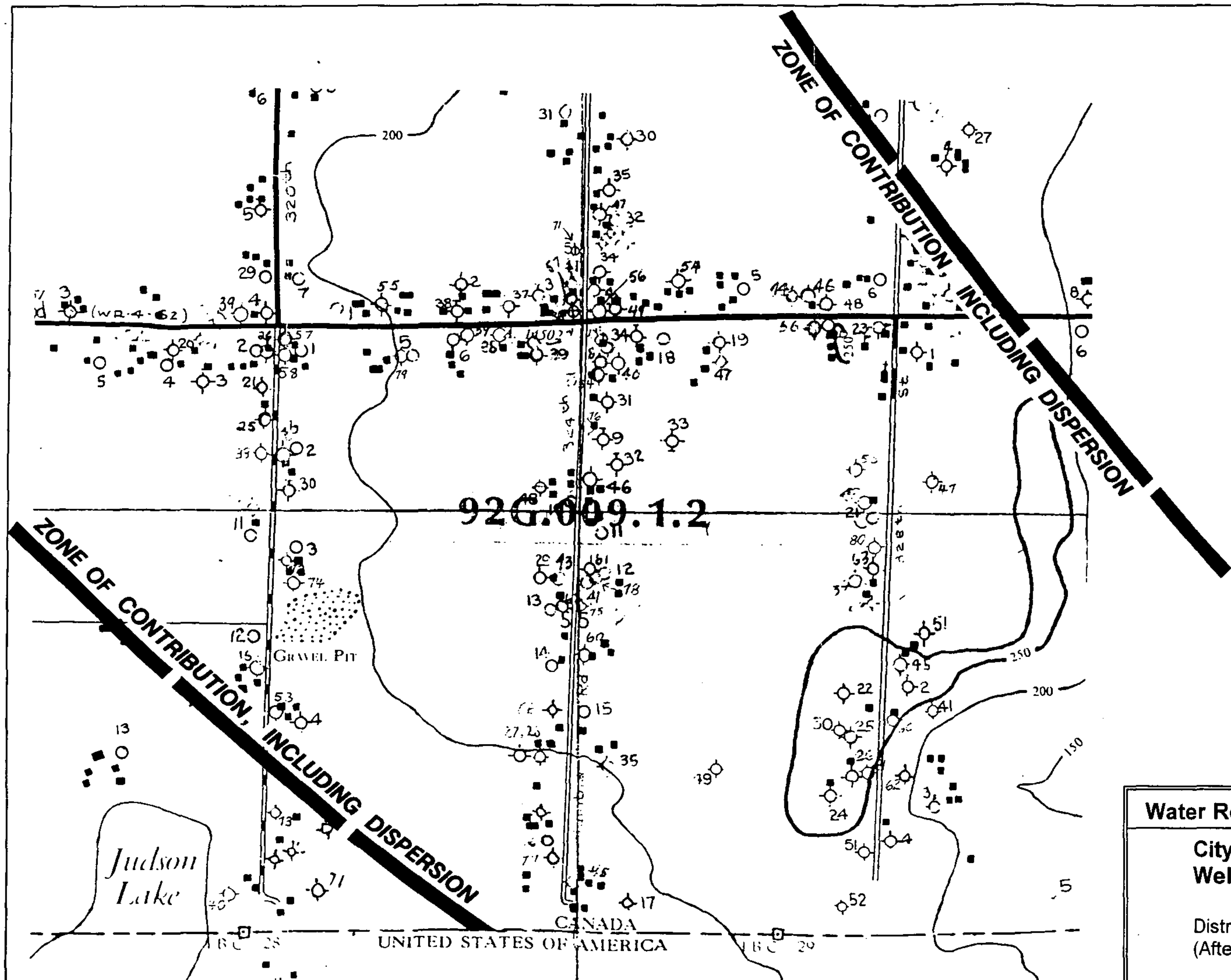

Legend

Houses ■

Wells ¤

Water Resources Consulting

City of Sumas, Washington
Wellhead Protection Program

Distribution of water wells in Abbotsford Aquifer
(After B.C. Ministry of Environment 1957 map)

FIGURE 3-2-8	Date: Dec. 12, 1994

4.0 MANAGEMENT OPTIONS

4.1 INTRODUCTION

Ground water flows in response to hydrologic conditions of input and outflow, without respect to political boundaries or jurisdictional authority. Management of ground water and its quality by a mosaic of jurisdictions therefore must be coordinated for the common well-being of the constituents of those jurisdictions. Without a consistent comprehensive and coordinated plan for protection and management of ground water quality, a single governmental failure may result in a major resource failure for all people using the same essential resource. As the data prepared for this study shows, water quality in the City of Sumas has been, and is being, adversely affected by upgradient land uses.

At issue is how best to manage existing sources of contamination as well as sources of contamination that may occur in the future. This task is further complicated by the intricacies of managing land and resources in two sovereign nations as well as the fact that the two countries and their subdivisions have different environmental, political, and social agendas.

As discussed during meetings held throughout 1994 and 1995, and as presented in Section 3.0, the principal concerns regarding ground water protection are as follows: (1) on-site sewage disposal systems; (2) fuel storage tanks; (3) agriculture; (4) poultry production; (5) gravel mining and processing; (6) hazardous waste sites; (7) household hazardous materials; (8) unprotected wells; (9) industrial and commercial facilities; (10) storm water management; and (11) linear transportation sources.

The recommended options that follow focus on threats posed by all of the above-noted sources with the exception of storm water management. As noted in Section 3.0, storm water management is not a present concern, particularly within the delineated wellhead protection zones.

While the risks posed by many of the identified land uses are obvious, and generally well accepted (e.g., it is undisputed that hazardous waste sites contaminate ground water resources), successful management of these risks is best accomplished by focusing on the element(s) of the land use that threaten ground water quality, as opposed to the land use itself. For example, on-site septic systems work well to remove bacteria, but do little to treat viruses or nitrogen occurring in wastewater. By focusing on the specific aspects of septic systems that are of concern, Sumas is better able to devise realistic and practical management approaches. Thus, protecting ground water from excessive nitrogen loading from septic systems can be accomplished by limiting overall septic system density within the zones of contribution, educating homeowners on the need to maintain septic systems and leach fields, and instituting a regulatory program requiring that septic systems be inspected upon transfer of property ownership.

Focusing on the elements of land use that threaten water quality also allows City, County and Abbotsford officials to increase the effectiveness of each management measure they choose to pursue. For example, by focusing on the threat of nitrogen loading to the aquifer, officials can successfully mitigate impacts from most of the eleven land uses cited as potential contamination sources.

Listed below are a menu of choices relevant to the management process given the types of ground water threats known, or expected in the future. This menu was the subject of various discussions during the course of this study and are recommended for adoption by the parties responsible for the protection of the aquifer and the City's public supply wells.

The menu of options is divided as follows: (1) legislative recommendations, (2) non-regulatory recommendations, and (3) regulatory recommendations. It is suggested that the legislative recommendation and all the non-regulatory recommendations be acted upon as soon as possible, e.g., within the next 6-12 months for adoption, implementation or development. It is suggested that the regulatory recommendations be acted upon only after thorough discussion and analysis by all parties concerned, e.g., at some point after 8-18 months.

Each of the recommendations that follow include reference to the element(s) of risk that it is designed to eliminate or reduce.

4.2 MANAGEMENT OPTIONS FOR CONSIDERATION

4.2.1 **Legislative**

4.2.1.1 Option 1: Adopt Ground Water Protection Enabling Legislation in British Columbia

Introduction: As Figure 1 makes clear, well over 90% of the recharge area to the City of Sumas' public supply wells lies in British Columbia. During the course of this study and throughout International Task Force meetings on the Abbotsford-Sumas Aquifer, British Columbia officials have made it clear, however, that they do not believe that sufficient local authority exists to protect ground water resources within the Province.

While local authority does exist relative to zoning and land use control, Canadian officials argued strongly that this authority "bites at the margins" and is grossly inadequate to protect ground water systems in a comprehensive manner. (In a recent and forward thinking policy paper entitled *Stewardship of the Water of British Columbia*, prepared by the British Columbia Ministry of Environment, Lands and Parks, Water Management Division, 1993, the authors note "A limited measure of protection is afforded by acts, regulations, guidelines, by-laws, standards and objectives enacted over the years by federal, provincial and municipal levels of government.").

This Option, therefore, is possibly the most important recommendation made within this report. Yet it is not a new recommendation. Similar recommendations have been made before, most noteworthy in the above-noted *Stewardship* paper. What then, is the best approach toward this critically important step? What form should the expansion/revision of the existing Water Act take? How should ground water be regulated in British Columbia for the benefit of users on both sides of the border?

The answers to these questions are well beyond the scope of this report, but, fortunately, many important details are contained in the 1993 *Stewardship* report. First, governments (Provincial and/or municipal) need encouragement and assistance to identify recharge areas to existing and future water supplies and authority to protect the land areas from uses that are known water quality threats. Mentioned within the *Stewardship* report as "Groundwater Management Areas", this approach has been successful in over thirty United States territories and states, including the State of Washington through the use of state and locally adopted wellhead protection programs. Given the similarities in Canadian and United States land use practice and law, it is likely that the "groundwater management" approach would be very successful.

Second, it is important to note that wellhead protection is designed to protect the *quality* of ground water; it is not focused on water *quantity* issues. This distinction is important as independent governments are forever in disagreement over water allocation and water use. In the case of wellhead protection, however, all parties share the goal of preserving water quality. In the present case, the aquifer from which Sumas obtains its water is the same aquifer available to Abbotsford residents. It benefits both governments to preserve the aquifer's quality.

Third, and as noted above and again, below, it is beyond the scope of this report to suggest how British Columbia authorities move forward with this recommendation. However, many existing channels are available, including the International Task Force for the Abbotsford-Sumas Aquifer project, the Committee organized for the purposes of this project, as well as the various agencies on both sides of the border whose job it is to protect local and regional ground water resources. "Selling" the need for ground water legislation could therefore occur in many different forums. The protection of Sumas' well fields provides a perfect case study, and hopefully impetus, for the adoption of ground water protection legislation in British Columbia.

Finally, it is important to note that the *Stewardship* report recommended a clear and concise course of action for the Province to take in protecting its ground water resources. Virtually all of the recommendations made speak to the issues and problems identified during the course of this study; issues and problems representatives on both sides of the border identified as solvable only if the Province enacts some sort of comprehensive management scheme for ground water.

Specific recommendations include actions on regulating: (1) ground water use; (2) new well construction; (3) well abandonment and (4) activities in close proximity to wells. The document made equally valuable recommendations regarding: (1) establishing ground water management districts, (2) requiring ground water monitoring and (3) integrating protection strategies of ground water and surface water. Encouraged by representatives from the City of Abbotsford and Provincial government to emphasize the need for enactment of Province-wide legislation, it is hoped that this recommendation is acted upon quickly and with the vision and breadth of the 1993 *Stewardship* paper.

Goal: To empower local governments within the Province to manage and protect ground water resources free from various preemption clauses (real and perceived) existing within Federal and Provincial statutes.

Approach: The Abbotsford-Sumas Aquifer International Task Force has recognized that the lack of Provincial legislation governing ground water management has, and will, hamper efforts at protecting ground water resources at the local level. During both Task Force meetings and meetings held with Canadian officials during the course of the Sumas wellhead protection project, the clear recommendation was that while local governments do have options available to protect natural resources via local controls, these controls are generally inadequate absent specific enabling authority from either the federal or provincial government. Thus, this recommendation focuses on the immediate need for the International Task Force, in concert with the City of Sumas to lobby for the enactment of Provincial or Federal legislation granting municipalities and regional districts in British Columbia powers and jurisdiction to manage ground water resources. In the alternative, the Province needs to adopt legislation to manage ground water resources at the Provincial level. The preferred course of action is beyond the scope of this report; it is left to Canadian authorities to determine the most appropriate means of resource management.

4.2.2 Non-Regulatory

4.2.2.1 Option 1: Develop a Roadside Information Program

Goal: To educate Sumas and Abbotsford residents about the location of the delineated wellhead protection zones.

Approach: The signs would be printed with language such as Entering Wellhead Protection District; For Additional Information Call___-_____ or Entering Wellhead Protection Zone: Land Area Drains to Drinking Water Supplies; For Additional Information Call___-_____ or Entering Sensitive Ground Water Protection District: In Case of A Release of Hazardous Material, Call ___- ____, or words of similar import. The intent would be to narratively describe that the pedestrian or motorist is entering a sensitive area and/or alert them to the fact that the wellhead protection study exists.

Cost: Approximately $50.00 per sign, plus labor for installation.

Frequency: One time cost; road signs have very long life spans.

Responsibility: Joint effort; Cities of Sumas and Abbotsford.

Effectiveness: While no known quantitative study has been conducted, it is our opinion that road signage is a very effective means of communicating the presence of the delineated wellhead protection areas. Signs provide warnings in case of spills and provoke questions (e.g., what is a wellhead protection area?).

Similar efforts have been developed for communities in the west and east coast with a very strong success rate.

Protection Against: Threats from household hazardous materials, unprotected wells, linear transportation sources. In addition, it is believed that road signage has a positive effect on the public at large. As noted earlier, one of the priority contamination threats is application of poultry manure to raspberry fields in excessive amounts. Thus, one of the target audiences for the road signs are agricultural operators and workers passing and re-passing roadways within the delineated zones of contribution. In that the avoidance of over-fertilization is "controllable" (e.g., there is no compelling reason why raspberry fields continue to receive excess fertilization) the presence of road "warning" signs can have a positive educational message, particularly when coupled with educational posters and workshops (discussed below).

4.2.2.2 Option 2: Draft and Print an Educational Poster and/or Brochures

Goal: To educate Sumas and Abbotsford residents about ground water issues in general, and about the relationship between land use and their drinking water quality, in particular.

Approach: The poster and/or brochure would be designed to be eye catching and geared toward a lay, non-technical audience. The intent would be to illustrate graphically and narratively through specific local examples the relationship between land use and water quality and conclude with a listing of steps the average resident can do to protect ground water quality.

Cost: Poster: $6,000-$6,500 for 3,000 copies, full color, 24 x 36 inches.

Brochure: $2,000.00 for 3,000 copies, full color, 12 x 12 inches (with folds).

Frequency: One time cost. A repetition of the effort should be considered every 2 or 3 years, particularly as land use and water quality issues change.

Responsibility: City of Sumas

Effectiveness: The poster approach has proven to be highly effective as a public education and information disseminating tool in a variety of locations, including Nantucket, Massachusetts, Moloka`i, Hawaii, and Dutchess County, New York.

Protection Against: Threats from intentional and unintentional disposal of hazardous materials, increased awareness of the sensitivity of the underlying aquifer (see discussion under Option 2, above).

4.2.2.3 Option 3: Hold Educational Workshops

Goal: To educate key municipal officials, agricultural operators and land owners viz-a-viz a series of educational workshops on various issues of ground water protection in the two jurisdictions. These workshops can be held in concert with the on-going (twice a year) training programs geared toward agricultural operators, or they can be held independently. The workshops will serve several purposes, the most of important of which may be a means of disseminating the results of the AESI study . The workshops also provide an opportunity for Sumas and Abbotsford officials to begin to jointly discuss longer term issues such as joint management of the aquifer.

Approach: If held independent of the on-going workshops, this series would be held approximately four (4) times, twice in the US and twice in Canada. The workshop agenda would follow the basic approach of the AESI study ; ground water hydrogeology, ground water contamination and ground water management. The workshops would be specific to the issues and concerns facing Sumas and Abbotsford residents and be designed to offer specific and detailed options regarding management of the ground water resource.

Cost: $2,000 to $4,000 per workshop

Frequency: Up to four (4) times per year.

Responsibility: Joint effort; Cities of Sumas and Abbotsford.

Effectiveness: Workshops are a very effective means of transmitting technical information, especially to groups identified in this study as presenting risks to ground water quality (e.g., gravel and agricultural operators). The most striking weakness of seminars and workshops is that they typically do not reach large numbers of people. To make this option effective, therefore, key or selected individuals (e.g., agricultural operators) will need to be selectively invited (and pressured to attend?).

Protection Against: Threats from intentional and unintentional disposal of hazardous materials, increased awareness of the sensitivity of the underlying aquifer, improved agricultural practices and use of fertilizers and pesticides (see discussion under Option 2, above).

4.2.2.4 Option 4: Establish Well Closure/Capping Program

Goal: Abandoned wells are often the greatest source of contamination of ground water. While the contaminant source inventory did not report the location of abandoned or poorly constructed wells, it did infer that many of these wells exist within the study area. The goal of a closure/capping program

	is to identify, inventory and properly close (seal) wells improperly constructed and/or abandoned.
Approach:	Unlike the regulatory approach recommended in the following section (Option 1a), this option revolves around volunteers, homeowners and government officials to identify, inventory and close wells that threaten the aquifer system.
Cost:	Unclear at this time. As the human resources will likely be volunteers and government officials, it is difficult to quantify total labor costs. The greatest expense will result from the well closures once identified. A ballpark estimate is $300.00 per well.
Frequency:	Well closure programs require on-going identification and inventory, but the bulk of the labor effort should be limited to a one or two time effort of identification, inventory and closure.
Responsibility:	Joint effort; Cities of Sumas and Abbotsford.
Effectiveness:	Very high. A closure program can effectively seal off the aquifer from direct conduits of contamination.
Protection Against:	Threats from intentional and unintentional disposal of hazardous materials, fertilizers and pesticides.

4.2.2.5 Option 5: Establish Septic System Maintenance Program

Goal:	This option seeks to contact property owners using septic systems for wastewater disposal and educate them as to the impact of poorly maintained systems on ground water quality. Most homeowners are unaware as to what a septic system is, where on their property it is located and how it works, let alone the fact that it needs to be pumped and maintained on a regular basis.
Approach:	Property owners can be educated as to the workings of septic systems and the role they play in ground water protection either via a poster or brochure discussed in Option 2, or workshops discussed in Option 3.
Cost:	Low, particularly if combined with Options 2 and/or 3.
Frequency:	A workshop or distribution of a targeted brochure once a year would likely be sufficient (e.g., a brochure mailed with property tax bills).
Responsibility:	Most likely agency responsible for Options 2 and/or 3, above.

Effectiveness: This campaign is similar to the public education efforts discussed above. Because it is difficult to regulate the pumping of septic systems (although there are communities that do), the most effective means of ensuring that they are maintained is a public education program.

Protection Against: Threats from viruses, bacteria and excessive nitrogen loading from properly functioning septic systems. Protection against "breakout" of raw sewage from malfunctioning systems.

4.2.2.6 Option 6: Establish a Contingency Plan for Emergencies*

Goal: Few, if any of the actions taken by the municipalities as a result of this study will be sufficient to avoid an accidental (or deliberate) spill or release of contamination. A contingency plan is simply a plan of action should a release of contaminants occur. However, because one of the priority threats within the zones of contribution are fuel storage tanks, and because regulatory authority does not exist to require all pre-existing underground storage tanks to be removed, a contingency plan should be considered more than merely a re-active approach. The Sumas-Abbotsford contingency plan could be used as a pro-active fact finding document, and when coupled with Option 7 below, could result in the elimination of serious threats to the underlying aquifer system.

Approach: A contingency plan is usually simply a piece of paper, outlining who will be contacted should a spill occur, identifying resources to handle a spill (money for a laboratory, backhoe operator, etc.), who is in charge of coordinating the spill response, and a precise order of steps that will need to be taken given the particulars of the release. In keeping with the discussion above, however, it is recommended that the Sumas-Abbotsford contingency plan be more than a plan of reaction, but rather a plan to help reduce known contaminant threats, particularly from fuel storage systems.

Cost: The plan itself costs almost nothing. It is the implementation of the plan that requires expenditure of funds, although it is difficult to identify the range of funds that will be required.

Frequency: If the plan is to have any value, it must be updated regularly in concert with Sumas' and British Columbia's hazardous waste coordinator, fire department and industry. Given its location as a heavily traveled border crossing, the plan must continually be updated with predictions as to the types and volumes of hazardous materials entering the wellhead protection areas.

Responsibility: Joint effort; Cities of Sumas and Abbotsford.

Effectiveness: Very effective. A remedial action plan is critical for logical and coordinated response in the event of a contaminant release overlying the aquifer.

Protection Against: Unanticipated disasters, large or small (e.g., contamination incident within a zone of contribution, loss of a well due to contamination or power failure, etc.)

*Note: The City of Sumas is preparing a contingency plan as part of its submission to the State of Washington Department of Health. This recommendation is targeted toward the City of Abbotsford, British Columbia. A combined, jointly developed contingency plan is highly recommended.

4.2.2.7 Option 7: Establish An Inventory of Underground Fuel Storage Tanks

Goal: This option seeks to contact property owners using underground fuel storage tanks and educate them as to the threat to ground water quality from underground tanks. The focus of the inventory can be limited to fuel storage tanks "buried" underground, as opposed to within enclosed basements or above-ground. Most homeowners are unaware as to the threats (and liability) posed by buried fuel storage tanks, and particularly on properties developed before the 1980s, often do not even know where on their property the tanks are located.

Approach: Property owners can be educated as to the threats posed by underground fuel storage tanks either via a poster or brochure discussed in Option 2, workshops discussed in Option 3 or via a coordinated inventory program similar to the program conducted during the course of this study.

Cost: Low, particularly if combined with Options 2 and/or 3.

Frequency: A workshop or distribution of a targeted brochure once a year would likely be sufficient (e.g., a brochure mailed with property tax bills).

Responsibility: Most likely agency responsible for Options 2 and/or 3, above.

Effectiveness: This campaign is similar to the public education efforts discussed above. Although Washington state and British Columbia law governing fuel storage and contamination liability is considered "aggressive", inspection of pre-existing under-ground fuel storage tanks goes largely undone. It is believed that a non-regulatory, "inventory and education" approach is the most effective means of getting landowners to maintain and ultimately remove their underground tanks.

Protection Against: Threats from extremely hazard materials included within motor fuel and home heating oil.

4.2.2.8 Option 8: Identify Key parcels for Acquisition, Development Rights, Purchase, or Use of Transfer of Development Rights Procedure

Goal: There is little debate that acquisition or less than fee simple ownership of land is the best means of protecting the underlying aquifer system from contamination. Throughout this project, there appeared to be support for the concept of acquiring key parcels, use of development rights of land for protection and/or transfer of development rights.

Approach: Key parcels could be defined in one of two ways, or a combination of both. First, they could be identified as those parcels that lie within the delineated wellhead protection areas, regardless of where they fall in the time of travel analysis. Second, they could be identified as those parcels that represent the greatest near-term threat (e.g., parcels which are currently built-upon that pose a serious threat or parcels that are likely to be built upon in the near future).

Cost: Unknown at this time although parcel acquisition costs are likely to be high, at least compared to the other recommendations made herein.

Frequency: Parcel acquisition is an on-going strategy (e.g., once identified parcels are identified, the goal is to attempt their acquisition). In many cases, it can take several years to acquire the parcels initially identified during the priority setting exercise.

Responsibility: Unclear at this time, although it seems logical that the acquisition of key and likely expensive parcels is best accomplished by joint efforts of the two municipalities.

Effectiveness: Very high. Municipal ownership (either in fee or in easement) is the strongest form of control, and therefore protection, for the underlying ground water supply.

Protection Against: Improper land use. Municipal ownership presumes that the parcels are perpetually restricted from development.

4.2.3 **Regulatory**

4.2.3.1 Option 1: Draft and Adopt Zoning Regulations as Follows:

Introduction: Throughout the course of this study a variety of regulatory options for both jurisdictions to consider were discussed at length. There appeared to be support for moving forward with regulatory adjustments in both jurisdictions, albeit slowly. We discussed three broad regulatory options and agreed on two. One of the options involve establishing or strengthening permitting programs (well construction/abandonment and underground injections). The additional option involved revising the zoning regulations relative to allowable uses and minimum lot sizes for allowable uses.

Option 1(a): Purpose: This option suggests that the County adopt well construction and abandonment standards within the delineated wellhead protection areas more stringent than those adopted by the State as provided for in RCWA 18.104. The County's justification and rationale for these standards is the vulnerability of the aquifer and proximity of new and/or abandoned ended wells to the City of Sumas' public supply wells.

Draft and adopt a well construction and well abandonment regulation to merge within existing zoning ordinances. The purpose of these regulations is to strengthen standards governing the installation of new irrigation as well as drinking water wells within the wellhead protection areas. Similarly, because abandoned wells are often the greatest source of contamination of ground water, the regulations will be designed to require well closure/abandonment permits. Enforcement of this regulation is best accomplished by establishing some sort of tracking program for well permits and requiring well owners/operators to annually confirm that the well is in operation, in good working order and not abandoned.

Option 1 (b): Purpose: These options suggest that the County and City of Abbotsford adopt revisions to their existing zoning regulations to provide greater protection to ground water resources. While there is no doubt as to the County's regulatory authority under Washington Revised Code Annotated (e.g., Title 36), much discussion centered on Abbotsford's ability to regulate for ground water protection. A brief analysis of Abbotsford's powers under Provincial and Canadian Federal law is found in Appendix B.

Revise allowable use and density standards within the zoning ordinances of both jurisdictions. As discussed during Committee meetings, both jurisdictions are advised to consider revising the allowable use standards within the wellhead protection areas to the May Road and Sumas well fields. In Sumas, these revisions include amendments to the Agricultural District (May Road wellfield) and the Rural Residential-2 District (Sumas wellfield).

Within the Agricultural District, options include:

Placing limitations on animal equivalent units allowed under Section 20.40.050;

deletion of various conditional uses allowed under Section 20.40.150 (e.g., multiple-family uses, aircraft landing strips, public outdoor recreation, public utilities, transitory solid waste facilities and commercial extraction of sand and gravel);

revisions to Section 20.40.650 governing development standards to include greater restrictions on feedlots within wellhead protection areas.

Within the Rural Residential-2 District, options include:

Prohibiting clustering of units within wellhead protection areas and encouraging clustering outside of delineated areas as provided in Section 20.32.300;

allowing clustering even without public sewer provided all septic systems are located outside of the delineated wellhead protection areas (Section 20.32.251 precludes clustering with on-site waste disposal systems);

downzoning the remaining land within the wellhead protection areas to at least 1 dwelling unit per 60,000 square feet if the dwelling is not on public sewer and the land is not developed as a cluster subdivision;

deleting any bonus option for cluster developments that are within a wellhead protection area (Section 20.32.252);

establishing performance standards for uses allowed under Section 20.32.150 (Conditional uses) to limit nitrogen loadings or threatening uses within wellhead protection areas (e.g., retirement, boarding, convalescent homes, public schools, etc.).

General comments that apply to revisions for both the Agricultural and Rural Residential Districts include:

Revisions to Section 20.84.010 (variances) to require greater findings of no harmful consequences before issuing a variance within wellhead protection areas;

revisions to Section 20.89.010 (density transfer/transfer of development rights) to preclude transfer of development rights into wellhead protection areas and encourage transfer of development rights out of delineated wellhead areas.

In Abbotsford, suggested revisions include amendments to the Agricultural (Section 200), Industrial (Section 600) and Institutional (Section 700) Districts.

Within the Agricultural District, options include:

Establishing a conditional use permit program for agricultural operations within the wellhead protection areas. This permit program would be designed to establish controls over the density of animals and livestock units within the wellhead protection areas, as well as establish performance standards for nutrient loading to ground water (Sections 202 and 204).

Within the Industrial District, options include:

Eliminating a range of noxious and ground water threatening uses, including almost all the uses listed in Section 601.2(3) (e.g., manufacturing, processing, refining, mixing or bulk storage of petroleum...);

revising impervious coverage standards as established in Section 601.4 to allow for greater recharge of precipitation and storm water runoff.

Within the Institutional District, options include:

Revising the allowable use schedule to provide greater predictability in the land uses that will likely occur in the future (e.g., Section 701.2 provides for a extremely broad range of uses within the P-1 district, many of which could seriously threaten ground water quality).

Cost: The recommendations noted above represent a large part of the ultimate cost of revising the respective ordinances. Additional costs (approximately $2,000 to $4,000) are likely to be incurred in revising the above language and providing codified camera-ready text. Associated workshops and/or public hearings, if desired, would also incur additional costs.

Frequency: Zoning, as with any regulatory scheme, should be revised frequently, but since the revisions noted above are based on the specific findings of the AESI study, they represent a one time occurrence only.

Responsibility: Joint responsibility; City of Sumas, Whatcom County, City of Abbotsford

Effectiveness: Very high; the recommendations noted above are considered essential for the protection of the aquifer system.

Protection Against: Threats from virtually all of the sources of contamination identified during the course of this study. It is important to emphasize, however, that the above-noted regulatory recommendations focus on revising existing loopholes in the respective ordinances. As noted throughout the course of the study, over-reliance on a regulatory program is not the recommended solution to the threats posed to the City's ground water supply. Rather, a combination of the legislative, non-regulatory and regulatory recommendations is seen as the most appropriate strategy to protect the City's ground water supplies.

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5.0 SPILL RESPONSE PLANNING

The Safe Drinking Water Act of 1986 established a requirement that ground water dependent public water systems implement a wellhead protection program. The City of Sumas applied in 1993 for funding from the Washington Department of Ecology to carry out a wellhead protection program. The Department of Health guidance document (Department of Health, 1993) outlines the contents of wellhead protection programs, which include a discussion of contingency planning and spill response planning. This section and the following section (Section 6.0) respond to these two requirements.

5.1 INTRODUCTION

Because of the natural vulnerability of the Abbotsford-Sumas Aquifer to contamination from the surface, it is appropriate to incorporate special ground water protection procedures into first-response planning. The most preferable approach is to prevent contaminant spills in the first place; the next best is to stop them and contain them; the least desirable is to have to clean them up after they have occurred, an option that may even be impossible to achieve.

Spill response planning should be distinguished from contingency planning. The former concerns what to do to contain the damage from a spill so that it does not compromise a ground water supply source. The latter concerns what to do to replace the source once it has become contaminated or threatened to the extent that the use of the water supply cannot be continued. Roads in the Sumas aquifer recharge area are mostly secondary, rather than main haul routes for large volumes of chemicals. The situation is less immediately vulnerable than, for instance, Samish Lake, with surface water coming from I-5 with a travel time of less than an hour from spill site to a surface water body. Local delivery of fuels, agricultural chemicals, etc. are routine in the Abbotsford-Sumas area however. Specific sources of potential contamination are discussed in the inventory section of this report.

5.2 EXISTING SPILL RESPONSE MECHANISMS

The likely sequence of events following a spill in the American part of the Sumas aquifer recharge area would be initiated by a 911 call. This would be answered by WhatComm Communications, and transferred to local fire and police departments. The City of Sumas has a separate dispatch system, responding to the number 332-8781. In a situation where there were a spill potentially affecting the water system, Whatcom County Emergency Services would be called. They would mobilize equipment, supplies, and personnel; an officer of the Washington State Patrol would be involved and would probably assume responsibility as "Incident Commander."

The first challenge presented by a spill would be identifying the material spilled, and establishing its characteristics whether it is acutely toxic, explosive, flammable, or a water supply contaminant. Before these characteristics have been determined, it is not advisable to have unprotected personnel attempt to do anything about it. Commercial transportation of dangerous materials is regulated so that shipments are required to be accompanied by shipping papers, and identified by a placard and a four-digit number that identifies at least generically the material being shipped. Information from these sources can be used to construct an appropriate spill response. The U.S.

Department of Transportation (1993) publishes a convenient handbook with generic identifications and response recommendations. Whatcom County Emergency Services maintains a computer database with more specific and detailed information, akin to what would be contained in a Material Safety Data Sheet. In addition, the chemical industry service organization CHEMTREC maintains a toll-free help line (1-800-424-9300) and access to other services.

Whatcom County has a Local Emergency Planning Committee ("LEPC"). It has compiled a Hazardous Materials Plan for the County, which contains response procedures and call-out lists. There are three copies in the City of Sumas: two at the Police Department, and one at the Fire Department. This plan has a detailed geographic break-down for some parts of Whatcom County, and a clear identification of where there are drinking water supplies dependent on surface water. Comparable detail for ground water sources is lacking, and should be incorporated in future revisions of the plan.

The Pacific Northwest Emergency Management Agreement is a multi-state and Canadian arrangement that deals with potential liability and reimbursement procedures. By dealing with them in a routine agreement, worked out in advance of need, these details should not have to be worked out in the heat of an actual emergency. This should enhance the reliability of access to mutual aid resources. The Agreement is expected to be signed this summer. The need for such an arrangement was demonstrated in part by the Chelan fires of 1994. At present there are no mutual aid agreements between local governments on opposite sides of the border.

Joint table-top exercises have been held in which a hypothetical spill near the border takes place, and response personnel practice all the details of an actual response. These exercises are a most revealing way to identify needs and gaps.

Whatcom County Emergency Services applied for and received a grant of approximately $50,000 for a project entitled "Washington State and Canada Cross-Border Proposal: Local Emergency Planning Committee Hazard Planning and Response." It is a 75% EPA funded pilot project designed to develop and test a cross-border hazardous materials response plan, and serve as a blueprint for the Eastern Washington border area. This project is currently being implemented.

The communications alert capability in the Province of British Columbia is a 24-hour phone contact in Victoria (800-663-3456, operable from Washington State). First-response capability lies with the Provincial Ministry of Environment, Lands and Parks, which maintains a hazardous materials trained four-person team in Surrey; they can be contacted by telephone (604-582-5266) or fax (604-582-5334). They have materials to deal with a modest variety of emergencies, and contacts and authority to requisition more as needed. They also maintain a mobile emergency command post at the Fraser Valley Hatchery on Vye Road, a few miles north of Sumas. There is also a Provincial Emergency Program, based in Chilliwack; it serves a support role that includes caring for potential evacuees.

One limitation in the notification and response network on both sides of the border is first finding out about a spill on private property, and second doing anything about it. This is a potentially delicate question that would have to depend on those closest to the scene having prior information about the aquifer, and the diplomatic demeanor of response crews.

The Abbotsford area is home to approximately ten times the population base that lies on the south side of the border, so it has considerably more resources than anyone in the immediate Sumas area. Abbotsford has some stockpiled clean-up materials, equipment, and personnel. The City has under consideration development of a Hazardous Materials team, and more extensive materials and training.

5.3 AVAILABLE RESOURCES IN SUMAS AREA

There is not a large inventory of supplies or equipment in Sumas. The City would be well advised to discuss reasonable needs for first response materials with Whatcom County Emergency Services, and obtain a modest inventory (see next section). The Sumas Police Department is more of a first-response entity than the fire department, which would be called second in the list.

Several private industrial concerns in Whatcom County maintain spill response capability for their own operations. Two main ones are Arco at Cherry Point, and Trans Mountain Pipeline Company at Smith Road and Hanegan Road. They have made their private resources available when they have been needed in the past; a notable example was the April 1995 jet fuel spill at Lake Samish on I-5.

Because of the relatively isolated location of the City of Sumas relative to the rest of Whatcom County, the City should incorporate a considerable amount of self-reliance in its spill response planning. Travel time from Bellingham is 45 minutes, even assuming people there can be on the road immediately on notification.

5.4 POTENTIAL ENHANCEMENTS TO SPILL RESPONSE CAPABILITY

In the course of reviewing existing spill response capability, contact was made with numerous people who have thought about the vulnerability of the Sumas water system. Some of the suggestions they offer are the following:

> When a spill takes place, first responders should look for whatever drinking water contaminants would be reasonably expected given the identification of the spilled material. This would be some kind of pre-arranged priority pollutant list. An example is Ethylene Dibromide (EDB): although its use as a fuel additive has been discontinued in the U.S., it is still used in Canada. The April 1995 spill at Lake Samish consisted of Canadian jet fuel, which had EDB in it.
>
> Whatcom County Emergency Services has expressed an interest in developing an EPA Level B Hazardous Materials response capability. This would require substantial funds, people, materials, training, and equipment. The start-up cost of $40,000 to $80,000 would preclude its happening until more favorable budget conditions prevail in the County; and if it did happen, it is not clear that it would be the best answer for the City of Sumas' well protection problems.
>
> Fire pre-planning is increasingly becoming recognized as an important activity. Fire-fighting runoff can be heavily contaminated, and may need to be either

intercepted or minimized by alternative fire fighting methods. It is important to use appropriate methods and materials in aquifer recharge areas. There is a growing awareness of this factor among emergency response people, but they are not yet universally attuned to it and the issue needs further discussion.

Whatcom County has special access to U.S. Customs for allowing emergency materials to pass quickly through the border. This access needs to be maintained because of personnel turnover at Customs.

Emergency communications depend heavily on VHF radio frequencies. There are no shared frequencies between the first response entities in Canada and the United States; this should be remedied by assignment of one or two common frequencies.

Hazardous materials carriers have a responsibility to keep clean-up materials with them, but it is probably not feasible to require them to carry enough to clean up a full tanker load. The degree of compliance with existing requirements should be assessed, and the need for making them more restrictive in aquifer areas should be explored.

The particular nature of a spill on pervious ground determines what equipment should be available. There should be a backhoe and dump truck available on call, for instance. A sample inventory and accompanying cost estimate was compiled for the Lake Whatcom Spill Response Plan. The relevant items for the Sumas situation would be: salvage drums, shovels, dunnage lumber, plastic sheeting, absorbent materials, hand tools, personnel protective clothing, training. The cost of the equipment and supplies exclusive of training would be approximately $2,000.

The planned mutual aid agreements between Sumas and Abbotsford should be pursued energetically.

The Whatcom County Hazardous Materials Contingency Plan should be revised to include information about vulnerable ground water dependent water supplies in the County.

Regularly scheduled revisions and updates of Contingency Plans and call-out lists should be implemented.

A shift in education efforts at the level of policy development is needed. It is necessary to think in a systematic way about aquifer protection, as well as the more traditional concerns of protection of life and property.

6.0 CONTINGENCY PLANNING

6.1 INTRODUCTION

It is worth repeating how contingency planning is to be distinguished from spill response: It is based on a series of scenarios which hypothesize the loss of the largest water supply resources in the system in question, and focus attention on maintaining continuity of water supply to at least the most critical uses. Contingency planning consists of devising answers to a series of what-if questions.

6.2 DESCRIPTION OF CITY OF SUMAS WATER SUPPLY SYSTEM

Sumas is one of approximately five regional water supply purveyors in Whatcom County (Whatcom County Water Utilities Coordinating Committee, 1993). The City supplies water to its own customers and neighboring systems as follows:

> City of Sumas residential: 350 connections (each "residential" connection is the equivalent of approximately 2.3 people);
> City of Sumas industrial: The City's largest industrial customer is Sumas Cogeneration Incorporated. Its water requirements are met from the May Road well field, which is not being used for potable water supply at present.
> City of Nooksack: 233 connections
> Nooksack Valley Water Association: 200 connections
> Sumas Rural Water Association: 140 connections
> City of Everson: 670 connections (Emergency basis through intertie agreement)

The City of Sumas' service area extends, through the Everson intertie agreement, from the Canadian border south to the Massey Road.

The City supplies water from two sources, the Sumas well field and the May Road well field, each of which is described below.

Potable water is supplied from the Sumas well field, which consists of five closely-spaced wells with a combined total water right of 1,919 acre-feet per year (af/yr) and a maximum permissible instantaneous pumping rate of 2,250 gpm. The wells are arranged so that water is supplied to two distinct distribution systems.

> Nooksack system. This system supplies the City of Nooksack, the Nooksack Valley Water Association, and the City of Everson (on an emergency basis). On the average, this distribution system consumes 460 af/yr, which is equivalent to a steady-state pumping rate of 285 gpm. The system receives water from wells 1, 2, and 3, which all flow to a single booster pump station. The station contains three pumps of varying capacity (30 horsepower [hp], 20 hp, 15 hp) that can be operated in any combination. When all operate together, a total of 500 gpm is supplied to this distribution system, and the limiting factor appears to be well capacity rather than pump capacity. Although the peak pumping rate of 500 gpm

is substantially higher than the steady-state requirement of 285 gpm, there are occasions in the summer when demand exceeds supply, and water must be diverted to this system from the Sumas system through an interconnect.

Sumas system. This system supplies the City of Sumas and the Sumas Rural Water Association. On average, the system consumes about 540 af/yr, which is equivalent to a steady-state pumping rate of 335 gpm. The system receives water from wells 4 and 5. Each well is fitted with a 40 hp submersible pump capable of producing 700 gpm, and both wells pressurize the same water line. The wells are normally operated in alternation but can be operated simultaneously. Simultaneous operation is occasionally required in the summer months, particularly when water is supplied to the Nooksack system through the interconnect.

In combination, the two systems consume about 1,000 af/yr, which is substantially less than the permitted maximum of 1,919 af/yr. When all pumps operate simultaneously, a peak rate of 1,500 gpm is achieved, which is less than the sum of the individual capacities because of hydraulic limitations.

Industrial process water is supplied from the May Road well field, which consists of three closely-spaced wells with a combined total water right of 1,825 af/yr and a maximum permissible instantaneous pumping rate of 1,660 gpm. However, part of the flow from this field must be used as mitigation to maintain stream flows in the Sumas Creek. The useful water right is therefore 1,403 af/yr at a maximum rate of 1,361 gpm. Water from this field fails to meet drinking water standards because it contains excess nitrate.

Water from the May Road wells is piped to a single large user, an electric cogeneration facility that consumes an average of 440 gpm. Wells 1 and 3 are fitted for production, and well 2 is not yet developed. Well 1 is capable of producing about 150 gpm. Well 3 is capable of producing about 650 gpm and is normally the only well in use, because it can supply 440 gpm to the cogeneration plant as well as 90 gpm for stream mitigation. Well 1 is brought on line only during periods of peak demand. There are plans to build a second large facility that would consume an additional 350 gpm, which would result in a peak demand in excess of the combined capacity of wells 1 and 3.

There are several other public water supply systems that are unlikely to be included in the City's system because of various physical constraints. These are:

City of Lynden: Although Lynden carried out some of the original ground water investigations in the Sumas Aquifer, it has discontinued its search for additional ground water resources and is now emphasizing its Nooksack River surface water diversion. While Lynden has a wholesale agreement with Meadowdale Water Association, it is not likely that it would extend its mains to a point close enough to tie into the Sumas system. The Sumas distribution system does not extend west of the May Road well field.

Delta Water Association: while Delta is seeking intertie agreements to enhance reliability of service to its 155 customers, the relatively small Pangborn Road Water Association lies between Delta and Sumas. The terrain and the expense of pipeline construction would probably make any connection infeasible.

A water system that adjoins Sumas but is not currently connected by emergency intertie is the City of Abbotsford, B.C. The Abbotsford distribution system lies within approximately 150' of the border and could be feasibly interconnected.

6.3 MOST LIKELY CONTINGENCIES

Contingency planning is based on a) what is the most likely thing to happen; and b) what would cause the worst dislocations. These are subjective concepts, in the sense that they have not been assigned any quantitative probability or risk.

The most likely disruption would be the loss of use of one well in the Sumas well field. Although the wells are closely-spaced, there is considerable variability in water quality among the wells. Nitrate concentrations in well 3, for instance, are typically 4 mg/l higher than those in well 1, despite the fact that these wells are only 150 feet apart. This variability reveals the possibility that one well could become contaminated while others remain useful.

The greatest disruption of service would be caused by loss of use of the entire Sumas well field, which would force the City to look to other sources to meet its municipal customers' potable water needs.

It is conceivable that some contingency could affect both the May Road and City well fields to the point that they would be unusable. If one thinks in terms of pollution episodes, it would have to be a very large contaminant spill in the area between the two Zones of Contribution that have been delineated (See aquifer delineation section of this report). The Abbotsford-Sumas aquifer sediments are porous and saturated, which accounts for relatively narrow flow lines contributing to each well; however specific contaminant plume dispersion modelling has not been done for this area. There is a somewhat lesser likelihood that a contaminant plume would affect both well fields than one of them.

6.4 POSSIBLE RESPONSES TO CONTINGENCIES

Response to a water system emergency would have several components, such as cleaning up the mess, providing for continuity of service in the short term, remediation, etc. The component of interest here is providing for continuity of service. Thus the most obvious responses have to do with connecting alternate sources either those under the control of the City, or others.

If the City were to lose the use of one well at the Sumas well field, service to customers could be continued almost as normal, except in periods of peak demand. Assuming first that the contaminated well was one of those supplying the Nooksack system (i.e., number 1, 2, or 3), the offending well could be isolated from the system with existing valves, and water could be supplied to the Nooksack system from the Sumas system as necessary through the existing interconnect. The wells supplying the Sumas system, numbers 4 and 5, could be operated simultaneously to provide the needed source.

Assuming next that the contaminated well was either number 4 or 5, the offending well could be isolated with existing valves, and the remaining well could be run continuously instead of at a fifty-percent duty cycle. As noted earlier, though, there are times when both well 4 and 5 are needed to meet peak demand. At times of peak demand, it would be possible to activate an existing emergency intertie with the City of Everson. The Everson intertie is discussed in greater detail as Option 2 in the following discussion about loss of use of the entire Sumas well field.

If the City were to lose the use of the entire City well field, it would have three possible short-term courses of action. They are:

1) Connect the May Road well field to the municipal distribution systems and supply the City from May Road. This would require a relatively simple physical connection, but it would also require consideration of issues related to water rights, pumping capacities, and nitrate concentrations.

   The best place to connect the municipal and industrial systems would be at Garrison's Corner, where an 8-inch Nooksack line, a 10-inch Sumas line, and a 10-inch industrial line are located in close proximity. In an emergency, the connection could be accomplished by the City public works crew within less than 24 hours.

   As described earlier, the City has a total water right of 1,825 af/yr at the May Road well field, of which 1,403 af/yr may be used for industrial purposes, with the remainder used for maintenance of stream flow. Existing demand amounts to 1,710 af/yr including the Nooksack system, the Sumas system, and the industrial customer. Unless the stream-mitigation flow was reduced, the May Road field would be incapable of providing all the needed water. The shortfall would be exacerbated if the anticipated second major industrial customer (with a consumption of 560 af/yr) was also in the picture. Aside from the issue of the total volume of water, there is also an inadequacy related to instantaneous rate of withdrawal. Existing peak demand amounts to about 2,000 gpm, whereas only 1,660 gpm can be withdrawn at May Road, including the water dedicated to stream flow. The City would need to consult the Department of Ecology with regard to any reduction in stream-mitigation flows and any use of water for a purpose not specified in a water right.

   Aside from inadequacies that exist on paper (i.e., water rights), the more pressing problem would be the inadequacy of installed pumping capacity. The May Road wells are capable of providing only 800 gpm as presently configured, far less than the peak demand of 2,000 gpm, and less than even the average demand of 1,060 gpm.

Note that if the industrial customers could tolerate the contaminant affecting the Sumas well field, it would be possible to swap the two supplies. A swap would again involve new connections at Garrison's corner, as well as the installation of new valves to isolate the Sumas well field from the municipal distribution systems. Such a swap would resolve the problems related to inadequacy of existing pumping capacity, except during periods of high demand.

As of this writing the nitrate concentration in May Road well 3 is only slightly above the maximum contaminant level (MCL) of 10 mg/l. It would be possible to supply water to the municipal system from this well if notification of the MCL violation were made to customers. Informal discussions with Whatcom County Health Department personnel indicate that this would be a reasonable contingency measure.

Nitrate at the May Road has been showing a gradual downward trend over the last two years. The pattern over time and the geographic distribution of nitrate concentrations in other wells give reason to hope that the May Road wells might be acceptable over the long run; the Meadowdale well on Van Buren Road has a history of 2-3 mg/l, which is considered "background" by the U.S. Geological Survey (1993). The new Abbotsford wells "A", "B", and "C" in the Industrial Road area north of the City of Sumas also have low nitrate levels. Other wells are higher as much as 26 mg/l.

The effectiveness of this option could be increased by installing some improvements ahead of time. The pumping capacity at the May Road well field could be upgraded to match the peak withdrawal rate specified in the water right, and an emergency industrial-to-municipal intertie could be installed at Garrison's Corner.

2) Request backup water supply from the City of Everson. There is an emergency intertie between the Nooksack distribution system and the Everson municipal system at the east end of Everson city limits, about 8 miles southwest of Sumas. Everson is capable of providing enough water to serve the City of Nooksack as well as the southern portion of the Nooksack Valley Water Association service area, which would close some of the gap between the actual demand and the pumping capacity of the May Road wells.

3) Request backup water supply from the City of Abbotsford at or near the Sumas border crossing. The logistics of an emergency intertie between Abbotsford and Sumas are relatively straightforward. The existing Abbotsford water distribution system consists of 6-inch lines that come within a quarter mile of the border in several locations between McCallum Road and Angus Campbell Road. The distribution system pressure in this area is generally in excess of 100 psi. The sources are the Farmer Road and Industrial Road well fields, which would be capable of delivering several hundred gallons per minute on an emergency basis. A permanent emergency intertie line could be installed at a cost of at most $30,000.

One potential but remote complication could attend the use of water from Abbotsford in the Sumas system. Abbotsford obtains some of its water from surface streams north of the Fraser River. This water will not be subject to any requirements comparable to the U.S. Surface Water Treatment Rule (40 CFR 141) until after the year 2000. Most of Abbotsford's supply comes from ground water, particularly in the southern part of its service area; the zone where the two sources would equalize lies in the former Municipality of Matsqui. Thus there is only the most remote possibility that en emergency intertie would entail piping noncomplying water into the Sumas system, but that possibility requires consideration.

In the event of loss of the Sumas well field, an effective public-information campaign will be crucial, with the aim of reducing demand throughout the system. As seen above, even the combination of options 1 and 2 (which are the options that can be put in place most readily) would not be sufficient to meet peak demand.

One long-term course of action open to the City of Sumas would be to undertake an exploration for additional source water to meet possible contingency needs. There would be substantial development costs of a type that are familiar to the City from its experience in developing the May Road site; in addition, there would be complications of water rights. It is highly unlikely that surface water could be found. A contingency ground water source would have to be evaluated by balancing the cost of the new source against the likelihood and cost of losing the use of present sources, and the fact that the new source would likely not be a revenue producer.

6.5 RESOURCES OR ACTIONS NEEDED TO IMPLEMENT RESPONSES

Contingency planning would be furthered by agreements in advance of need between the City, Canadian counterparts, the state and county health departments, and the Department of Ecology.

The desirable interconnections between systems could be accomplished with a modest amount of pipe and engineering.

Contingency planning for the City of Sumas should not proceed without anticipating the water rights issue raised by using water outside of the point of use allowed by existing water rights permits. The various contingency measures and the means of implementing them are summarized in the following table.

Likely contingency	Possible response	Needed for implementation
Loss of one well in Sumas well field	Use remaining wells. Divert water between distribution systems using existing intertie. Activate existing intertie with city of Everson.	Nothing. Plumbing and interlocal agreement in place.
Loss of entire Sumas well field	1) Activate existing intertie with city of Everson.	Nothing. Plumbing and interlocal agreement in place.
	2) Connect to May Road on emergency basis.	New intertie. Upgrade of pump capacity. Notification of WDOH. Notification of customers if nitrate > 10 mg/l, pursuant to WAC 246-290-330.
	3) Connect to City of Abbotsford	New intertie. Notification of WDOH, with possible complication from SWTR. New interlocal agreement with Abbotsford.

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APPENDIX A

WELLS WITHIN THE SUMAS/MATSQUI VICINITY USED IN THE WHPA STUDY

6 British Columbia Geographic System

6.1 The B.C.G. System is a geographic system in which the coverage in minutes and seconds of longitude is double the coverage in minutes and seconds of latitude for sheets at all scales. The smallest scale in the system is 1:20 000 derived from a breakdown of the N.T.S. 1:250 000 sheet into 100 parts. Larger scales are obtained by successive quartering or further division into 100 parts. A map number consists of the appropriate N.T.S. 1:250 000 map number followed by the numbers of each successive breakdown, each separated by a period. See Table 2 and Figures 7, 8 and 9.

Table 2: B.C.G.S. Scales, Map Numbers & Coverage

SCALE	MAP NUMBER	LONGITUDE	LATITUDE
1: 20 000	82F.035	12'	6'
1: 10 000	82F.035.1	6'	3'
1: 5 000	82F.035.2.2	3'	1' 30"
1: 2 500	82F.035.4.4.4	1' 30"	45"
1: 1 250	82F.035.3.3.3.3	45"	22.5"
1: 2 000	82F.035.063	1' 12"	36"
1: 1 000	82F.035.045.1	36"	18"
1: 500	82F.035.045.2.2	18"	9"

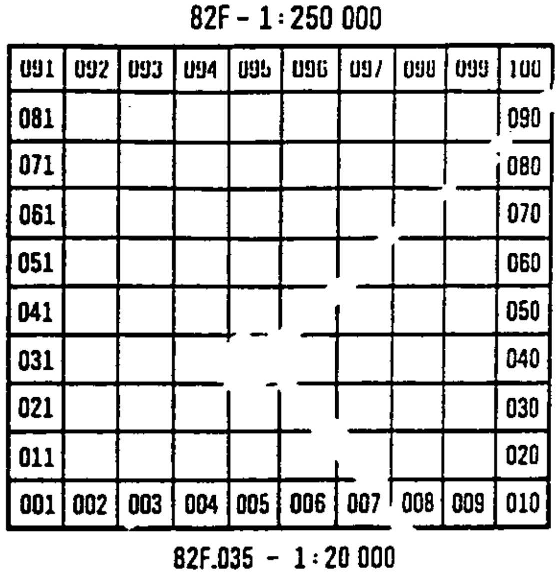

Fig. 7

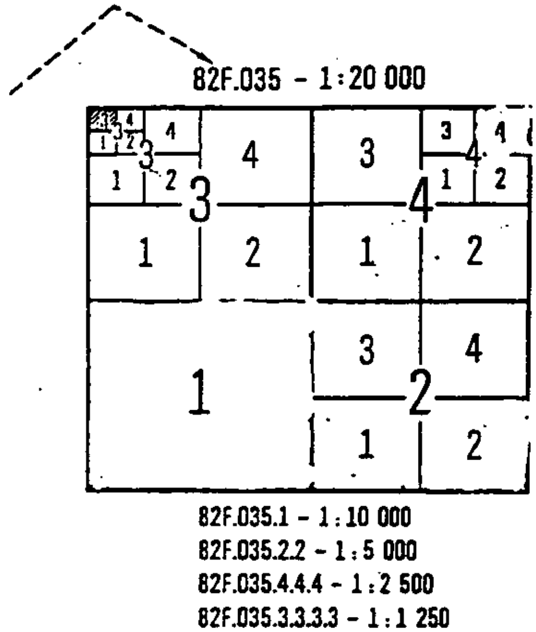

Fig. 8

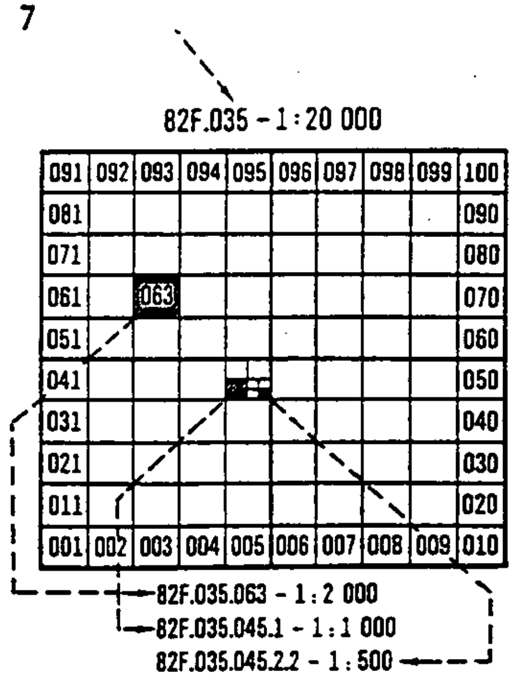

Fig. 9

TABLE A-1

WELLS WITHIN THE SUMAS/MATSQUI VICINTIY USED IN WHPA STUDY
CITY OF SUMAS WELLHEAD PROTECTION PROGRAM
SUMAS, WASHINGTON

LOCATION	Kahle, 1989 well #	LAT. (decimal degrees)	LONG (decimal degrees)	OWNER OF RECORD	DATE COMPLETED	GS ELEVATION (ft)	DRILLED DEPTH (ft)	CASING DEPTH (ft)	CASING DIAMETER (in)	TOP OF SCREEN DEPTH (ft)	BOTTOM OF SCREEN DEPTH (ft)	TOP OF AQUITARD DEPTH (ft)	BOTTOM OF AQUITARD DEPTH (ft)	TOP OF BASAL AQUITARD DEPTH (ft)	TOP OF SCREEN ELEVATION (ft)	BOTTOM OF SCREEN ELEVATION (ft)	TOP OF AQUITARD ELEVATION (ft)	BOTTOM OF AQUITARD ELEVATION (ft)	TOP OF BASAL AQUITARD ELEVATION (ft)	DATE OF WATER LEVEL	SWL DEPTH (ft)	SWL ELEVATION (ft)	YIELD (gpm)	DRAW DOWN (ft)	SPECIFIC CAPACITY	USE	INTERPRETED GEOLOGIC COMPLETION ZONE	WELL LOG	SOURCE	COMMENTS
T40NR4E-7A2	16U			Meadowdale Water Assn	26-Feb-87	70	89	79		79	89	NE	NE	90	21	11	NE	NE	20	26-Feb-87	8	92	200	8	25	DOM	Qso	Yes	DOE	Loc. to 40 ac. Two thin clay layers present in @ 14 and 41' bgs
T40NR4E-7C		0	0	Lynden Ready-Mix	30-Sep-87	NA	20	21	36	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	NA	8	NA	300	3	100	IRR	Qso	Yes	DOE	
T40NR4E-7H1		48.97278	122.3319	Elizabeth F. Tyler	01-Oct-71	85	NA	25	6	NA	NA	2	8	NE	NA	NA	83	77	NE	01-Oct-71	6	79	20	6	3.3333333	DOM	Qso	Yes	DOE	Loc. to 40 ac. Mod. relief. Aquitard described as clay and gravel.
T40NR4E-7H2		0	0	Peter Kilgore	12-Jan-88	NA	165	24	6	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	NA	NA	NA	0	NA	NA	DOM	Qso	Yes	DOE	
T40NR4E-7G	14U	48.97472	122.3386	Aggregates West	30-Nov-88	110	78	83	8	63	73	NE	NE	NE	47	37	NE	NE	NE	30-Nov-88	5	105	200	2.5	80	IND	Qso	Yes	USGS/DOE	Loc. to 40 ac. Low to mod relief. Two thin clay stringers present.
T40NR4E-7G	14U	48.97472	122.3386	Aggregates West	30-Nov-88	110	78	83	8	63	73	NE	NE	NE	47	37	NE	NE	NE	22-May-90	2.39	107.61			NA	NA	Qso	Yes	USGS	
T40NR4E-8A	17U	48.9775	122.3108	Vern Dykstra	27-Jun-80	56	57	42	10	42	47	3	35	NE	14	9	53	21	NE	27-Jun-80	8.5	47.5	150	1.8	83.75	TW	Qso	Yes	K/USGS/DOE	Aquitard described as silt, sand, clay, gravel (till?). Sumas Valley confined
T40NR4E-8A	17U	48.9775	122.3108	Vern Dykstra	27-Jun-80	56	57	42	10	42	47	3	35	NE	14	9	53	21	NE	22-May-90	7.18	48.82	150	1.8	83.75	TW	Qso	Yes	USGS	
T40NR4E-8C		48.97621	122.3215	Les Postma	25-Jun-79	57	78	68	8	68	78	43	56	NE	-11	-21	14	1	NE	25-Jun-79	9	48	375	10	37.5	IRR	Qso	Yes	DOE	Sumas confined. Water overlies aquitard. 5' sand layer w/ water in aquitard
T40NR4E-S8D		48.97556	122.3289	Ralph Stuvinga	20-Aug-91	85	45	41	6	41	45	4	41	45	44	40	81	44	50	20-Aug-91	13	72	7	17	0.4117647	DOM	Qso	Yes	DOE	Upland Confined. Loc. to 40 ac. Mod relief. Aquitard is till
T40NR4E-S8L	18U	48.98072	122.3203	Herman Bosher	08-Jul-85	60	58	42	6	42	58	10	30	NE	18	2	50	30	NE	08-Jul-85	8	52	200	0.5	400	IRR	Qso	Yes	USGS/DOE	Sumas valley confined. Aquitard is sandy clay
T40NR4E-9Q1		48.98528	122.2961	Pete Bums	21-Jun-79	55	59	49	8	49	59	0	18	NE	6	-4	55	37	NE	21-Jun-79	4	51	280	5	56	IRR	Qso	Yes	USGS/DOE	
T40NR4E-9Q1		48.98528	122.2961	Pete Bums	21-Jun-79	55	59	49	8	49	59	0	18	NE	6	-4	55	37	NE	23-May-90	2.87	52.13			ERR		Qso	Yes	USGS	
T40NR4E-10G		48.97444	122.2742	Bill Bosman	31-Oct-79	47	69	59	8	59	69	0	30	NE	-12	-22	47	17	NE	31-Oct-79	12	35	125	5	25	TW	Qso	Yes	USGS/DOE	Second clay aquitard present 45-55 bgs
T40NR4E-10G		48.97444	122.2742	Bill Bosman	31-Oct-79	47	69	59	8	59	69	0	30	NE	-12	-22	47	17	NE	30-May-90	8.74	38.26	125	5	25	TW	Qso	Yes	USGS	
T40NR4E-11E		48.97444	122.2608	Jay De Jong	04-Jun-75	50	40	40	36	NA	NA	0	18	NE	NA	NA	50	32	NE	NA	NA	NA	NA	NA	NA	TW	Qso	Yes	DOE	
T40NR4E-11M		48.98972	122.2608	Harry Faber	20-May-87	50	63	51	6	51	63	4	25	NE	-1	-13	46	25	NE	20-May-87	6.5	43.5	200	2	100	IRR	Qso	Yes	DOE	
T41NR3E-34L		49.00083	122.4056	Ken Zylstra	20-May-88	141	38	38	6	28	38			38	113	103			103	07-Jul-90	3.73	137	250	6	41.666667	IRR	Qso	Yes	USGS/DOE	
T41NR3E-36J		48.99806	122.3525	Gerald Holmquist	22-Sep-83	165.2	92	87	6	87	92	NE	NE	92	78.2	73.2	NE	NE	73.2	22-Sep-83	30	135.2	125	NA	NA	DOM	Qso	Yes	DOE	
T41NR3E-36J		48.99806	122.3525	Gerald Holmquist	22-Sep-83	165.2	92	87	6	87	92	NE	NE	92	78.2	73.2	NE	NE	73.2	07-Jul-90	25	140.2	125	NA	NA	DOM	Qso	Yes		
T41NR4E-31G		49.00217	122.3376	Columb. Aggregates MW-1	09-Nov-91	156.2	26	15.5	2	15.5	25.5	NE	NE	NE	140.7	130.7	NE	NE	NE	12-Nov-91	15.12	141.08	NA	NA	NA	TW	Qso	Yes	G	Sand and gravel coarsens downward.
T41NR4E-31J		48.98611	122.3289	John Frantzen	13-Dec-79	169	77	77	6	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	13-Dec-79	43	126	NA	NA	NA	DOM	Qso	Yes	DOE	2 dia.'s of casing used
T41NR4E-31J		48.98611	122.3289	John Frantzen	13-Dec-79	169	77	77	6	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	09-May-90	33.63	135.37	NA	NA	NA	DOM	Qso	Yes		No aquitard. Lots of boulders, gravel in aquifer
T41NR4E-31R		48.98742	122.3292	Columb. Aggregates MW-3	11-Oct-91	172.97	53	32.5	2	32.5	52.5	NE	NE	NE	140.47	120.47	NE	NE	NE	12-Nov-91	39.48	133.49	NA	NA	NA	TW	Qso	Yes	G	Sand and gravel. Clay at 10' bgs
T41NR4E-32E		49.00083	122.3283	North American Exploration	25-Sep-81	206	400	260	6					213	NA	NA	NE	NE	-7	NA	NA	NA	NA	NA	NA	TW	Qso	Yes	USGS/DOE	No aquitard. Good control for top of basal aquitard
T41NR4E-32E2		49.00064	122.3229	Columb. Aggregates MW-2	09-Nov-91	203.9	82.5	59.5	2	59.5	82.5	NE	NE	NE	144.4	121.4	NE	NE	NE	12-Nov-91	69.8	134.1	NA	NA	NA	TW	Qso	Yes	G	Sand and gravel coarsens downward
T41NR4E-32M	13	48.98806	122.3269	Elmer H. Anderson	10-Dec-79	189.29	96	95	8	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	10-Dec-79	61	128.29	NA	NA	ERR	DOM	Qso	Yes		2 dia.'s of casing used
T41NR4E-32M	13	48.98806	122.3269	Elmer H. Anderson	10-Dec-79	189.29	96	95	8	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE		49.81	139.48	NA	NA	ERR		Qso	Yes	K/USGS/DOE	
T41NR4E-32M	13	48.98806	122.3269	Elmer H. Anderson	10-Dec-79	189.29	96	95	8	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE			131.38	NA	NA	ERR		Qso	Yes	USGS	95 ft of sand and gravel. Coarsens down.
T41NR4E-32M	13	48.98806	122.3269	Elmer H. Anderson	10-Dec-79	189.29	96	95	8	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE			138.24	NA	NA	ERR		Qso	Yes	K	
T41NR4ES32M	13	48.98806	122.3269	Elmer H. Anderson	10-Dec-79	189.29	96	95	8	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	10-Dec-79	64		150	20	7.5	IRR	Qso	Yes	K	Describes sand, gravel and clay between 15 and 66 bgs
T41NR4E-32N		48.98389	122.3256	Columb. Aggregates MW-4	11-Oct-91	158.01	43	22.5	2	22.5	42.5	NE	NE	NE	135.51	115.51	NE	NE	NE	12-Nov-91	30.44	127.57	NA	NA	NA	TW	Qso	Yes	G	Sand and gravel coarsens downward
T41NR4E-33O		48.98519	122.2923	Harold Teisma	08-May-80	47.5	63	52	8	52	63	0	16	65	-4.5	-15.5	47.5	31.5	-17.5	08-May-80	7.33	40.17	100	3.33	30.03003	TW	Qso	Yes		Sumas Valley confined aquifer. Basal aquitard questionable. Wood described in log
T41NR4E-33H1		49.00069	122.2878	City of Sumas #1	21-Aug-71	49	69	69	12	45	65	0	45	NE	4	-16	49	4	NE	NA	NA	NA	1300	NA	NA	MUN	Qso	Yes	DOE	Confining unit is 30' of peat over 15' clayey gravel. 1 of 3 wells serving Nooksack area.
T41NR4E-33H2		49.00111	122.2883	City of Sumas #2	08-Feb-62	49	58	47	12	47	57	0	45	58	2	-8	49	4	-9	NA	NA	NA	750	NA	NA	MUN	Qso	Yes	DOE/USGS	Confining unit is 27' of peat over 15' blue clay and 3' clayey gravel. Elev. from USGS. Serves Nooksack
T41NR4E-33H3		49.00167	122.2883	City of Sumas #3	12-Sep-65	49	58	47	12	47	57	0	45	58	2	-8	49	4	-9	NA	NA	NA	500	NA	NA	MUN	Qso	Yes	DOE/USGS	Confining unit is 27' of peat over 15' blue clay and 3' clayey gravel. Elev. from USGS. Serves Nooksack
T41NR4E-33H4		49.00139	122.2878	City of Sumas #4	21-Aug-71	50	69	69	12	45	65	0	45	58	5	-15	50	5	-8	NA	NA	NA	1300	NA	NA	MUN	Qso	Yes	DOE/USGS	Confining unit is 30' of peat over 5' clayey gravel and 3' gravelly clay. Elev. from USGS. Serves Sumas
T41NR4E-33H5		49.00083	122.2878	City of Sumas #5	02-Jun-92	48	86.5	20	12	59	79.5	0	48.5	80	-11	-31.5	48	-0.5	-32	09-Jun-92	-11.57	59.57	1100	5.36	205.22388	MUN	Qso	Yes	RN	2 screens used. Conf. unit is 26.5 ft of peat, over 22' silty/clayey gravel. Basal aquit. is silt and f. sand
T41NR4E-33N2	16	48.98839	122.3056	City Sumas/May Rd/OB-2	15-Oct-87	119.39	200	74	6	76	81	32	54	104	43.39	38.39	87.39	65.39	15.39	11-Oct-88	23.5	95.89			ERR	MUN	Qso	Yes	GK/USGS	Conf. unit is clayey silt. Over 100 ft of fine sand w/ silt @ 104' bgs underlies completion
T41NR4E-33N3	17	48.98867	122.3008	City Sumas/May Rd/OB-3	15-Oct-87	86.95	78.5	64.6	6	64.6	69.6	19.5	56	71	22.35	17.35	67.45	30.95	15.95	11-Oct-88	-1.57	88.52			ERR	MUN	Qso	Yes	GK/USGS	Conf. unit is clay. Aquifer is sand coarsening down. Overlies clay >7.5 ft thick.
T41NR4E-33N3	17	48.98867	122.3008	City Sumas/May Rd/OB-3	15-Oct-87	86.95	78.5	64.6	6	64.6	69.6	19.5	56	71	22.35	17.35	67.45	30.95	15.95	18-Mar-89	-4.35	91.3			ERR		Qso	Yes	GK/USGS	Kahle, 1989 water level
T41NR4E-33N4	18	48.98611	122.3008	City Sumas/May Rd/TW-1	15-Oct-87	87.53	72	53.5	8	53.5	70.5	23	54	71.5	34.03	17.03	64.53	33.53	18.03	11-Oct-88	-0.59	88.12			ERR	TEST	Qso	Yes	GK/USGS	Conf. unit is clay
T41NR4E-33N4	18	48.98611	122.3008	City Sumas/May Rd/TW-1	15-Oct-87	87.53	72	53.5	8	53.5	70.5	23	54	71.5	34.03	17.03	64.53	33.53	18.03	18-Mar-89	-2.75	90.28			ERR		Qso	Yes	GK/USGS	Kahle, 1989 water level
T41NR4E-33N5	19	48.98389	122.3008	City Sumas/May Rd/OB-4	15-Oct-87	109.87	81	67.6	6	67.6	72.6	19	53	78	42.27	37.27	90.87	56.87	31.87	11-Oct-88	25.75	84.12			ERR	MON	Qso	Yes	GK/USGS	Clay conf. unit has 15 ft sand layer interfingered
T41NR4E-33N5	19	48.98389	122.3008	City Sumas/May Rd/OB-4	15-Oct-87	109.87	81	67.6	6	67.6	72.6	19	53	78	42.27	37.27	90.87	56.87	31.87	18-Mar-89	22.9	86.97			ERR	MON	Qso	Yes	GK/USGS	Kahle, 1989 water level
T41NR4E-33N6		48.98583	122.3008	City Sumas/May Rd/Well 1	18-Mar-92	85.5	65	44	12	44	53.7	31	41	55	41.5	31.8	54.5	44.5	30.5	27-Apr-92	-3.6	89.1	200	34.15	5.8565154	MUN	Qso	Yes	RN/DOE	Elevation from well log. Aquifer coarsens with depth.
T41NR4E-33N7		48.98839	122.3008	City Sumas/May Rd/Well 3	18-Jun-92	88	74	31	12	48.5	66	23	47.5	67	39.5	22	65	21	14	09-Jun-92	-2.5	90.5	920	36.9	24.932249	MUN	Qso	Yes	RN/DOE	Elevation from well log. Aquifer coarsens with depth.
092G 9 1 1 1-0		49.00861	122.3814	BCMOE Gwater Section	24-Mar-88	184.77	35	35	2	29	32	NE	NE	NE	135.77	132.77	NE	NE	NE	26-Apr-88	11.975	152.795	NA	NA	ERR	TW	Qso	Yes	BCME/USG	No aquitard. USGS elevation 4.77' lower than on well log. Boring also has 20' completion
092G 9 1 1 1-0		49.00861	122.3814	BCMOE Gwater Section	24-Mar-88	184.77	35	35	2	29	32	NE	NE	NE	135.77	132.77	NE	NE	NE	11-Jun-90	9.3	155.47	NA	NA	ERR	·	Qso	Yes		
092G 9 1 1 1-9		49.0025	122.3919	Inland Waters Directorate	29-Mar-88	151	29	29	NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	18-Jun-90	6.6	144.4	NA	NA	ERR	TW	Qso	Yes	BCME/USG	No aquitard. Coarsens downward
092G 9 1 1 2-1		49.00861	122.3706	BCMOE Gwater Section	16-Mar-88	168.71	35	29	2	29	32	NE	NE	NE	139.71	136.71	NE	NE	NE	11-Jun-90	11.6	157.11	NA	NA	ERR	TW	Qso	Yes	BCME/USG	Sand and gravel and aquifer.
092G 9 1 1 2-1		49.00833	122.3706			167.6	75		NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	11-Jun-90	11.56	156.04	NA	NA	ERR		Qso	Yes	BCME/USG	Sand and gravel
092G 9 1 1 2-2		49.00306	122.3592	Raiser	28-Aug-85	166	55	42.2	8	42	48	NE	NE	48	124	118	NE	NE	118	15-Jun-90	14.54	151.46	150	NA	ERR		Qso	Yes	BCME/USG	Good control for basal aquitard
092G 9 1 1 2-9		49.00556	122.3589	Inland Waters Directorate	22-Mar-88	167	25	25	NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	15-Jun-90	10.63	156.37	NA	NA	ERR	TW	Qso	Yes	BCME/USG	Sand and gravel coarsens down. Piezometer #ABB-88-2
092G 9 1 1 4-1		49.01194	122.3519			180	41	41	NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	14-Jun-90	10.02	169.98	NA	NA	ERR	TW	Qso	Yes	BCME/USG	Gravel
092G 9 1 1 4-1		49.02444	122.3533		22-Oct-79	200	60	55	NA	55	60	NE	NE	NE	145	140	NE	NE	NE	14-Jun-90	19.37	180.63	NA	NA	ERR		Qso	Yes	BCME/USG	Sand and gravel
092G 9 1 1 4-1		49.01694	122.3706	BCMOE Gwater Section	25-Feb-88	156.88	35	29	2	29	32	NE	NE	NE	127.88	124.88	NE	NE	NE	11-Jun-90	10.2	146.68	NA	NA	ERR		Qso	Yes	BCME/USG	Sand and gravel. Dual completion monitoring well
092G 9 1 1 4-1		49.01867	122.3706			170	75		NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	11-Jun-90	10.3	159.7	NA	NA	ERR	TW	Qso	Yes	BCME/USG	Sand and gravel
092G 9 1 1 4-9		49.01278	122.3592	Inland Waters Directorate	30-Mar-88	180	30	30	NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	18-Jun-90	17.3	162.7	NA	NA	ERR	TW	Qso	Yes	BCME/USG	Silty sand w/ cobbles. Piezometer #ABB-88-6
092G 9 1 2 1-2		49.01167	122.3353		28-Mar-80	190	161	161	NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	15-Jun-90	41.17	148.83	NA	NA	ERR	NA	Qso	Yes	BCME/USG	Sand and gravel
092G 9 1 2 1-9		49.00611	122.3367	Inland Waters Directorate	22-Mar-88	190	58	58	NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	18-Jun-90	35.7	154.3	NA	NA	ERR	TW	Qso	Yes	BCME/USG	Sand and gravel. Piezometer #ABB-88-3
092G 9 1 2 2-3		49.00861	122.3026		15-Mar-84	140	160	80	NA	80	90	23	150	NE	60	50	117	-10	NE	18-Jun-90	35.11	104.89	NA	NA	ERR	NA	Qso	Yes	BCME/USG	Aquitard is clay and silt. 75-80'bgs sand and gravel layer present w/in aquitard

TABLE A-1

WELLS WITHIN THE SUMAS/MATSQUI VICINTIY USED IN WHPA STUDY
CITY OF SUMAS WELLHEAD PROTECTION PROGRAM
SUMAS, WASHINGTON

LOCATION	Kahle, 1989 well #	LAT. (decimal degrees)	LONG. (decimal degrees)	OWNER OF RECORD	DATE COMPLETED	GS ELEVATION (ft)	DRILLED DEPTH (ft)	CASING DEPTH (ft)	CASING DIAMETER (in)	TOP OF SCREEN DEPTH (ft)	BOTTOM OF SCREEN DEPTH (ft)	TOP OF AQUITARD DEPTH (ft)	BOTTOM OF AQUITARD DEPTH (ft)	TOP OF BASAL AQUITARD DEPTH (ft)	TOP OF SCREEN ELEVATION (ft)	BOTTOM OF SCREEN ELEVATION (ft)	TOP OF AQUITARD ELEVATION (ft)	BOTTOM OF AQUITARD ELEVATION (ft)	TOP OF BASAL AQUITARD ELEVATION (ft)	DATE OF WATER LEVEL	SWL DEPTH (ft)	SWL ELEVATION (ft)	YIELD (gpm)	DRAW DOWN (ft)	SPECIFIC CAPACITY	USE	INTERPRETED GEOLOGIC COMPLETION ZONE	WELL LOG	SOURCE	COMMENTS
T40NR3E-1A1	44	48.99161	122.3536	Martin Vande Hoef	18-Jul-73	185.23	65	65	6	80	85	18	21	NE	105.23	100.23	147.23	144.23	NE	18-Jul-73	27.67	137.56	NA	NA	NA	DOM	Qso	Yes	DOE,K	Confined, Located to nearest 40 acres.
T40NR3E-1A1	44	48.99161	122.3536	Martin Vande Hoef	18-Jul-73	185.23	65	65	6	80	85	18	21	NE	105.23	100.23	147.23	144.23	NE	08-Oct-88	31.04	134.19	NA	NA	NA	DOM	Qso	Yes	DOE	
T40NR3E-1A1	44	48.99161	122.3536	Martin Vande Hoef	18-Jul-73	185.23	65	65	6	80	85	18	21	NE	105.23	100.23	147.23	144.23	NE	18-Mar-89	24.84	140.39	NA	NA	NA	DOM	Qso	Yes	DOE	
T40NR3E-1A2		48.99202	122.3544	Martin Vande Hoef	22-Jun-81	164	78	78	8	80	78	45	58	78	104	86	119	106	86	22-Jun-81	24	140	400	NA	NA	IRR	Qso	Yes	DOE	Confined. Accurate location given on well log.
T40NR3E-1A3	45	48.98955	122.356			140.67	24	24	36	20	24	NE	NE	NE	120.67	116.67	NE	NE	NE	08-Oct-88	5.95	134.72	NA	NA	NA	NA	Qso	Yes	K	All data from Kahle, 1989
T40NR3E-1A3	45	48.98955	122.356			140.67	24	24	36	20	24	NE	NE	NE	120.67	116.67	NE	NE	NE	18-Mar-89	2.71	137.96	NA	NA	NA	NA	Qso	Yes	K	
T40NR3E-1C		48.99161	122.3644	Richland Farm	25-Apr-86	140	60	0	8	NA	NA	0	NE	NE	NA	NA	140	NE	NE	NA	NA	NA	NA	NA	NA	IRR	NA	Yes	DOE	Well not completed. 15' of peat over clay. Located to nearest 40 ac.
T40NR3E-1D1		NA	NA	Richland Farm	09-Apr-87		50	44	8	29	44	NA	NA	NA	NA	NA	NA	NA	NE		10					TW		Yes	DOE	
T40NR3E-1D2	46	48.99326	122.369	Richland Farm	28-Apr-86	154.65	40	40	8	24	40	40	NA	NA	NA	NA	114.65	NA	NE	28-Apr-86	11	143.65	200	1.5	133.3	TW	Qso	Yes	DOE,K	dd after 1 hour, Kahle, 1989 location
T40NR3E-1D2	46	48.99326	122.369	Richland Farm	28-Apr-86	154.65	40	40	8	24	40	40	NA	NA	NA	NA	114.65	NA	NE	08-Oct-88	13.6	141.05	200	1.5	133.3		Qso		K	Water level by Kahle, 1989
T40NR3E-1D2	46	48.99326	122.369	Richland Farm	26-Apr-86	154.65	40	40	8	24	40	40	NA	NA	NA	NA	114.65	NA	NE	18-Mar-89	8.25	146.4	200	1.5	133.3		Qso		K	Water level by Kahle, 1989
T40NR3E-1P1	NA	48.9807	122.3644	Rod Visser	07-Jul-92	140	98	98	10	86	98	21	32	NE	54	44	119	108	NE	07-Jul-92	16	124	500	29	17.2	IRR	Qso	Yes	DOE	dd after 4 hour; confined, coarsens doward. Located nearest 40 ac. Other Visser well due south in Kah
T40NR3E-1P2	NA	48.9807	122.3644	Pangborn Water Assoc.	05-Apr-91	140	50	49	10	39	49	49	NA		101	91	91	NA		05-Apr-91	12.17	127.83	70	4.17		DOM		Yes	DOE	dd after 5 hour
T40NR3E-2A1				Moe Sanga	23-Aug-88		24	24	36	NA	NA	NA	NA		NA	NA	NA	NA			13		250	28		IRR		Yes	DOE	dd after 8 hour
T40NR4E-3J		48.98222	122.2661	Jim Skillman	29-Jun-79	45	60	59	8	49	59	2	25	NE	-4	-14	43	20	NE		6	39	150	4	37.5	IRR	Qso	Yes	USGS/DOE	Sumas valley confined; Driller suspects close to clay at 60' bgs. Aquitard is grey clay.
T40NR4E-4E		48.98998	122.3042	Mike McGee	27-Apr-91	140	87	87	6	82	87	9	73	NE	-22	-27	51	-13	NE	27-Apr-91	82	-2	12	5	2.4	DOM	Qso	Yes	DOE	confined; dd after 4 hour; aquitard described as hard pan and gravel and clay. Elev to 40 ac.
T40NR4E-4N		48.9888	122.3042	Edgar Stone	01-Apr-85	52	28	28	6	NA	NA	2	17	NE	NA	NA	50	35	NE	NA	14	38	10	4	2.5	DOM	Qso	Yes	DOE	Sumas valley confined aquifer. Aquitard is sandy & gravelly clay. Elev. to 40 ac. Flat section.
T40NR4E-4Q		48.98111	122.2922	E. May Coraron	24-Apr-79	48	37	37	6	NA	NA	0	25	NE	NA	NA	48	23	NE	NA	9	39	35	4	8.75	DOM	Qso	Yes	DOE	Sumas valley confined aquifer. Aquitard is sand w/ loam. Elev to 40 ac. Flat section.
T40NR4E-5A		48.99111	122.3014	Corrie Akkerman		150	82.5	82.5	6	77.5	82.5	2	16	NE	72.5	67.5	148	134	NE	08-Feb-92	40	110	12	15	0.8	DOM	Qso	Yes	DOE	Upland unconfined. Aquitard is clay. Boulders over gravel / sand aquif. El. to 40 ac. High relief sect.
T40NR4E-5B		48.99111	122.3071	Paul Roorda	20-Jul-88	175	88	88	8	87.5	88	79.5	80	NE	107.5	87	95.5	95	NE	20-Jul-88	33.5	141.5	NA	NA	NA	IRR	Qso	Yes	DOE	Loc. to 40 ac. High relief section. 1/4 section location not consistent with address.
T40NR4E-5C		48.99111	122.3129	Glen Terpstra	12-May-83	140	48	47	6	43	47	38	42	NE	97	93	104	98	NE		28	112	20	8	2.5	DOM	Qso	Yes	DOE	bailer test; dd after 4 hour. Loc. to 40 ac. Mod. relief quad. Aquifer fines downward.
T40NR4E-5D1	26	48.98917	122.3289	Bill Visser	22-Jul-88	182.28	77	77	8	55	75	NA	NA	77	107.28	87.28	NA	NA	85.28	22-Jul-88	54.5	107.78	400	NA	NA	IRR	Qso	Yes	USGS/DOE	Upland unconfined. No aquitard. Fines downward.
T40NR4E-5D1	26	48.98917	122.3289	Bill Visser	22-Jul-88	182.28	77	77	8	55	75	NA	NA	77	107.28	87.28	NA	NA	85.28	10-Oct-88	33.56	128.72	400	NA	NA	IRR	Qso	Yes	K	
T40NR4E-5D1	26	48.98917	122.3289	Bill Visser	22-Jul-88	182.28	77	77	8	55	75	NA	NA	77	107.28	87.28	NA	NA	85.28	18-Mar-89	29.42	132.86	400	NA	NA	IRR	Qso	Yes	K	
T40NR4E-5D1	26	48.98917	122.3289	Bill Visser	22-Jul-88	182.28	77	77	8	55	75	NA	NA	77	107.28	87.28	NA	NA	85.28	16-May-90	29.4	132.88	400	NA	NA	IRR	Qso	Yes	USGS	
T40NR4E-5D2	25	48.99278	122.3289	Paul Roorda	18-Jul-79	181.08	95	70	8	70	80	10	50	81	111.08	101.08	171.08	131.08	100.08	18-Jun-79	50	131.08	300	NA	NA	IRR	Qso	Yes	/USGS/DOE	Aquitard designation uncertain. Kahel shows Boyon as owner of record.
T40NR4E-5D2	25	48.99278	122.3289	Paul Roorda	18-Jul-79	181.08	95	70	8	70	80	10	50	81	111.08	101.08	171.08	131.08	100.08	08-Oct-88	45.85	135.23	NA	NA	NA	IRR	Qso	Yes	K	Not available for 10/88 measurement by Kahle.
T40NR4E-5D2	25	48.99278	122.3289	Paul Roorda	18-Jul-79	181.08	95	70	8	70	80	10	50	81	111.08	101.08	171.08	131.08	100.08	18-May-90	45.03	136.05	NA	NA	NA	IRR	Qso	Yes	USGS	
T40NR4E-5E	5U	48.9875	122.3289	Bill Visser	20-Jul-87	158	140	138	8	NA	NA	19	NE	NE	NA	NA	139	NE	NE	NA	NA	NA	NA	NA	NA	TW	Qso	Yes	K/DOE	first sign of clay is at 19 ft. Uncompleted test well. Suggests thick aquitard sequence beneath uncon. aq
T40NR4E-5E2		48.98917	122.3156	Dave Swanson	10-Aug-82	130	40	39	6	36	39	40	NE	NE	94	91	90	NE	NE	NA	23	107	15	8	1.875	DOM	Qso	Yes	DOE	Loc. to 40 ac. Mod. relief section.
T40NR4E-5G1		48.98917	122.3071	Wilfred Connell	12-Aug-93	75	29.5	29.5	6	24.5	29.5	1	10	30	50.5	45.5	74	65	45	12-Aug-93	14	61	25	1	25	DOM	Qso	Yes	DOE	Loc. to 40 ac. high relief section.
T40NR4E-5G2		48.98917	122.3071	Wilfred Connell	12-Jan-90	75	58	58	6	52.5	57	15	22	58	22.5	18	60	53	17	12-Jan-90	20	55	35	NA	NA	DOM	Qso	Yes	DOE	Loc. to 40 ac. high relief section.
T40NR4E-5L1		48.98461	122.3129	Les Posma	27-Jun-79	125	80	78	6	68	78	12	67	NE	57	47	113	58	NE	27-Jun-79	8	117	400	NA	NA	IRR	Qso	Yes	DOE	confined. Water bearing sand w/in aquitard 18' thick. Loc. to 40 ac. High relief.
T40NR4E-5L2		48.98461	122.3129	Larry Van Andel	12-Oct-84	125	91	87	6	87	91	8	76	NE	38	34	117	49	NE	18-Jul-73	69	56	18	0	ERR	DOM	Qso	Yes	DOE	unconfined. Layers of dry pea gravel and sand within aquitard. Loc. to 40 ac. High relief.
T40NR4E-5L3		48.97937	122.3271	William Visser	03-Aug-73	100	39	35	6	35	38	21	27	NE	65	62	79	73	NE	03-Aug-73	19	81	16	4	4	DOM	Qso	Yes	USGS/DOE	20' tile drain overlies aquitard. Aquifer fines downward. Aquitard described like silt.
T40NR4E-5F	27	48.9875	122.3225	Loren Crabtree	21-Jun-82	127.8	47	47	6	NA	NA	0	32	NE	NA	NA	127.8	95.8	NE	21-Jun-82	34	93.8	30	NA	NA	DOM	Qso	Yes	K/DOE	Kahle log matches but diameter is shown as 36-in. Aquitard described like silt.
T40NR4E-5F	27	48.9875	122.3225	Loren Crabtree	21-Jun-82	127.8	47	47	6	NA	NA	0	32	NE	NA	NA	127.8	95.8	NE	08-Oct-88		117.8								
T40NR4E-5F	27	48.9875	122.3225	Loren Crabtree	21-Jun-82	127.8	47	47	6	NA	NA	0	32	NE	NA	NA	127.8	95.8	NE	18-Mar-89		121.83								
T40NR4E-5N		48.98611	122.3289	William Visser	01-Jun-73	100	34	29	8	29	34	NE	NE	NE	71	66	NE	NE	NE	01-Jun-73	2	98	250	NA	NA	IRR	Qso	Yes	DOE	No aquitard present. Loc. to nearest 40 acre.
T40NR4E-5P1		48.98058	122.3208	Dale Steele	30-Mar-77	56.98	28.5	28	36	NA	NA	0	14	NE	NA	NA	56.98	42.98	NE	30-Mar-77	14	42.98	NA	NA	NA	DOM	Qso	Yes	USGS/DOE	Elev. discrep. between Kahle and USGS. Aquitard is sandy clay. Possible Sumas valley confined.
T40NR4E-5P1		48.98058	122.3208	Dale Steele	30-Mar-77	56.98	28.5	28	36	NA	NA	0	14	NE	NA	NA	56.98	42.98	NE	30-May-90	14.72	42.26	NA	NA	NA	DOM	Qso	Yes	USGS	
T40NR4ES5P2	31	48.98	122.3203	Dale Steel	17-Apr-74	74.32	23	23	36	NA	NA	2	10	NE	NA	NA	72.32	64.32	NE	30-May-90	15.72	58.6	65	2	42.5	DOM	Qso	Yes	USGS/DOE	Elev. discrep. between Kahle and USGS. Aquitard is clay w/ large rocks.
T40NR4E-5P3	29	48.98139	122.3194	Paul E. McAbee	05-Apr-77	73.78	28.5	28	36	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	05-Apr-77	13	60.78	NA	NA	NA	DOM	Qso	Yes	K/DOE	No aquitard.
T40NR4E-5P3	29	48.98139	122.3194	Paul E. McAbee	05-Apr-77	73.78	28.5	28	36	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	09-Oct-88	16.8	56.98	NA	NA	NA	DOM	Qso	Yes	K	
T40NR4E-5P3	29	48.98139	122.3194	Paul E. McAbee	05-Apr-77	73.78	28.5	28	36	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	18-Mar-89	12.61	61.17	NA	NA	NA	DOM	Qso	Yes	K	
T40NR4E-5N2	33	48.98125	122.3294	Mike Dahl	03-Aug-79	139.82	86	86	6	NE	NE	17	63	NE	NA	NA	122.82	76.82	NE	03-Aug-79	69	70.82	15	1	15	DOM	Qso	Yes	/USGS/DOE	Aquitard described as hardpan.
T40NR4E-5N2	33	48.98125	122.3294	Mike Dahl	03-Aug-79	139.82	86	86	6	NE	NE	17	63	NE	NA	NA	122.82	76.82	NE	15-May-90	62.72	77.1	15	1	15	DOM	Qso	Yes	USGS	
T40NR4E-5N2	33	48.98125	122.3294	Mike Dahl	03-Aug-79	139.82	86	86	6	NE	NE	17	63	NE	NA	NA	122.82	76.82	NE	08-Oct-88	67.1	72.72	15	1	15	DOM	Qso	Yes	K	
T40NR4E-5N2	33	48.98125	122.3294	Mike Dahl	03-Aug-79	139.82	86	86	6	NE	NE	17	63	NE	NA	NA	122.82	76.82	NE	18-Mar-89	62.96	76.86	15	1	15	DOM	Qso	Yes	K	
T40NR4E-6A1		48.99139	122.3302	Everett E. Lorsen	20-Jun-51	174.25	80	69	8	69	80	44	60	NE	105.25	94.25	130.25	114.25	NE	26-Apr-94	46.13	128.12	180	NA	NA	IRR	Qso	Yes	DOE	Aquitard is sand gravel and yellow silt. Location and elev. from Dave Garland/DOE study.
T40NR4E-6B1		48.99308	122.3381	Paul Roorde	01-Nov-73	168	77	75	6	NA	NA	2	6	NA	NA	NA	166	162	NE	01-Nov-73	36	132	50	NA	NA	DOM	Qso	Yes	USGS/DOE	Thin, shallow aquitard described as hardpan.
T40NR4E-6B1		48.99308	122.3381	Paul Roorde	01-Nov-73	168	77	75	6	NA	NA	2	6	NA	NA	NA	166	162	NE	16-May-90	31.78	136.22	50	NA	NA	DOM	Qso	Yes	USGS	
T40NR4E-6N1		48.9807	122.3475	L. Sikes	25-Jul-90	140	59	59	6	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	29-Jul-90	3.5	136.5	20	5	4	DOM	Qso	Yes	DOE	Loc. to 40 ac. Mod. relief. Water level suspect
T40NR4E-6K1	37	48.98611	122.3394	Ten Vanderveen	25-Nov-87	135.93	25.5	20.75	6	20	25	25.5	NE	NE	115.93	110.93	110.43	NE	NE	25-Nov-87	12.5	123.43	15	NA	NA	TW	Qso	Yes	/USGS/DOE	
T40NR4E-6K1	37	48.98611	122.3394	Ten Vanderveen	25-Nov-87	135.93	25.5	20.75	6	20	25	25.5	NE	NE	115.93	110.93	110.43	NE	NE	22-May-90	8.69	127.24	15	NA	NA	TW	Qso	Yes	USGS	
T40NR4E-6K1	37	48.98611	122.3394	Ten Vanderveen	25-Nov-87	135.93	25.5	20.75	6	20	25	25.5	NE	NE	115.93	110.93	110.43	NE	NE	08-Oct-88	10.3	125.63	15	NA	NA	TW	Qso	Yes	K	
T40NR4E-6K1	37	48.98611	122.3394	Ten Vanderveen	25-Nov-87	135.93	25.5	20.75	6	20	25	25.5	NE	NE	115.93	110.93	110.43	NE	NE	18-Mar-89	7.6	128.33	15	NA	NA	TW	Qso	Yes	K	
T40NR4ES8H		0	0	B. DeHoog	22-Feb-89		35	35	8											22-Feb-89	7		20	2	10	DOM	Qso	Yes	DOE	
T41NR4E-31Q		48.99361	122.3342	Bathe Farms, Inc.	05-Mar-87	164.61	50	42	6	42	50	3	38	50	122.61	114.61	161.61	126.61	114.61		36	128.61	25	8	3.125	MUN	Qso	Yes	DOE	Loc. & elev from Dave Garland Ecology study. Aquitard described as cemented gravel.
T40NR4E-7A1		48.9758	122.3319	Elizabeth F. Tyler	01-May-73	105	28	28	6			3	7				102	98		01-May-73	16	89	12	1	12	DOM	Qso	Yes	DOE	

TABLE A-1

WELLS WITHIN THE SUMAS/MATSQUI VICINTIY USED IN WHPA STUDY
CITY OF SUMAS WELLHEAD PROTECTION PROGRAM
SUMAS, WASHINGTON

LOCATION	Kahle, 1990 well #	LAT. (decimal degrees)	LONG. (decimal degrees)	OWNER OF RECORD	DATE COMPLETED	GS ELEVATION (ft)	DRILLED DEPTH (ft)	CASING DEPTH (ft)	CASING DIAMETER (in)	TOP OF SCREEN DEPTH (ft)	BOTTOM OF SCREEN DEPTH (ft)	TOP OF AQUITARD DEPTH (ft)	BOTTOM OF AQUITARD DEPTH (ft)	TOP OF BASAL AQUITARD DEPTH (ft)	TOP OF SCREEN ELEVATION (ft)	BOTTOM OF SCREEN ELEVATION (ft)	TOP OF AQUITARD ELEVATION (ft)	BOTTOM OF AQUITARD ELEVATION (ft)	TOP OF BASAL AQUITARD ELEVATION (ft)	DATE OF WATER LEVEL	SWL DEPTH (ft)	SWL ELEVATION (ft)	YIELD (gpm)	DRAW DOWN (ft)	SPECIFIC CAPACITY	USE	INTERPRETED GEOLOGIC COMPLETION ZONE	WELL LOG	SOURCE	COMMENTS
092G 9.1.2.2-4		49.00839	122.3158		01-Dec-89	260	180	167	NA	167	178	0	120	178	93	82	260	140	82	15-Jun-90	116.87	143.13	NA	NA	ERR	NA	Oso	Yes	BCME/USG	Aquitard is gravelly till. Basal aquitard is fine sand w/clay.
092G 9.1.2.3-1		49.01808	122.3417		01-Dec-89	180	63	63	NA	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	14-Jun-90	37.55	142.45	25	1.1	22.727273	NA	Oso	Yes	BCME/USG	Sand an gravel. Multiple water level measurements.
092G 9.1.2.3-6		49.02583	122.3261	George Siemens	07-Apr-80	225	175	152	NA	152	162	0	140	160	73	63	225	85	65	18-Jun-90	69.11	155.89	250	NA	ERR	NA	Oso	Yes	BCME/USG	Aquitard consists of tight sand and gravel, clay and till. Basal aquitard silt and clay.
092G 9.1.2.4-3		49.02222	122.3131		01-Jan-70	215	183	183	NA			92	132				123	83	NE	19-Jun-90	91.2	123.8	NA	NA	ERR	NA	Oso	Yes	BCME/USG	Aquitard is till blue clay.
092G 9.1.3.3-0		49.04167	122.38	Matsqui Municipality	01-Sep-70	180	52	25	NA	25	35	0	11	52	155	145	180	169	128	13-Jun-90	8.19	171.81	331	NA	ERR	MUN	Oso	Yes	BCME/USG	Aquitard is till at surface. TDS=126; pH=6.2; referred to as south Mt. Lehman well
092G 9.1.3.3-2		49.04	122.3842	Karl Arndt	23-Nov-79	183	49	44	NA	44	49	NE	NE	NE	139	134	NE	NE	NE	13-Jun-90	13.87	169.13	20	NA	ERR	DOM	Oso	Yes	BCME/USG	Tight gravel overlying water bearing sand
092G 9.1.3.4-2		49.0425	122.3656			180	45		NA	41	45	NE	NE	NE	139	135	NE	NE	NE	14-Jun-90	17.05	162.95	NA	NA	ERR	DOM	Oso	Yes	BCME/USG	Sand and gravel
092G 9.1.3.4-3		49.03778	122.3592	Tony Gill	25-Jul-85	195	84	75	NA	75	85	NE	NE	NE	120	110	NE	NE	NE	14-Jun-90	30.42	164.58	NA	NA	ERR	DOM	Oso	Yes	RCME/USG	Sand and gravel
092G 9.2.1.2-9		49.00917	122.2744	BCMOE Obs. Well 272	01-Feb-82	45	119	111	6	111	119	NE	NE	NE	-66	-74	NE	NE	NE	18-Jun-90	18.63	26.37	NA	NA	ERR	TW	Oso	Yes	BCME/USG	120' of sand and gravel
092G 9.2.1.3-4		49.01611	122.2756	BCMOE Obs. Well 274	01-Feb-82	150	220	218	6	210	218	NE	NE	NE	-60	-68	NE	NE	NE	18-Jun-90	135.08	14.92	NA	NA	ERR	TW	Oso	Yes	BCME/USG	Multiple water level measurements. Groundwater elevation is inconsistent with surrounding wells.
092G 9.2.1.3-4		49.01722	122.2872		01-Mar-73	175	87			NA	NA	38	49				137	126	NE	18-Jun-90	58.62	116.38	23	0	ERR	HATCH	Oso	Yes	BCME/USG	Multiple water level measurements. Aquitard is described as compact silty sand w/ gravel
092G 9.2.1.4-2		49.02306	122.2725	Fraser Val. Hatchery No. 3	02-Apr-73	100	251	155	6	155	160	NE	NE	171	-55	-60	NE	NE	-71	18-Jun-90	42.54	57.46	NA	NA	ERR	HATCH	Oso	Yes	BCME/USG	Makes lots of water 121-166' bgs. Good control for basal aquitard. Penetrates 80' of clay.
092G 9.2.1.4-2		49.02	122.2725	Fraser Val. Hatchery No. 1	01-May-73	90	320		6	NA	NA	NE	NE	NE	NA	NA	NE	NE	NE	18-Jun-90	38.21	51.79	NA	NA	ERR	HATCH	Oso	Yes	BCME/USG	Partial log only
092G 9.2.1.4-5		49.0325	122.3147			230	88			NA	NA	10	45	NE	NA	NA	220	185	NE	03-Jun-77	63	167	NA	NA	ERR	NA	Oso	Yes	BCME/USG	Aquitard is till.
092G 9.2.1.4-9		49.01944	122.2725	Fraser Val. Hatchery No. 4	01-Jan-80	77.32	299	119.42	20	119.42	265.5	NE	NE	NE	-42.1	-188.18	NE	NE	NE	NA	37.73	39.59	1775	33	53.787879	HATCH	Oso	Yes	BCME/USG	No aquitard. Not consistant with other 9.2.1.4-23
092G 9.2.1.1-3		49.01	122.2781	District of Abbotsford	07-Oct-81	50	112	112	8	95.8	112	108	NE	NE	-45.8	-62	-58	NE	NE	18-Jun-90	24.8	25.2	NA	NA	ERR	MON	Oso	Yes	BCME/USG	Aquitard is till.
092G 9.2.1.1-3		49.01	122.2789	District of Abbotsford	23-Nov-82	50	148	133	18	114	133	93.72	105.6		-64	-83	-43.72	-55.6	NE	28-Dec-82	5	45	1084	74.58	14.534728	MON	Oso	Yes	BCME/USG	Aquitard is till. TDS=148 mg/l, pH=8.0; Consultants report available.
092G 9.2.2.1-03		49.00278	122.2442		01-Sep-75	30	78	NA	NA	NA	NA	0	56	NE	NA	NA	30	-26	NE	19-Jun-90	3.59	26.41	200	NA	ERR	NA	Oso	Yes	BCME/USG	Sumas valley confined. Confining layer is silt and clay.
092G 9.2.2.3-11		49.01833	122.2308	J. Geldermen	13-Apr-82	32	65	44	8	44	65	0	42	NE	-12	-33	32	-10	NE	19-Jun-90	5.16	26.84	400	NA	ERR	IRR	Oso	Yes	BCME/USG	Sumas valley confined. Confining layer is silt.
092G 9.2.3.1-32		49.02778	122.2931	Ephoney	01-Sep-82	210	90	85	6	85	90	14	57	NE	125	120	196	153	NE	19-Jun-90	58.33	151.67	20	NA	ERR	DOM	Oso	Yes	BCME/USG	Aquitard is silty clay and till.
092G 9.3.1.2-2		49.08056	122.3636			375	157	NA	NA	111	NA	0	112	157	264	NA	375	263	218	14-Jun-90	84.8	290.2	NA	NA	ERR	NA	Oso	Yes	BCME/USG	Aquitard is hardpan, clay and sand. Aquifer is fine sand.
092G 9.3.1.2-2		49.05278	122.3603			215	125	NA	NA	NA	NA	NE	NE	125	NA	NA	NE	NE	90	18-Jun-90	38.21	176.79	NA	NA	ERR	NA	Oso	Yes	BCME/USG	Gravel over clay at 125 ft?

ABBREVIATIONS:

NA- INFORMATION NOT AVAILABLE
NE - UNIT NOT ENCOUNTERED DURING DRILLING

IRR - IRRIGATION
DOM - DOMESTIC
TW - TEST WELL
MUN - MUNICIPAL SUPPLY
IND - INDUSTRIAL
HATCH - FISH HATCHERY

BCME - BRITISH COLUMBIA MINISTRY OF ENVIRONMENT
USGS - UNITED STATES GEOLOGICAL SURVEY LENS STUDY
K - KAHLE (1990)
DOE - DEPARTMENT OF ECOLOGY WATER WELL REPORT
G - GOLDER ASSOCIATES (1992)
RN - ROBINSON AND NOBLE

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

KEY TO 40 ACRE SUBSECTION DESIGNATION - WASHINGTON WELLS

APPENDIX B

WASHINGTON STATE DEPARTMENT OF ECOLOGY LETTER OF ACCEPTANCE

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
P.O. Box 47600 • Olympia, Washington 98504-7600
(206) 407-6000 • TDD Only (Hearing Impaired) (206) 407-6006

RECEIVED
DEC 21 1995

December 13, 1995

Mr. David Davidson
City of Sumas
Post Office Box 9
Sumas, WA 98295

Re: Wellhead Protection Plan

Dear Mr. Davidson:

Staff from Ecology's Northwest Regional Office and from Ecology's Headquarters in Olympia reviewed the draft Wellhead Protection Plan for the city of Sumas and found no substantial issues. Therefore, the plan has been accepted as fulfilling the requirements of wellhead protection planning and the requirements identified in the grant scope of work.

Please proceed with making copies of the final report.

If you have any questions, please call me at (360) 407-6551

Sincerely,

William A. Hashim

William A. Hashim, Project Manager
Financial Management Section
Water Quality Program

WAH:dp