

Ground-Water Quality Data from the Abbotsford-Sumas Aquifer of Southwestern British Columbia and Northwestern Washington State, February 1997

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CONTENTS

Abstract.....	1
Introduction	2
Purpose and scope	2
Description of the aquifer	2
Sample collection and analysis.....	4
Site selection.....	4
Water-quality constituents	4
Sample collection and processing procedures	4
Laboratory procedures	15
Quality assurance.....	16
Quality-assurance/quality-control samples.....	16
Data quality assessment.....	16
Water-quality results	20
Nutrients, common ions, and trace elements	20
Pesticides and volatile organic compounds	21
Chlorofluorocarbons	21
Summary.....	22
References cited.....	23
Appendix	25

FIGURE

1. Map showing location of wells sampled in the Abbotsford-Sumas aquifer, February 1997..... 3

TABLES

1. Water-level and well construction information of sampled wells..... 5
2. Field measurements, common ions, nutrients, and trace elements measured in filtered ground-water samples collected from wells in the Abbotsford-Sumas aquifer, February 1997..... 6
3. Volatile organic compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life
4. Pesticide compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life
5. Volatile organic compounds and pesticides detected in samples of shallow ground water from the transboundary region of the Abbotsford-Sumas aquifer, February 1997.....
6. Field measurements and concentrations of inorganic constituents in transboundary ground water from the Abbotsford-Sumas aquifer
7. Concentration of chlorofluorocarbons in ground-water samples and calculated equilibrium vapor phase concentration

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km ²)	0.3861	square mile
liter (L)	0.2642	.gallon

Temperature: To convert temperature given in this report in degrees Celsius (°C) to degrees Fahrenheit (°F), use the following equation: °F = 9/5 °C + 32.

Sea Level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Elevation: In this report, “elevation” is measured in meters above sea level.

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ABSTRACT

Ground-water quality and hydrogeologic data were collected from nine wells in the Abbotsford-Sumas aquifer near the international boundary separating Canada and the United States. The samples were collected to provide detailed information on the concentrations of chemical constituents in ground water moving from Canada to the United States. Samples were analyzed for a selection of common ions, nutrients, trace elements, pesticides, and volatile organic compounds including three chlorofluorocarbons used to estimate residence times of ground water. The concentrations of nitrate were greater than 10 milligrams per liter in seven of nine wells exceeding criteria for both Canadian and United States drinking water guidelines and standards, respectively. The concentrations of common ions, trace elements, and other nutrients were generally small. Twenty-three pesticides and volatile organic compounds were detected in the ground water. The concentrations of these organic compounds ranged from 0.01 to 23 micrograms per liter, which were below drinking water guidelines or standards. Three chlorofluorocarbons were detected in these ground-water samples. Concentrations of chlorofluorocarbons were generally much greater than would be useful to provide reliable estimates of ground-water residence time.

RÉSUMÉ

Des données concernant la qualité des eaux souterraines et des données hydrogéologiques ont été recueillies à partir d'échantillons prélevés dans neuf puits plongeant dans la nappe aquifère d'Abbotsford-Sumas, près de la frontière canado-américaine. Les échantillons ont été prélevés pour déterminer avec précision la concentration des produits chimiques contenus dans les eaux souterraines qui passent du Canada aux États-Unis. On a mesuré dans ces échantillons un certain nombre d'ions communs, de nutriments, d'oligo-éléments, de pesticides et de composés organiques volatiles, dont trois chlorofluorocarbones utilisés pour estimer le temps de séjour de l'eau souterraine.

La concentration de nitrates s'est avérée supérieure à 10 milligrammes par litre dans sept des neuf puits, ce qui dépasse les directives canadiennes et les normes américaines en matière d'eau potable. La concentration des ions communs, des oligo-éléments et des autres nutriments était en générale faible. Vingt-trois pesticides et composés organiques volatiles ont d'autre part été détectés dans les échantillons. La concentration de ces composés organiques variait entre 0,01 et 23 microgrammes par litre, au-dessous de la limite imposée par les directives et les normes en matière d'eau potable. Trois chlorofluorocarbones ont été détectés mais leur concentration était en général trop grande pour que l'on puisse les utiliser pour estimer de façon fiable le temps de séjour de l'eau souterraine.

INTRODUCTION

The Abbotsford-Sumas aquifer is bisected by the international boundary between the Province of British Columbia, Canada, and the State of Washington, United States of America (fig. 1). In this area, the Abbotsford-Sumas aquifer is the most extensively used aquifer on both sides of the international boundary. It supplies water for domestic, municipal, agricultural, and industrial purposes for residents of both countries. Residents of Abbotsford and Sumas, as well as most rural residents in the area, obtain their water from this aquifer. During peak water demands, the aquifer currently supplies water to over 115,000 people. In addition, the aquifer provides the majority of baseflow to several fish rearing tributaries of the Nooksack, Sumas, and Fraser Rivers.

Land use over most of the aquifer is largely agricultural. Poultry and raspberry production are the predominant agricultural activities over the Canadian side of the aquifer while dairy and raspberry production are the major activities over the United States side of the aquifer. Other agricultural activities include corn, potato, and swine production. Urban development and light industry are centered around the Cities of Abbotsford, Lynden, and Sumas. Rural residential housing is increasing throughout the area.

The quality of ground water in the Abbotsford-Sumas aquifer is a concern to residents and government agencies of both Canada and the United States. Previous investigations have identified nitrate contamination and the presence of selected pesticides in ground water of the Abbotsford-Sumas aquifer at a number of locations on both sides of the international boundary (Liebscher and others, 1992; Erickson and Norton, 1990; Cox and Kahle, 1999). Information was lacking on the occurrence and concentrations of a broad spectrum of other organic compounds and water-quality constituents in ground water flowing across the boundary.

Purpose and Scope

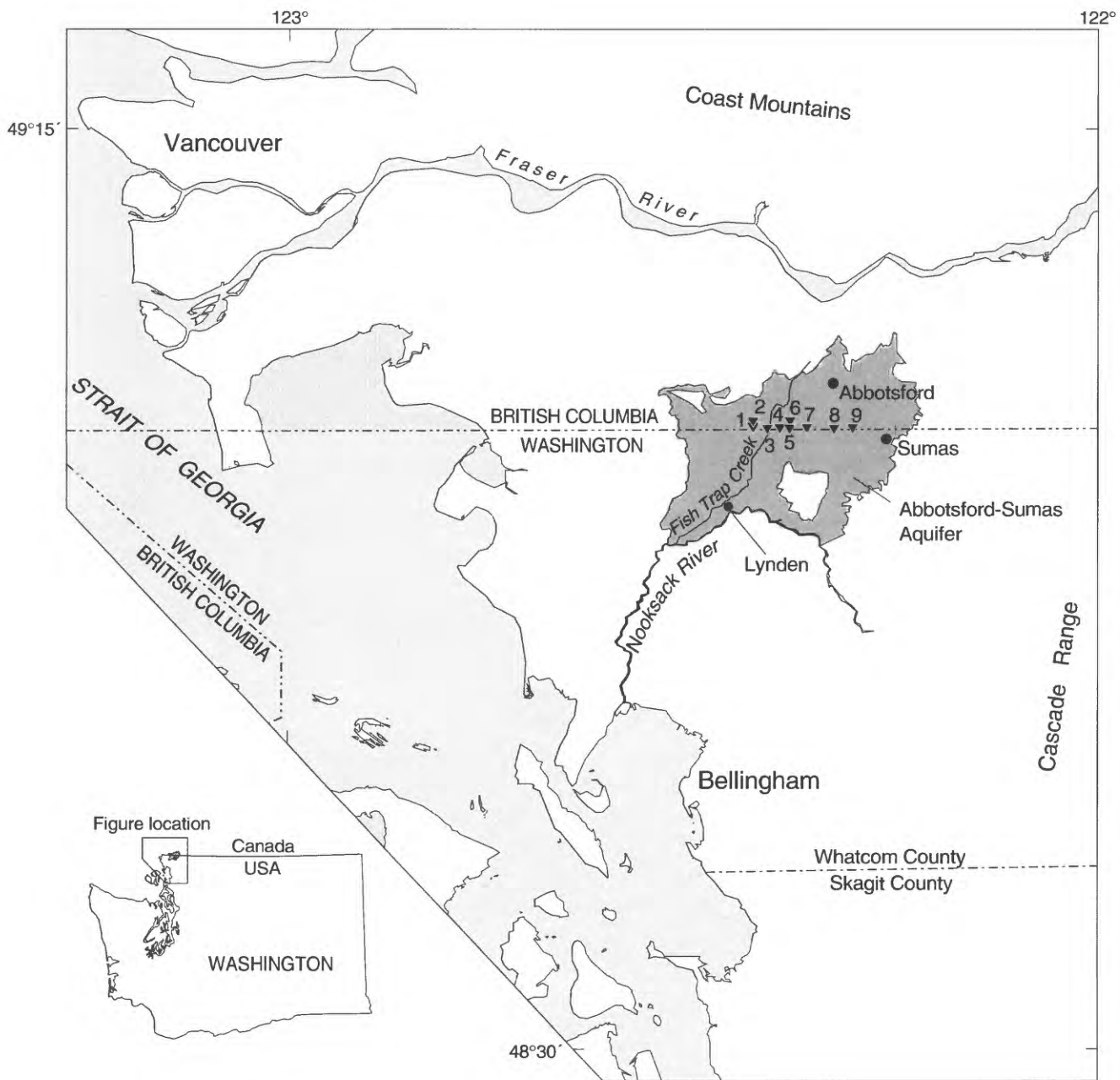
The objective of this investigation was to determine if selected organic compounds and trace elements were present in a single set of ground-water samples collected from the transboundary area of the Abbotsford-Sumas aquifer. This report presents data from 10 samples of ground water collected from 9 water-table

wells located near the boundary between Canada and the United States from February 3 to February 7, 1997. The data were collected jointly by the U.S. Geological Survey (USGS) and Environment Canada (EC), utilizing sampling and analytical techniques developed by the USGS to accurately measure low concentrations of organic compounds and trace elements in ground water.

Description of the Aquifer

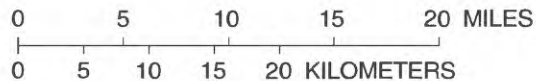
The Abbotsford-Sumas aquifer is a surficial aquifer, located from the City of Abbotsford, British Columbia, to Lynden, Washington (fig. 1). The Abbotsford-Sumas aquifer is part of a larger surficial aquifer that extends throughout much of the Nooksack and Fraser River Lowland. The aerial extent of the Abbotsford-Sumas aquifer is approximately 161 square kilometers (62 square miles) and is roughly bisected by the Canadian-United States boundary. Ground water generally flows southerly, moving across the international boundary from Canada to the United States (Liebscher and others, 1992; Cox and Kahle, 1999). Recharge to the aquifer is primarily from direct precipitation, which occurs predominantly from October to May. Mean annual precipitation varies from about 100 centimeters (40 inches) near Lynden to 165 centimeters (65 inches) near Abbotsford. Discharge from the aquifer is by pumping and seepage to streams, most notably Fishtrap Creek and the Nooksack River (fig. 1).

The Abbotsford-Sumas aquifer is made up predominantly of uncompacted sands and gravels of a glacial outwash plain that are permeable and allow rapid infiltration. Lenses of fine-grain sediments are commonly found throughout the aquifer resulting in complex ground-water flow paths. The aquifer is underlain by an extensive fine-grain glaciomarine deposit that is referred to in Canada as the Fort Langley clays, (Halstead, 1986) and in the United States as the Everson Glacio-Marine Drift (Easterbrook, 1976). The aquifer is typically unconfined and ranges from 0 to 65 meters (0 to 213 feet) thick. The aquifer is thickest in the northeastern part of the aquifer where glacial terminal moraine deposits are incorporated within the outwash deposits thickening the aquifer and resulting in semiconfined conditions at some locations. The water table is generally from 3 to 25 meters below land surface in the transboundary area.



EXPLANATION

▼² Well sampled for ground-water quality



Map Number	Well Name	National Water Information System Site Identifier
1	91-13	490023122252902
2	91-15	490023122252901
3	FTC-1-24	490009122243102
4	ABB5	490020122213201
5	94-LEH	490010122252901
6	BCME-B-20	49003112225301
7	ABB2	490020122213201
8	ABB4	490011122193201
9	94-SR-29	490011122181001

Figure 1. Location of wells sampled in the Abbotsford-Sumas aquifer, February, 1997.

SAMPLE COLLECTION AND ANALYSIS

Site Selection

Ground-water samples were collected from nine existing monitoring wells screened in the Abbotsford-Sumas aquifer and located in Canada within 400 meters of the international boundary (fig. 1). The criteria for selection of wells for sampling included: (1) wells located along and close to the international boundary; and (2) existing water-table wells completed in the Abbotsford-Sumas aquifer. Six wells were within 50 meters north of the international boundary. The other wells, BCME-B-20, 91-13, and 91-15, were located about 400 meters north of the boundary. Wells with shallow depth to water were selected, because the potential for contamination was thought to be greatest near the water table. Well 94-SR-29, which is screened about 16 meters below the water table, was also selected because ground water from the area near this well flows toward water-supply wells used by the City of Sumas, Wash. (Associated Earth Sciences Inc., 1996).

All wells were constructed of PVC plastic pipe, 5.1 centimeters (2 inches) in diameter. The length of the well screen for four of the observation wells was 1.51 meters (5 feet); four other wells had screens that were 1 meter (3.3 feet) in length. The remaining well, 94-LEH, was screened from a depth of 4.6 to 21.3 meters (15 to 70 feet). However, prior to sampling, a temporary 0.5-meter (1.6 feet) cellulose packer was installed from 5.5 to 6 meters below land surface so that only the upper 1 meter of the well screen was open to the aquifer while water was being pumped from the well. Generally, the static water level in wells was near the screened interval. Well-construction and water-level data collected prior to sampling are listed in table 1. Drillers' descriptions of lithology encountered while drilling the wells are included in the appendix.

Water-Quality Constituents

The ground-water samples were collected during the winter season because seasonal variations in ground-water nitrate concentrations in the Abbotsford-Sumas aquifer have been observed to be larger during the winter (Dasika, 1996). It is likely that other water-quality constituents related to land-use activities would also be largest in the winter.

Ground-water samples from all wells were analyzed in the field at the time of sampling to determine the concentration of dissolved oxygen, pH, specific conductance, and alkalinity of a filtered water sample. Samples collected in polyethylene or glass bottles were sent to the National Water Quality Laboratory (NWQL), in Arvada, Colo., for laboratory analysis of common ions, nutrients, dissolved organic carbon, trace elements, volatile organic compounds (VOCs), and pesticides. A listing of constituents and minimum reporting levels (MRLs) is presented in table 2 for field parameters, common ions, nutrients, and trace elements. An alphabetical listing of the VOCs and pesticides that were analyzed, their chemical names, common names, Chemical Abstract Services registry numbers, MRLs, and drinking water standards or guidelines from the U.S. Environmental Protection Agency and Health Canada is presented in tables 3 and 4. Water-quality data from these analyses are stored in the USGS National Water Information System (NWIS). Site identifiers used to locate information in NWIS are shown in figure 1.

Additional samples from seven wells were sent to the USGS Chlorofluorocarbon Laboratory in Reston, Virg., for determination of the concentrations of three chlorofluorocarbon (CFC) compounds: trichlorofluoromethane, CFC-11; dichlorodifluoromethane, CFC-12; and 1,1,2-trichloro-1,2,2-trifluoroethane, CFC-113. In some instances concentrations of these compounds have been shown to be useful in determining when ground water was recharged and thereby provide an estimate of the ground-water residence times (Busenberg and Plummer, 1992).

Sample Collection and Processing Procedures

Sample collection procedures followed the protocols and guidelines established for the USGS National Water Quality Assessment (NAWQA) program to minimize sample contamination (Koterba and others, 1995). All sampling equipment used was dedicated to sampling ground water with low concentrations of organic and inorganic constituents. Equipment that came in contact with the samples during collection procedures, including the submersible pump, fittings, and water lines, were composed of either 316 Stainless Steel, Teflon® or copper. Copper tubing was used only in the collection of CFC samples where refrigeration-grade copper tubing was used

Table 1. Water-level and well construction information of sampled wells
[NWIS, National Water Information System]

Well name	91-15	91-13	FTC-1-24	ABB2	ABB4	ABB5	BCME- B-20	94- LEH	94- SR-29
Land surface altitude, meters (feet) above mean sea level	46.35* (152.0)	46.41 (152.2)	43.87 (143.9)	49.11 (161.0)	64.90 (212.9)	46.40 (152.2)	49.73 (163.1)	48.78 (160.0)	42.68 (140.0)
Well depth, meters (feet)	11.41 (37.4)	20.8 (68.2)	7.32 (24.0)	7.62 (25.0)	29.26 (96.0)	8.84 (29.0)	6.09 (20)	21.3 (68)	28.93 (95.0)
Screened interval, meters below land surface	8.23- 9.73	18- 19.5	6.4 7.32	6.62- 7.62	28.26- 29.20	7.84- 8.84	4.09- 6.09	4.57- 21.3	27.43- 28.93
Depth to ground water, February/97, meters (feet)	2.49 (8.17)	3.35 (11.0)	1.89 (6.19)	0.67 (2.21)	21.56 (70.71)	0.98 (3.23)	2.15 (7.06)	1.25 (4.10)	11.09 (36.37)
Distance from water level to top of screen interval, meters (feet)	5.73 (18.8)	14.33 (47.0)	5.43 (17.80)	5.95 (19.51)	6.92 (22.69)	7.86 (25.77)	0.85 (2.78)	3.35 (10.9)	13.41 (44.0)

* Metric unit, meters; English unit in feet in parentheses.

Table 2. Field measurements, common ions, nutrients, and trace elements measured in filtered ground-water samples collected from wells in the Abbotsford-Sumas aquifer, February 1997

[mg/L, milligrams per liter; µg/L, micrograms per liter. The filter size was 0.45 µm (micrometer, or micron). Ammonia, nitrate, and nitrite are reported as nitrogen, and orthophosphate is reported as phosphorus]

FIELD MEASUREMENTS ¹			
Constituent or physical property	Reporting units	Constituent or physical property	Reporting units
Temperature	Degrees C	pH	Standard unit
Specific Conductance	µs/cm	Dissolved oxygen	mg/L
Alkalinity	mg/L as CaCO ₃		

COMMON IONS AND NUTRIENTS			
Constituent of physical property	Minimum Reporting level (mg/L)	Constituent or physical property	Minimum Reporting level (mg/L)
Calcium	0.02	Nitrate plus nitrite, as N	0.05
Magnesium	0.01	Nitrite, as N	0.01
Sodium	0.2	Ammonia, as N	0.015
Potassium	0.1	Ammonia plus	
Chloride	0.1	organic nitrogen	0.02
Sulfate	0.1	Orthophosphate, as P	0.01
Fluoride	0.1	Phosphorus	0.01
Silica, as SiO ₂	0.01	Carbon, organic, total as C	0.01
Bicarbonate, as HCO ₃	0.01	Residue on evaporation	1
Ion balance	(percent) ²	Sum of dissolved constituents	1

TRACE ELEMENTS					
Element	Minimum Reporting level (µg/L)	Element	Minimum Reporting level (µg/L)	Element	Minimum Reporting level (µg/L)
Antimony	1	Chromium	1	Molybdenum	1
Aluminum	1	Cobalt	1	Nickel	1
Arsenic	1	Copper	1	Selenium	1
Barium	1	Iron	3	Silver	1
Beryllium	1	Lead	1	Uranium	1
Bromide	1	Manganese	1	Zinc	1
Cadmium	1	Mercury	0.1		

¹ Field parameters other than alkalinity, measured in unfiltered sample water.

² Ion balance is the (sum of the cations minus the sum of anion) / total sum of cations and anions; expressed as percent.

Table 3. Volatile organic compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life [$\mu\text{g/L}$, micrograms per liter; --, data not available]

Volatile organic compounds	Common or alternate name(s)	Chemical Abstract Services registry number	Minimum reporting level ($\mu\text{g/L}$)	U.S.		Canadian	
				drinking water standard or guideline ($\mu\text{g/L}$) ¹	drinking water standard or guideline ($\mu\text{g/L}$) ²	fresh water chronic protection of aquatic life ($\mu\text{g/L}$) ³	fresh water chronic protection of aquatic life ($\mu\text{g/L}$) ⁴
Acrylonitrile	--	107-13-1	2	6	--	--	--
<i>tert</i> -Amyl methyl ether	TAME	994-05-8	0.1	--	--	--	--
Benzene	--	71-43-2	0.05	5	5	370	--
Bromobenzene	Phenyl bromide	108-86-1	0.05	--	--	--	--
Bromochloromethane	Methylene chlorobromide	74-97-5	0.1	10	--	--	--
Bromodichloromethane	Dichlorobromomethane	75-27-4	0.1	100	--	--	--
Bromoethane	Vinyl bromide	593-60-2	0.1	--	--	--	--
Bromomethane	Methyl bromide	74-83-9	0.1	10	--	--	--
2-Butanone	Methylethylketone	78-93-3	5	--	--	--	--
<i>n</i> -Butylbenzene	1-phenylbutane	104-51-8	0.05	--	--	--	--
<i>sec</i> -Butylbenzene	2-phenylbutane	135-98-8	0.05	--	--	--	--
<i>tert</i> -Butylbenzene	2-methyl-2-phenylpropane	98-06-6	0.05	--	--	--	--
Carbon Disulfide	--	107-05-1	0.05	--	--	--	--
Chlorobenzene	Phenyl chloride	108-90-7	0.05	100	80	1.3	--
Chloroethane	Ethyl chloride	75-00-3	0.1	--	--	--	--
Chloroethene	Vinyl chloride	75-01-4	0.1	2	--	--	--
Chloromethane	Methyl chloride	74-87-3	0.2	3	--	--	--
2-Chloro-1-methylbenzene	<i>o</i> -Chlorotoluene	95-49-8	0.05	--	--	--	--
4-Chloro-1-methylbenzene	<i>p</i> -Chlorotoluene	106-43-4	0.05	--	--	--	--
3-Chloro-1-propene	--	107-05-1	0.1	--	--	--	--
Dibromochloromethane	--	124-48-1	0.1	100	--	--	--
Dibromomethane	Methylene bromide	74-95-3	0.1	--	--	--	--
1,2-Dibromo-3-chloropropane	DBCP	96-12-8	0.5	0.2	--	--	--
1,2-Dibromoethane	EDB	106-93-4	0.1	0.05	--	--	--
1,2-Dichlorobenzene	<i>o</i> -Dichlorobenzene	95-50-1	0.05	600	200	0.7	--

8 **Table 3.** Volatile organic compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life--Continued

Volatile organic compounds	Common or alternate name(s)	Chemical Abstract Services registry number	Minimum reporting level (µg/L)	U.S.	Canadian	U.S.	Canadian
				drinking water standard or guideline (µg/L) ¹	drinking water standard or guideline (µg/L) ²	fresh water chronic criteria for protection of aquatic life (µg/L) ³	fresh water chronic criteria for protection of aquatic life (µg/L) ⁴
1,3-Dichlorobenzene	<i>m</i> -Dichlorobenzene	541-73-1	0.05	600	--	--	150
1,4-Dichlorobenzene	<i>p</i> -Dichlorobenzene	106-46-7	0.05	75	5	--	26
<i>trans</i> -1,4-Dichloro-2-butene	--	110-57-6	5.0	--	--	--	--
Dichlorodifluoromethane	CFC-12	75-71-8	0.2	1,000	--	--	--
1,2-Dichloroethane	Ethylene dichloride	107-06-2	0.05	5	5	--	100
<i>cis</i> -1,2-Dichloroethene	<i>cis</i> -DCE	156-59-4	0.05	70	5	--	100 total DCE
<i>trans</i> -1,2-Dichloroethene	<i>trans</i> -DCE	156-60-5	0.05	100	--	--	100 total DCE
1,1-Dichloroethane	Ethylidene chloride	75-34-3	0.05	--	--	--	--
1,1-Dichloroethene	--	75-35-4	0.1	7	--	--	--
Dichloromethane	Methylene chloride	75-09-2	0.1	5	50	--	98
1,2-Dichloropropane	1,2-DCP	78-87-5	0.05	5	--	--	--
1,3-Dichloropropane	--	142-28-9	0.2	--	--	--	--
1,1-Dichloropropene	--	563-58-6	0.2	--	--	--	--
2,2-Dichloropropene	--	594-20-7	0.05	--	--	--	--
<i>cis</i> -1,3-Dichloropropene	--	100-61-015	0.1	10	--	--	--
<i>trans</i> -1,3-Dichloropropene	--	100-61-026	0.1	10	--	--	--
Diethylether	Ethyl ether	60-29-7	0.1	--	--	--	--
Diisopropylether	--	108-20-3	0.1	--	--	--	--
Ethylbenzene	--	100-41-4	0.05	700	2.4	--	90
Ethyl- <i>t</i> -butyl ether	ETBE	637-92-3	0.1	--	--	--	--
2-Ethyl Toluene	<i>o</i> Ethyl Toluene	611-14-3	0.05	--	--	--	--
Ethyl Methacrylate	--	97-63-2	1.0	--	--	--	--
Hexachloroethane	--	67-72-1	0.05	--	--	--	--
Hexachlorobutadiene	HCBD	87-68-3	0.2	--	--	--	0.1
2-Hexanone	--	591-78-6	5.0	--	--	--	--
Iodomethane	Methyl iodide	74-88-4	--	0.5	--	--	--

Table 3. Volatile organic compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life--Continued

Volatile organic compounds	Common or alternate name(s)	Chemical Abstract Services registry number	Minimum reporting level (µg/L)	U.S.	Canadian	U.S.	Canadian
				drinking water standard or guideline (µg/L) ¹	drinking water standard or guideline (µg/L) ²	fresh water chronic protection of aquatic life (µg/L) ³	fresh water chronic protection of aquatic life (µg/L) ⁴
Isopropyl benzene	Cumene	98-82-8	0.05	--	--	--	--
<i>p</i> -Isopropyltoluene	<i>p</i> -Cymene	99-87-6	0.05	--	--	--	--
Methyl Acrylate	--	96-33-3	2	--	--	--	--
Methyl Acrylonitrile	--	126-98-7	2	--	--	--	--
Methyl <i>tert</i> -butyl ether	MTBE	163-40-44	0.1	20	--	--	--
Methylbenzene	Toluene	108-88-3	0.05	1,000	24	--	2
4-Methyl-2-Pentanone	Methyl isobutylketone	108-10-1	5.0	--	--	--	--
Methyl Methacrylate	--	80-62-6	1	--	--	--	--
Napthalene	--	91-20-3	0.2	--	--	--	--
2-Propanol	Acrolein	107-02-8	2	--	--	--	--
2-Propanone	Acetone	67-64-1	5	--	--	--	--
<i>n</i> -Propylbenzene	1-Phenylpropane	105-65-1	0.05	--	--	--	--
Tetrachloroethene	Perchloroethylene, PCE	127-18-4	0.2	5	--	--	111
Tetrachloromethane	Carbon tetrachloride	56-23-5	0.05	5	5	--	13.3
Tetrahydrofuran	--	109-99-9	5	--	--	--	--
1,1,1,2-Tetrachloroethane	--	630-20-6	0.05	70	--	--	--
1,1,2,2-Tetrachloroethane	--	79-34-5	0.1	--	--	--	--
1,2,3,5-Tetramethylbenzene	Isodurene	527-53-7	0.05	--	--	--	--
1,2,3,4-Tetramethylbenzene	Preritene	488-23-3	0.05	--	--	--	--
Tribromomethane	Bromoform	75-25-2	0.2	100	--	--	--
1,2,3-Trichlorobenzene	--	87-61-6	0.2	--	--	--	8.0
1,2,4-Trichlorobenzene	--	120-82-1	0.2	70	--	--	24.0
Trichloroethene	TCE	79-01-6	0.2	5	50	--	21
Trichlorofluoromethane	CFC-11	75-69-4	0.1	2,000	--	--	--
Trichloromethane	Chloroform	67-66-3	0.05	100	--	--	1.8
1,1,1-Trichloroethane	Methyl chloroform, TCA	71-55-6	0.05	200	--	--	--

Table 3. Volatile organic compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life--Continued

Volatile organic compounds	Common or alternate name(s)	Chemical Abstract Services registry number	Minimum reporting level (µg/L)	U.S. drinking water standard or guideline (µg/L) ¹	Canadian drinking water standard or guideline (µg/L) ²	U.S. fresh water chronic criteria for protection of aquatic life (µg/L) ³	Canadian fresh water chronic criteria for protection of aquatic life (µg/L) ⁴
1,1,2-Trichloroethane	Vinyl trichloride	79-00-5	0.2	5	--	--	--
1,1,2-Trichloro-1,2,2-trifluoroethane	CFC-113	76-13-1	0.05	--	--	--	--
1,2,3-Trichloropropane	--	96-18-4	0.2	40	--	--	--
1,2,3-Trimethylbenzene	--	526-73-8	0.05	--	--	--	--
1,2,4-Trimethylbenzene	Pseudocumene	95-63-6	0.05	--	--	--	--
1,3,5-Trimethylbenzene	Mesitylene	108-67-8	0.2	--	--	--	--
Vinyl Acetate	--	108-05-4	5.0	--	--	--	--
Styrene	Vinyl benzene	100-42-5	0.2	100	--	--	72
<i>meta</i> & <i>para</i> Xylene	--	108-38-3	0.05	--	300	--	--
<i>ortho</i> Xylene	--	95-47-6	0.05	--	--	--	--

¹ Unless otherwise noted, guidelines from U.S. Environmental Protection Agency (1996).

² Unless otherwise noted guidelines from Health and Welfare Canada (1993).

³ Criteria for the protection of freshwater aquatic life are recommended maximum concentrations in water by National Academy of Sciences and National Academy of Engineers from Nowell and Resek (1994).

⁴ Guidelines for the protection of freshwater aquatic life are from Canadian Council of Ministers of the Environment (1993).

Table 4. Pesticide compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life [µg/L, micrograms per liter; U.S., United States; H, herbicide; I, insecticide; M, metabolite; --, no value]

Pesticide compound	Trade or common name(s)	Type of pesticide	Chemical Abstract Services registry number	Minimum reporting level (µg/L)	U.S. drinking water standard (µg/L) ¹	Canadian drinking water standard (µg/L) ²	U.S. fresh water chronic criteria for protection of aquatic life (µg/L) ³	Canadian fresh water chronic criteria for protection of aquatic life (µg/L) ⁴
Gas Chromatography/Mass Spectrometry analytical data								
Alachlor	Lasso	H	15972-60-8	0.002	2	--	--	--
Atrazine	AAtrex	H	1912-24-9	0.001	3	60	1	1.8
Azinphos-methyl	Guthion	I	86-50-0	0.001	--	20	--	0.01
Benfluralin	Balan, Benefin	H	1861-40-1	0.002	--	--	--	--
Butylate	Sutan +, Genate Plus	H	2008-41-5	0.002	350	--	--	--
Carbaryl ⁶	Sevin, Savit	I	63-25-2	0.003	700	90	0.02	0.2
Carbofuran ⁶	Furadan	I	1563-66-2	0.003	40	90	--	1.8
Chlorpyrifos	Lorsban/Dursban	I	2921-88-2	0.004	20	90	0.001	0.0035
Cyanazine	Bladex	H	21725-46-2	0.004	4 ¹	10	--	2
DCPA	Dacthal	H	1861-32-1	0.002	5,000	--	--	--
<i>p,p'</i> -DDE	none	M	72-55-9	0.006	8 ^{0.1}	--	--	--
Desethylatrazine ^{9,10}	none	M	6190-65-4	0.002	--	--	--	--
Diazinon	several	I	333-41-5	0.002	5 ^{0.6}	--	0.009	--
Dieldrin	Panoram D-31	I	60-57-1	0.001	8 ^{0.002}	20	--	0.004
2,6-Diethylalanine	none	M	579-66-8	0.003	--	--	--	--
Disulfoton	Di-Syston	I	298-04-4	0.017	5 ^{0.3}	--	0.05	--
EPTC	Eptam, Eradicane	H	759-94-4	0.002	--	--	--	--
Ethalfuralin	Sonalan, Curbit EC	H	55283-68-6	0.004	--	--	--	--
Ethoprop	Mocap	I	13194-48-4	0.003	--	--	--	--
Fonofos	Dyfonate	I	944-22-9	0.003	5 ¹⁰	--	--	--
<i>alpha</i> -HCH	none	M	319-84-6	0.002	8 ^{0.006}	--	--	--
<i>gamma</i> -HCH	Lindane	I	58-89-9	0.004	0.2	--	0.02	--
Linuron ⁶	Lorox, Linex	H	330-55-2	0.002	--	--	--	7
Malathion	several	I	121-75-5	0.005	200	190	0.008	--
Methyl parathion	Pennacp-M	I	298-00-0	0.006	5 ²	--	--	--

2 **Table 4.** Pesticide compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life--Continued

Pesticide compound	Trade or common name(s)	Type of pesticide	Chemical Abstract Services registry number	Minimum reporting level (µg/L)	U.S. drinking water standard (µg/L) ¹	Canadian drinking water standard (µg/L) ²	U.S. fresh water chronic criteria for protection of aquatic life (µg/L) ³	Canadian fresh water chronic criteria for protection of aquatic life (µg/L) ⁴
<u>Gas Chromatography/Mass Spectrometry analytical data--Continued</u>								
Metolachlor	Dual, Pennant	H	51218-45-2	0.002	70	50	--	7.8
Metribuzin	Lexone, Sencor	H	21087-64-9	0.004	5100	80	--	1
Molinate	Ordram	H	2212-67-1	0.004	--	--	--	--
Napropamide	Devrinol	H	15299-99-7	0.003	--	--	--	--
Parathion	several	I	56-38-2	0.004	--	50	0.0004	--
Pebulate	Tillam	H	1114-71-2	0.004	--	--	--	--
Pendimethalin	Prowl, Stomp	H	40487-42-1	0.004	--	--	--	--
cis-Permethrin	Ambush, Pounce	I	57608-04-5	0.005	--	--	--	--
Phorate	Thimet, Rampart	I	298-02-2	0.002	--	2	--	--
Prometon	Pramitol	H	1610-18-0	0.018	5100	--	--	--
Pronamide	Kerb	H	23950-58-5	0.003	550	--	--	--
Propachlor	Ramrod	H	1918-16-7	0.007	590	--	--	--
Propanil	Stampede	H	709-98-8	0.004	--	--	--	--
Propargite	Comite, Omite	I	2312-35-8	0.013	--	--	--	--
Simazine	Aquazine, Princep	H	122-34-9	0.005	4	10	--	10
Tebuthiuron	Spike	H	34014-18-1	0.01	5500	--	--	1.6
Terbacil	Sinbar	H	5902-51-2	0.007	590	--	--	--
Terbufos	Counter	I	13071-79-9	0.013	50.9	1	--	--
Thiobencarb	Bolero	H	28249-77-6	0.002	--	--	--	--
Triallate	Far-Go	H	2303-17-5	0.001	--	230	--	0.24
Trifluralin	Treflan, Trilin	H	1582-09-8	0.002	55	45	--	0.2
<u>High-Performance Liquid Chromatography analytical data</u>								
2,4-D	several	H	94-75-7	0.15	70	100	3	4
2,4-DB	none	I	94-82-6	0.24	--	--	--	--

Table 4. Pesticide compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life--Continued

Pesticide compound	Trade or common name(s)	Type of pesticide	Chemical Abstract Services registry number	Minimum reporting level (µg/L)	U.S. drinking water standard (µg/L) ¹	Canadian drinking water standard (µg/L) ²	U.S. fresh water chronic criteria for protection of aquatic life (µg/L) ³	Canadian fresh water chronic criteria for protection of aquatic life (µg/L) ⁴
<u>High-Performance Liquid Chromatography analytical data--Continued</u>								
2,4,5-T	several	H	93-76-5	0.035	570	280	--	--
2,4,5-TP ⁹	Silvex	H	93-72-1	0.021	50	--	1.4	--
3-Hydroxy-carbofuran ⁹	none	M	1563-38-8	0.014	--	--	--	--
Acifluorfen	Blazer	H	50594-66-6	0.035	81	--	--	--
Aldicarb ^{9,10}	Temik	I	116-06-3	0.55	7	9	--	1
Aldicarb sulfone ^{9,10}	Standak	M	1646-88-4	0.1	7	--	--	--
Aldicarb sulfoxide ^{9,10}	none	M	1646-87-3	0.021	7	--	--	--
Bentazon	Basagran	H	25057-89-0	0.014	200	--	--	--
Bromacil	Hyvar, Urox B	H	314-40-9	0.035	590	--	--	5.0
Bromoxynil	Buctril, Brominal	H	1689-84-5	0.035	--	5	--	5.0
Carbaryl ^{6,9}	Sevin, Savit	I	63-25-2	0.008	5700	90	--	0.2
Carbofuran ^{6,9}	Furadan	I	1563-66-2	0.12	40	90	--	1.8
Chloramben	Amiben, Vegiben	H	133-90-4	0.42	5100	--	--	--
Chlorothalamil ¹⁰	Bravo	F	1897-45-6	0.48	81.5	--	--	0.18
Clopyralid	Stinger, Lontrel	H	1702-17-6	0.23	--	--	--	--
Dacthal, mono-acid)	none	M	887-54-7	0.017	--	--	--	--
Dicamba	Banvel	H	1918-00-9	0.035	5200	120	200	10
Dichlorprop	2,4-DP, Seritox 50	H	120-36-5	0.032	--	--	--	--
Dinoseb	DNBP, Dinitro	H	88-85-7	0.035	7	10	--	0.05
Diuron ¹⁰	Karmex, Direx	H	330-54-1	0.02	510	150	1.6	--
DNOC	Trifocid, Elgetol 30	I, F, H	534-52-1	0.42	--	--	--	--
Fenuron	Beet-Kleen	H	101-42-8	0.013	--	--	--	--
Fluometuron	Flo-Met, Cotoran	H	2164-17-2	0.035	590	--	--	--
Linuron ⁶	Lorox, Linex	H	330-55-2	0.018	--	--	--	7
MCPA	Metaxon, Kilssem	H	94-74-6	0.17	510	--	--	--

Table 4. Pesticide compounds analyzed in ground water from the Abbotsford-Sumas aquifer, February 1997, and minimum reporting levels, drinking water standards, and freshwater criteria for protection of aquatic life--Continued

Pesticide compound	Trade or common name(s)	Type of pesticide	Chemical Abstract Services registry number	Minimum reporting level (µg/L)	U.S. drinking water standard (µg/L) ¹	Canadian drinking water standard (µg/L) ²	U.S. fresh water chronic criteria for protection of aquatic life (µg/L) ³	Canadian fresh water chronic criteria for protection of aquatic life (µg/L) ⁴
High-Performance Liquid Chromatography analytical data--Continued								
MCPB	Can-Trol, Thistrol	H	94-81-5	0.14	--	--	--	2.6
Methiocarb	Grandslam, Mesuroil	I	2032-65-7	0.026	--	--	--	--
Methomyl	Lannate, Nudrin	I	16752-77-5	0.017	5 ²⁰⁰	--	--	--
Neburon	Neburex, Noruben	H	555-37-3	0.015	--	--	--	--
Norflurazon	Evital, Solicam	H	27314-13-2	0.024	--	--	--	--
Oryzalin ¹⁰	Surflan	H	19044-88-3	0.31	--	--	--	--
Oxamyl ⁹	Vydate	I	23135-22-0	0.018	200	--	--	--
Picloram ⁹	Tordon	H	1918-02-1	0.05	500	190	--	29
Propham	Chem-Hoe, IPC	H	122-42-9	0.035	5 ¹⁰⁰	--	--	--
Propoxur	Baygon	I	114-26-1	0.035	--	--	--	--
Triclopyr ⁹	Garlon, Grazon	H	55335-06-3	0.25	--	--	--	--

¹ Unless otherwise noted, guidelines from USEPA October 1996 drinking water regulations and health advisory EPA 822-B-96-002.

² Unless otherwise noted guidelines from Guidelines for Canadian Drinking Water Quality, fifth edition 1993 Health and Welfare Canada: Canada Communication Group-Publishing, Ottawa, Canada K1A-059.

³ Criteria for the protection of freshwater aquatic life are recommended maximum concentrations in water by National Academy of Sciences and National Academy of Engineers from Nowell and Resek (1994).

⁴ Guidelines for the protection of freshwater aquatic life are Canadian Water Quality Guidelines from Canadian Council of Ministers of the Environment (1993).

⁵ U.S. Environmental Protection Agency lifetime-health advisory for a 70-kilogram adult, from Nowell and Resek (1994).

⁶ Analyzed by both gas chromatography/mass spectrometry and high-performance liquid chromatography methods.

⁷ Interim guidelines for the protection of freshwater aquatic life are Canadian Water Quality Guidelines from Canadian Council of Ministers of the Environment (1993).

⁸ U.S. Environmental Protection Agency risk-specific dose health advisory associated with a cancer risk of 10-6 (one in a million), from Nowell and Resek (1994).

⁹ Pesticide target analyte is heat and light sensitive and therefore susceptible to degradation. This may result in poor overall recovery and precision (NAWQA/NWQL Quality Assurance Committee for the Schedule 2050/2051 Pesticide Analysis Method, written commun., 1995).

¹⁰ Low recovery of matrix spike (20-60 percent) indicates potential for false negative results.

between the submersible pump and the sampling apparatus. All field supplies, bottles, reagents, and surrogates that were used for sample collection were tested for contamination and approved by either the manufacturer or the USGS National Water Quality Laboratory.

Field instruments were calibrated at the beginning of each day and between every second sampling site. At each site, water levels and down-hole water temperature were measured before installation of submersible-pump sampling equipment. The sampling pump was positioned at or just above the well's screened interval and water was pumped at a rate of about 4 to 8 liters per minute. Each well was initially pumped to remove at least three casing volumes after which field parameters were monitored until stable readings of pH, specific conductance, temperature, and dissolved oxygen were obtained. These parameters were measured in a flow-through chamber so that ground water was not exposed to the atmosphere prior to monitoring. Stable readings were defined as variations about a central value of less than or equal to 0.1 pH units, 0.2°C (degrees Celsius) for temperature, plus or minus 3 percent for specific conductance, and 0.3 mg/L (milligram per liter) for dissolved oxygen between successive readings 3 minutes apart. Dissolved oxygen readings of less than 1 mg/L were confirmed using a Chemetrix rhodazine dye method (White and others, 1990). Field alkalinity of a filtered sample was determined at each site by incremental titrations.

Unfiltered water samples were collected for analysis of volatile organic compounds in 40-milliliter septum vials, which were filled slowly to avoid aeration and then preserved with one to three drops of hydrochloric acid to achieve a pH of from 1.7 to 2.0. Pesticide samples were filtered through a 0.7-micrometer glass fiber filter and field-extracted from the filtrate by pumping through solid-phase extraction cartridges as described by Shelton (1994) and Sandstrom and others (1992). Samples for analysis of trace elements, common ions, and nutrients were filtered using a 0.45-micrometer cellulose filter. Trace elements and cation samples were preserved with nitric acid to a pH of less than 2; samples for analysis of mercury were preserved with 10 milliliters of potassium dichromate. Samples for VOC, pesticide, nutrient, and organic carbon analysis were chilled to 4 degrees Celsius or less and shipped to the laboratory by overnight courier.

All samples received by the laboratory were analyzed within accepted holding times.

Following the collection of these samples, the submersible pump equipped with teflon discharge lines was decontaminated using 0.1 percent solution of Liquinox soap and deionized water following the general procedures described by Koterba and others (1995), however, the methanol rinse was omitted to minimize the potential for contamination of dissolved organic carbon samples. A second submersible pump with a discharge line made of refrigeration-grade copper tubing suitable for collecting CFC samples was installed in the well for collection of CFC samples. CFC samples were collected in triplicate using methods described by Busenberg and Plummer (1992).

Laboratory Procedures

Concentrations of common ions and trace elements were analyzed by inductively coupled plasma (ICP), with the exception of lead (analyzed by graphite furnace atomic absorption), mercury (analyzed by cold vapor atomic absorption), and chloride and sulfate (analyzed by ion-exchange chromatography). Minimum reporting levels and compounds quantified by these methods are listed in table 2. The analytical methods used are described further by Fishman (1993).

Concentrations of VOCs were determined by purge and trap gas chromatography with electron impact mass spectrometry (GC/MS) following U.S. Environmental Protection Agency (EPA) Method 524.2 (Rose and Schroeder, 1995; Connor and others, 1998). Minimum reporting levels and compounds quantified by this method are listed in table 3 along with corresponding United States and Canadian drinking water and freshwater guidelines (U.S. Environmental Protection Agency, 1996; Health and Welfare Canada, 1993; and Canadian Council of Ministers of the Environment, 1993). Pesticides were analyzed utilizing solid-phase extraction techniques and gas chromatography and mass spectrometry (GC/MS) analysis with selected ion monitoring as described by Werner and Johnson (1994), Zaugg and others (1995) and Werner and others (1996). Minimum reporting levels and compounds quantified by this method are listed in table 4. CFCs were analyzed by gas chromatography following procedures described by Busenberg and Plummer (1992).

QUALITY ASSURANCE

Procedures were followed to insure the collection of data with known and acceptable quality. These procedures included the use of non-contaminating sample collection techniques described in the previous section, the collection of quality assurance and control (QA/QC) samples, and review of laboratory data by laboratory and project personnel.

Quality-Assurance/Quality-Control Samples

Quality-control samples included two equipment-blank samples and one replicate sample of organic constituents collected as part of this study, and review of field-matrix spike data collected from a concurrent study. Laboratory QA/QC checks included the analysis of double blind reference materials, daily blanks, daily standards, daily instrument tuning, surrogate spike recovery, and other quality-control check samples as described by Pritt and Raese (1995). Analyte recovery and analytical precision and accuracy are described by Rose and Schroeder (1995), Werner and Johnson (1994), and Werner and others (1996).

Equipment blanks for VOCs were collected immediately before and after the 10 well-water samples were collected. Certified VOC-free water was used to process the equipment blanks. Laboratory grade deionized water was used to wash and decontaminate the equipment and was analyzed for VOCs, trace elements, and common ions prior to conducting field work. The VOC sample vials were precleaned and certified by the manufacturer to be free of VOCs; however, the minimum detection values shown on the certificate of analysis for the VOC sample vials was often larger than the minimum detection level reported for the analytical methods used by the NWQL. Equipment blanks for pesticides were collected immediately before, midway through the sampling, and after the 10 well-water samples were collected. The pesticide equipment-blank sample collected midway through this sampling was analyzed and contained no detectable concentrations of pesticides, as did the previous six pesticide equipment-blank samples obtained with this sampling equipment for other studies, thus no other pesticide equipment-blank samples were analyzed.

Short-term variability due to variations in sampling technique, variability in analytical technique, and short-term in-situ aquifer chemical variations

were assessed by the repeat sampling of one well (well 91-15) 3 days apart following the initial sample collection. Estimates of the bias and variability in the pesticide and VOC data caused by analyte degradation, the effects of ground-water matrix, and the analytical processes were assessed using data from two spike-replicate sample sets collected from a concurrent study which included the Abbotsford-Sumas aquifer. The spike-replicate sample sets were collected in September and December of 1996 as part of the National Water Quality Assessment (NAWQA) of the Puget Sound region. The sample sets were collected from shallow wells screened in glacial-outwash aquifers; one site located in the Abbotsford-Sumas aquifer and the other from a similar site about 200 kilometers south of the aquifer. In these samples, three replicate environmental samples were collected; known concentrations, typically 0.1 µg/L (microgram per liter) of many of the organic compounds were added to two of the replicate samples.

Data Quality Assessment

Review of quality-assurance data showed that overall, the majority of the 210 water-quality parameters examined showed little significant bias or variability; however, low concentrations of four VOCs and three trace elements were detected in equipment-blank samples indicating the occurrence of sampling or analytical bias for those constituents. All laboratory results are reported in tables 5, 6, and 7; results that may be affected by sampling or analytical bias are flagged with a "V". Field-matrix spike information (data not shown) showed low recoveries for three compounds not detected in the environmental samples and high recovery for one compound that was detected.

Three compounds (1-Naphthal, Dichlobenil, and Esfenvalerate) with matrix spike recoveries of less than 20 percent were removed from the analyte list. The concentration of Tebuthiuron, which showed a recovery greater than 140 percent, was flagged with the "V" code to indicate potential bias. Other organic compounds (Aldicarb, Aldicarb sulfone, Aldicarb sulfoxide, Chlorothalonil, Desethylatrazine, Diuron, and Oryzalin) that were not detected in the ground-water samples showed recoveries between 20 and 60 percent. A notation was added to the analyte list (table 4) indicating low recoveries and the potential for false-negative detections.

Table 5. Volatile organic compounds and pesticides detected in samples of shallow ground water from the trans-boundary region of the Abbotsford-Sumas aquifer, February 1997 (Complete analyte lists are in tables 3 and 4) [E, indicates some laboratory quantitative uncertainty and thus the value is flagged as estimated; V, indicates potential bias in environmental sample based on quality control data associated with environmental samples. All concentrations in micrograms per liter; µg/L, micrograms per liter; --, constituent not detected]

Organic compound Date in 1997	Report- ing level (µg/L)	Well name										Equipment blanks	
		91-15 2/4	91-15 2/7	91-13 2/4	FTC- 1-24 2/6	ABB2 2/5	ABB4 2/3	ABB5 2/6	BCME- B-20 2/5	94- LEH 2/7	94- SR-29 2/3	1/31	2/10
Trichlorfluor- methane	0.1	0.20	0.19	E.03	--	--	--	--	--	--	--	--	--
Carbon di- sulfide	0.05	--	--	--	--	--	--	--	E.005	E.007	--	E.02	--
1,1 Dichloro ethane	0.05	--	--	E.07	--	--	--	--	--	--	--	--	--
Methyl tert- butyl ether	0.1	E.09	E.09	--	E0.01	--	--	--	--	--	--	--	--
Chloroform	0.05	E.01	E.01	E.02	--	--	E.02	--	--	--	--	E.01	--
1,1,1 Trichloro ethane	0.05	E.04	E.04	0.54	--	0.14	E.009	--	--	--	--	--	--
Trichloro- ethylene	0.05	--	E.005	--	--	--	--	--	--	--	--	--	--
1,2 Dichlor- propane	0.05	E.06	E.07	0.11	E.04	0.15	0.14	0.24	0.48	0.37	--	--	--
<i>trans</i> - 1,3 Di- chloropropene	0.1	--	--	--	--	--	--	--	--	E.03	--	--	--
<i>cis</i> - 1,3 Di- chloropropene	0.1	--	--	--	--	--	--	--	--	E.02	--	--	--
1,3 Dichloro- propane	0.05	--	--	--	--	--	--	--	E.08	E.05	--	--	--
1,2,3 Tri- chloropropane	0.02	--	--	--	--	--	--	--	0.13	E.07	--	--	--
Tetrachloro ethylene	0.05	--	--	--	--	E.01	--	--	--	--	--	--	--
<i>meta</i> & <i>para</i> Xylene	0.05	--	--	--	--	--	--	--	--	E.007	--	--	--
1,2 Dibromo- chloropropane	0.5	E.07	E.07	--	--	--	--	--	--	--	--	--	--
Atrazine	0.001	E.004	E.004	--	E.006	--	--	--	E.002	--	--	--	--
Carbofuran	0.12	--	E.002	--	--	--	--	--	--	--	--	--	--
Desethyl atrazine	0.002	E.006	E.006	--	E.005	--	--	--	E.004	--	--	--	--
Dinoseb	0.035	0.06	0.06	--	--	--	--	--	--	--	--	--	--
Napropamide	0.003	0.011	0.011	--	--	--	--	--	--	--	--	--	--
Oxamyl	0.018	0.41	0.45	--	--	--	1.2	--	0.45	23	--	--	--
Simazine	0.005	0.084	0.082	--	--	--	--	--	0.021	0.021	--	--	--
Tebuthiuron	0.01	V.012	V.012	--	--	--	--	--	--	--	--	--	--

COMPOUNDS DETECTED IN SAMPLE WATER MOST LIKELY THE RESULT OF SAMPLING OR ANALYTICAL ARTIFACTS

Acetone (2-propa- none)	5.0	--	--	--	VE1.1	VE1.0	--	VE0.8	--	VE0.6	--	E5	E1.
Toluene (Methyl- benzene)	0.05	VE.03	VE.03	VE.04	VE.02	VE.03	VE.03	VE.03	VE.01	VE.03	VE.01	--*	E.07
1,1,2-Trichloro- 1,2,2-trifluoro- ethane (CFC-113)	0.05	VE.006	--	VE.01	VE.01	VE.01	VE.02	--	--	--	VE.02	0.12	E.04
1,2,4-Trimethyl Benzene	0.05	V.49	V.37	V.52	V.25	V.20	V.1	V.30	V.29	V.44	V.27	0.18	0.35

* Toluene was reported at 0.005 in both laboratory procedure blanks associated with this sample and thus not estimated below the detection level.

Table 6. Field measurements and concentrations of inorganic constituents in transboundary ground water from the Abbotsford-Sumas aquifer
[$\mu\text{S}/\text{cm}$, microsiemens per centimeter; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data]

Water-quality constituent	91-13	91-15	91-15	94-LEH	94-SR-29
Date--month/day/1997	2/4	2/4	2/7	2/7	2/3
Time	0900	1300	0930	1300	1000
Water temperature, degrees Celsius	11.5	11.6	11.5	9.8	10
Specific conductance, $\mu\text{S}/\text{cm}$	300	296	295	716	298
pH, Standard units	6.2	5.9	5.8	5.7	6.8
Dissolved oxygen, mg/L	5.2	8.4	8.0	10.3	7.2
Alkalinity, mg/L as CaCO_3	35	18	18	6.1	48
Calcium, mg/L as Ca	31	31	29	88	32
Magnesium, mg/L as Mg	7.8	6.5	6.5	17	8.7
Sodium, mg/L as Na	10	9.6	12	7.2	6.3
Potassium, mg/L as K	1.2	2.8	2.8	13	1.2
Bicarbonate, mg/L as HCO_3	42	21	22	7.4	57
Sulfate, mg/L as SO_4	34	28	28	41	16
Chloride, mg/L as Cl	13	14	14	28	6.5
Fluoride, mg/L as F	<0.1	<0.1	<0.1	<0.1	<0.1
Silica, mg/L as Si	22	13	13	12	20
Sum of dissolved constituents, mg/L (TDS)	205	196	196	508	200
Residue on evaporation, mg/L (ROE)	190	180	186	477	187
Ion Balance, percent difference	-2.39	-1.37	-1.28	-1.17	-2.66
Nitrite nitrogen, mg/L as N	0.02	0.02	<0.01	<0.01	0.02
Nitrate plus nitrite nitrogen, mg/L as N	15	18	18	67	18
Ammonia nitrogen, mg/L as N	<0.015	<0.015	<0.015	<0.015	0.07
Ammonia plus organic, mg/L as N	<0.2	<0.2	<0.2	<0.2	<0.2
Phosphorus, mg/L as P	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphate, ortho, mg/L as P	<0.01	<0.01	<0.01	<0.01	<0.01
Organic carbon, mg/L as C	1.1	--	--	0.8	--
Antimony, $\mu\text{g}/\text{L}$ as An	<1	<1	<1	<1	<1
Arsenic, $\mu\text{g}/\text{L}$ as As	<1	<1	<1	<1	1
Aluminum, $\mu\text{g}/\text{L}$ as Al	V4	V12	V13	V27	V3
Barium, $\mu\text{g}/\text{L}$ as Ba	8	9	10	225	17
Beryllium, $\mu\text{g}/\text{L}$ as Be,	<1	<1	<1	<1	<1
Bromide, $\mu\text{g}/\text{L}$ as Br	30	30	20	30	1,100
Cadmium, $\mu\text{g}/\text{L}$ as Cd	<1	<1	<1	<1	<1
Chromium, $\mu\text{g}/\text{L}$ as Cr	2	1	<1	<1	2
Cobalt, $\mu\text{g}/\text{L}$ as Co	<1	<1	<1	<1	<1
Copper, $\mu\text{g}/\text{L}$ as Cu	<1	<1	<1	<1	<1
Iron, $\mu\text{g}/\text{L}$ as Fe	<3	<3	<3	23	<3
Lead, $\mu\text{g}/\text{L}$ as Pb	<1	<1	<1	<1	<1
Manganese, $\mu\text{g}/\text{L}$ as Mn	<3	3	3	11	<1
Mercury, $\mu\text{g}/\text{L}$ as Hg	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum, $\mu\text{g}/\text{L}$ as Mo	<1	<1	<1	<1	<1
Nickel, $\mu\text{g}/\text{L}$ as Ni	<1	<1	<1	1	<1
Selenium, $\mu\text{g}/\text{L}$ as Se	<1	<1	<1	<1	<1
Silver, $\mu\text{g}/\text{L}$ as Ag	<1	<1	<1	<1	<1
Uranium, $\mu\text{g}/\text{L}$ as U	<1	<1	<1	<1	<1
Zinc, $\mu\text{g}/\text{L}$ as Zn	V3	V1	<1	V4	V1

Table 6. Field measurements and concentrations of inorganic constituents in transboundary ground water from the Abbotsford-Sumas aquifer--Continued

ABB2	ABB4	ABB5	FTC-1-24	BCME- B-20	Equipment blank	Equipment blank	Laboratory grade water
2/5	2/3	2/6	2/6	2/5	1/31	2/10	12/13
0900	1500	1000	1400	1200	1200	1200	0900
11.0	12.5	10.6	8.5	8.0	--	--	--
179	391	324	420	405	2.0	2	1
5.9	6.4	5.7	6.3	5.7	--	--	--
8.2	7.2	8.9	0.0	10.4	--	--	--
24	48	14	62	13	1.9	1.5	--
15	44	35	49	47	<0.02	<0.02	<0.002
2.7	12	6.7	15	7.8	<0.01	<0.01	<0.001
13	8.8	5.7	8.8	5.3	<0.2	<0.2	<0.025
0.9	1.5	0.8	4.3	5.3	<0.1	<0.1	--
29	59.0	17.0	76.1	16	--	--	--
19	27	19	130	19	<0.1	<0.1	--
7	13	9.4	9.6	13	<0.1	<0.1	--
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	--
15	23	15	16	11	<0.01	<0.01	<0.02
121	266	219	270	274	--	--	--
114	248	210	273	255	3.0	<1	--
-1.38	-0.47	-5.19	0.36	-2.59	--	--	--
0.02	0.02	<0.01	0.01	0.03	--	--	<0.001
8.0	24	27	<0.05	36	--	--	<0.05
<0.015	<0.015	<0.015	<0.015	<0.015	--	--	0.019
<0.2	<0.2	<0.2	<0.2	<0.2	--	--	--
<0.01	<0.01	<0.01	<0.01	<0.01	--	--	<0.001
<0.01	<0.01	<0.01	<0.01	<0.01	--	--	--
--	0.5	0.5	1.0	0.5	--	--	--
<1	<1	<1	<1	<1	<1	<1	<0.2
<1	<1	<1	2	<1	<1	<1	--
V12	V8	V7	V4.0	V17	4	4	<0.3
20	13	6	36	131	<1	<1	<0.2
<1	<1	<1	<1	<1	<1	<1	<0.2
80	30	30	30	20	<0.01	<0.01	--
<1	<1	<1	<1	<1	<1	<1	<0.3
<1	1	<1	<1	<1	<1	<1	<0.2
<1	<1	<1	<1	<1	<1	<1	<0.2
<1	<1	<1	<1	<1	<1	<1	<0.2
11	53	13	920	<3	<3	<3	<0.3
<1	<1	<1	<1	<1	<1	<1	<0.3
2	2	3	130	5	<1	<1	<0.1
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	--
<1	<1	<1	<1	<1	<1	<1	<0.2
<1	V1	<1	V4	<1	2	<1	<0.5
<1	<1	<1	<1	<1	<1	<1	--
<1	<1	<1	<1	<1	<1	<1	<0.2
<1	<1	<1	<1	<1	<1	<1	<0.2
V<1	V2	V1	V<1	V<1	5	5	<0.5

Variability in analyte concentrations reported in the replicate samples was generally low. Because the duration between replicate samples was 3 days, the observed variations in the replicate data could be due to either short-term temporal variation in the ground-water quality, variations due to sampling and handling, or variations due to laboratory analysis. All constituents of the two samples, except dissolved organic carbon, were analyzed in different batch lots. Constituent concentrations for replicate samples are shown side-by-side in tables 5 and 6, and show little variation. Identical laboratory results were reported for 95 percent of VOC and pesticide samples, 75 percent of trace-element samples, 71 percent of common ion and nutrient samples, and 20 percent of field parameters. In cases where different concentrations were reported, the relative percent difference between the samples was generally less than 10 percent.

Zinc, nickel, and aluminum were detected in equipment-blank samples at 5, 2, and 3 µg/L, respectively. Nickel was detected in one sample at 4 µg/L and in one blank sample at 2 µg/L. Zinc and aluminum have been shown to leach from the glass ampules used to store the nitric acid used in preserving trace-element samples and this leaching is suspected as the source of this contamination. The environmental concentrations of zinc were between less than 1 to 3.5 µg/L; thus it is possible that zinc and nickel were not present in samples where they were reported. The reported concentrations of aluminum were between 3 to 27 µg/L and, because of the bias shown in the blank samples, are likely to be somewhat larger than actual concentrations present in ground water of the aquifer. The laboratory results of the zinc, nickel, and aluminum analyses were tabulated as reported but were flagged with a “V” to indicate potential bias.

Four VOCs that were detected in equipment-blank samples and ground-water samples were acetone (2-propanone), toluene (methylbenzene), 1,1,2-trichloro-1,2,2-trifluoroethane, and 1,2,4-trimethylbenzene. For three of these compounds, values estimated by the NWQL were below the MRL. The compound 1,2,4-trimethylbenzene was present at concentrations above the MRL in all ground-water samples and in both pre- and post-sampling equipment blanks. The concentrations in the two equipment-blank samples were 0.18 and 0.35 µg/L, while concentrations in the ground-water samples were in a similar range, from 0.1 to 0.52 µg/L. Because of this sampling bias, data for 1,2,4-trimethylbenzene is interpreted as

not present in the ground water at concentrations greater than 1 µg/L. 1,2,4-trimethylbenzene is a common component of gasoline. The laboratory results of these four VOCs were tabulated as reported but were flagged with a “V” to indicate potential bias.

WATER-QUALITY RESULTS

For each sample, 210 water-quality parameters were measured. Most of these had concentration values that were less than the MRL. The data are presented as two groups. Inorganic constituents including common ions, trace elements, nutrients, and the field parameters are the first group. Organic compounds are the second group, which includes 87 VOCs, 82 pesticides, and the 3 CFC compounds (trichlorofluoromethane, CFC-11; dichlorodifluoromethane, CFC-12; and 1,1,2-trichloro-1,2,2-trifluoroethane, CFC-13). The MRL is the concentration at which a quantitative value for the concentration can be reliably determined. The laboratory analytical methods can generally detect the presence of a compound at concentrations smaller than the reporting level; however, analytical uncertainty is larger at these lower concentrations, and thus only qualitative estimates are reported in these instances. In instances when a compound was detected below the MRL, the laboratory provided an estimated concentration that is flagged with an “E” to denote the estimated concentration. The “E” flag was also used for results in instances where matrix effects or a calibration curve was exceeded.

Nutrients, Common Ions, and Trace Elements

Nitrate concentrations ranged from <0.05 to 67 mg/L as nitrate nitrogen and were above the drinking water standard or guideline of 10 mg/L (U.S. Environmental Protection Agency, 1996; Health and Welfare Canada, 1993) at seven of nine wells. Nitrate contamination in this aquifer is well documented and these results were not unexpected. The concentrations of other common ions, trace elements, and nutrients in the Abbotsford-Sumas aquifer are generally small resulting in ground water having total dissolved solids typically less than 275 mg/L. Calcium was the cation most prevalent in all of these ground-water samples, while the most prevalent anion was either nitrate,

sulfate, or bicarbonate. Most trace-element concentrations were below the MRL. Zinc, nickel, and aluminum were detected in equipment blanks as discussed earlier and are estimated values. Aluminum, arsenic, chromium, manganese, nickel, and zinc were found at or near the MRL in several of the ground-water samples. All samples had concentrations of barium and bromide at concentrations greater than five times the MRLs, while most also had similar concentrations of iron and manganese. The largest trace-element concentration was 1,100 µg/L of bromide in well 94-SR-29.

The ground water is slightly acidic having pH values between 5.7 to 6.8 and is generally well oxygenated with dissolved oxygen concentrations typically greater than 7 mg/L. The water quality in well FTC-1-24, which is located adjacent to Fishtrap Creek, is anomalous compared to the other wells. It has low concentrations of nitrate and dissolved oxygen, and generally has higher concentrations of iron, manganese, and sulfate.

Pesticides and Volatile Organic Compounds

Twenty-seven pesticides and volatile organic compounds (VOCs) were detected by the laboratory analysis (table 5). Only 23 of these detected compounds are likely present in the ground water of the Abbotsford-Sumas aquifer. Four of the detected VOCs are likely the result of sampling and analytical bias and were discussed in the previous section on data quality assessment. The concentrations of detected compounds ranged from 0.01 to 23 µg/L. None of the reported concentrations of VOCs and pesticides (table 5) exceed the drinking water guidelines or standards for those compounds listed in tables 3 and 4. Since most of the organic compounds that were analyzed were not detected, table 5 presents data only for those compounds with detectable concentrations.

Comparison of the concentrations of detected compounds in replicate samples from well 91-15 shows good agreement among replicates (table 5), indicating that variability due to sampling and analysis was small. Most of the compounds detected were at concentrations very near their detection limits. Of the 15 compounds detected in both samples, 10 had identical concentrations in the samples collected 3 days apart. The relative percent difference in concentrations for the five compounds with differing concentrations

ranged from 2 to 28 percent. However, if 1,2,4-trimethylbenzene, which was thought to be an artifact of sampling, is excluded, then the range for the relative percent difference is 2 to 15 percent, averaging about 8 percent.

The number of detections of organic compounds in the ground-water samples was typically from three to eight compounds in each sample; however, in the deepest well, 94-SR-29, no organic compounds were detected. The most frequently detected organic compound was 1,2-dichloropropane (1,2-DCP), which was observed in all but the deepest well (94-SR-29) at concentrations ranging from 0.04 to 0.48 µg/L, typically greater than two times the MRL. In the two wells with 1,2-DCP concentrations greater than 0.35 µg/L, additional chlorinated propanes were also detected. Oxamyl was found in four wells at concentrations ranging from 0.41 to 23 µg/L. Simazine, atrazine, and desethylatrazine were each present in three wells.

Chlorofluorocarbons

CFCs are synthetic organic compounds that are entirely of man-made origin. The primary use of these compounds is as a refrigerant, which began in the 1930's. The ultimate environmental fate of CFCs is release to the atmosphere, where CFCs can dissolve into precipitation that recharges aquifers. Atmospheric concentrations of CFCs have increased steadily from earliest detections until peak concentrations were reached in 1993 and 1994. Maximum atmospheric CFC concentrations for the period prior to 1997 are: CFC-11, 276 parts per trillion, volume (pptv); CFC-12, 544 pptv; and CFC-113, 84.8 pptv (Eurybiades Busenberg, U.S. Geological Survey, written commun., 1997). CFCs have been used to date some ground water recharged after 1940 based on the presumption that the source of the CFCs in the ground water is from atmospheric equilibration of CFCs present in the atmosphere at the time precipitation recharged the aquifer (Busenberg and Plummer, 1992). Concentrations larger than the maximum atmospheric concentrations indicate CFCs from sources in addition to atmospheric equilibration.

CFC concentrations were measured in water samples from seven wells and the equilibrium vapor phase concentrations, which can be compared to atmospheric concentrations, were computed following the procedures of Busenberg and Plummer (1992).

Table 7. Concentration of chlorofluorocarbons in ground-water samples and calculated equilibrium vapor phase concentration

[mg/L, milligrams per liter; pg/kg, picograms per kilogram; pptv, parts per trillion by volume]

Well name	Sample date	Sample time	Dissolved oxygen (mg/L)	CFC-11		CFC-12		CFC-13	
				Concentration in sample (pg/kg)	Calculated atmospheric concentration (pptv)	Concentration in sample (pg/kg)	Calculated atmospheric concentration (pptv)	Concentration in sample (pg/kg)	Calculated atmospheric concentration (pptv)
91-15	2/4/97	11:23	8.4	15,900	5,506	791	1,200	49.3	41.1
		11:39		16,300	5,660	796	1,210	50.8	42.3
		11:47		15,500	5,380	622	944	35.9	29.9
91-13	2/4/97	13:30	5.2	24,000	8,310	3,290	5,000	182	151.4
		13:45		23,900	8,290	3,330	5,050	189	158
		13:53		23,000	7,980	3,000	4,550	99.7	83
FTC-1-24	2/27/97	12:30	<0.1	7.9	2.7	97.4	148	24.4	20.3
		12:41		8.2	2.8	106	161	4.4	3.7
ABB4	2/3/97	17:00	7.2	1,280	443	2,970	4,510	75	62.5
		17:16		1,280	443	2,900	4,410	61.5	51.3
		17:30		1,210	420	2,920	4,440	76.1	63.4
ABB5	2/6/97	11:30	8.9	613	212	382	580	76.6	63.9
		11:38		605	210	382	579	77.8	64.9
		11:52		597	207	330	501	66.1	55.1
BCME-B-20	2/5/97	14:05	10.4	676	234	464	703	157	130
		14:30		663	230	430	649	11.2	9.3
94-SR-29	2/3/97	11:25	7.2	256	88.8	441	669	140	117
		11:38		255	88.6	437	664	143	119
		12:05		257	89	467	709	81.1	67.6

These data are shown in table 7. Vapor phase concentrations for over half of the reported values are larger than the maximum atmospheric concentration, indicating the widespread presence of CFCs from non-atmospheric sources in the ground water. In one well, FTC-1-24, CFC concentrations were small, much less than the maximum concentrations, possibly indicating ground water older than 50 years. However, this well is also anoxic and recent studies have shown that CFCs can be microbially degraded under reducing conditions such as those present in this well. A subsequent sample from FTC-1-24 was analyzed for tritium, which produced a concentration of 26 tritium units indicating that the ground-water age was young, less than 50 years

and confirming that the low concentrations of CFCs in this well were likely due to microbial degradation of the CFCs. Thus, the use of CFC concentrations for age-dating ground-water samples in the transboundary region of the Abbotsford-Sumas aquifer is unreliable.

SUMMARY

Ground-water quality and hydrogeologic data were collected from nine wells in the transboundary region of the Abbotsford-Sumas aquifer. Water-quality data included the concentrations of selected common ions, trace elements, pesticides, and volatile organic

compounds, including three chlorofluorocarbons used to estimate residence times of ground water. The concentrations of common ions and trace elements were generally small resulting in low total dissolved constituents. However, the concentrations of nitrate were generally large: seven of nine wells yield water having concentrations of nitrate greater than both Canadian and United States drinking water guidelines and standards. Nitrate was the only water-quality constituent detected in these samples at concentrations above the Canadian and United States drinking water guidelines or standards. Twenty-seven organic compounds were detected in the ground-water samples with concentrations ranging from 0.01 to 23 µg/L. Four of these compounds are thought to be affected by sampling or analytical bias. Three chlorofluorocarbons, CFC-11, CFC-12, and CFC-113, were detected, typically at concentrations greater than the maximum atmospheric concentrations, indicating additional sources of CFCs other than atmospheric equilibration and that CFCs would not be a reliable ground-water age-dating tool for this aquifer.

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APPENDIX

Appendix A. Logs of lithologic description obtained during drilling of observation-monitoring piezometers, in the Abbotsford-Sumas Aquifer, British Columbia

[--, no data]

Lithological description	Depth interval below land surface	
	(meters)	(feet)
Piezometer: 91-13; completed May 1991		
Top soil and few gravel	0.0 - 0.9	0.0 - 3.0
Sand and gravel	0.9 - 8.2	3.0 - 15.0
Sandy gravel	4.6 - 8.2	15.0 - 27.0
Sand and gravel	8.2 - 9.4	27.0 - 31.0
Brown sand	9.4 - 11.9	31.0 - 39.0
Sandy gravel	11.9 - 14.3	39.0 - 47.0
Sand and gravel	14.3 - 20.4	47.0 - 66.9
Clay	20.4 - 29.0	66.9 - 95.0
Number 10 slot screen	18.6 - 20.1	61.0 - 66.0
Piezometer: 91-15; completed May 1991		
Top soil and few gravel	0.0 - 0.9	0.0 - 3.0
Sand and gravel	0.9 - 4.6	3.0 - 15.0
Sandy gravel	4.6 - 9.4	15.0 - 31.0
Brown sand	9.4 - 11.9	31.0 - 39.0
Number 10 slot screen	8.2 - 9.8	27.0 - 32.0
Piezometer: FTC-1-24; completed October 1991		
Gravel, cobble, and sand	0.0 - 0.3	0.0 - 4.0
Sand with clay, brown	0.3 - 2.4	4.0 - 8.0
Sand, medium to coarse, with gravel; greyish brown	2.4 - 3.7	8.0 - 12.0
Sand, medium to coarse with fine gravel; grey	3.7 - 11.0	12.0 - 36.0
Number 10 slot screen	6.4 - 7.3	20.9 - 24.0
Piezometer: ABB2; completed March 1988		
Sand and fine to medium gravel	0.0 - 1.8	0.0 - 6.0
Sand and coarse gravel	1.8 - 2.9	6.0 - 9.5
Grey sand and cobbles (2.5 centimeters diameter)	2.9 - 3.6	9.5 - 12.0
Grey sand; fine to medium gravel	3.7 - 5.8	12.0 - 19.0
Grey sand; coarse gravel	5.8 - 7.0	19.0 - 23.0
Sand less silt; cobbles	7.0 - 7.6	23.0 - 25.0
Number 10 slot screen	6.6 - 7.6	21.7 - 25.0

Appendix A. Logs of lithologic description obtained during drilling of observation-monitoring piezometers, in the Abbotsford-Sumas Aquifer, British Columbia--Continued

Lithological description	Depth interval below land surface	
	(meters)	(feet)
Piezometer: ABB4; completed March 1988		
Sand and coarse gravel, oxidized	0.0 - 0.9	0.0 - 3.0
Grey sand and very coarse gravel	0.9 - 6.9	3.0 - 22.5
Grey sand; fine to coarse gravel	6.9 - 11.0	22.5 - 36.0
Sand; very fine gravel	11.0 - 14.5	36.0 - 47.5
Sand; coarse gravel	14.5 - 14.6	47.5 - 48.0
Silty sand and fine gravel	14.6 - 17.2	48.0 - 56.5
Silty sand and very fine gravel	17.2 - 17.4	56.5 - 57.0
Grey sand and coarse gravel	17.4 - 19.4	57.0 - 63.5
Grey sand; very fine gravel	19.4 - 20.3	63.5 - 67.0
Grey sand; fine to coarse gravel	20.3 - 24.5	67.0 - 80.5
Sand and gravel; cobbles	24.5 - 24.8	80.5 - 81.5
Sand and very fine gravel to coarse gravel	24.8 - 26.2	81.5 - 86.0
Sand and coarse gravel	26.2 - 28.5	86.0 - 93.5
Sand and gravel; some cobbles	28.5 - 29.3	93.5 - 96.0
Number 10 slot screen	28.3 - 29.3	92.7 - 96.0
Piezometer: ABB5; completed March 1988		
Clayey sand and gravel; oxidized	0.0 - 3.7	0.0 - 12.0
Silty brown sand; slight clay	3.7 - 5.3	12.0 - 17.5
Grey sand and coarse gravel	5.3 - 6.4	17.5 - 21.0
Grey sand and fine gravel; cobbles	6.4 - 7.6	21.0 - 25.0
Grey sand and pea gravel	7.6 - 7.9	25.0 - 26.0
Sand and coarser gravel; cobbles	7.9 - 8.5	26.0 - 28.0
Grey sand and gravel; no pebbles	8.5 - 8.8	28.0 - 29.0
Number 10 slot screen	7.8 - 8.8	25.7 - 29.0
Piezometer: BCME-B-20; complete 1988		
Top soil	0.0 - 0.6	0.0 - 2.0
Sand and gravel with lenses of sand	0.6 - 10.7	2.0 - 35.0
Number 10 slot screen	3.0 - 5.5	10.0 - 18
Piezometer: 94 LEH; completed 1994		
Top soil	0.0 - 0.3	0.0 - 4.0
Sand and gravel	0.3 - 22.9	4.0 - 75'
Number 10 slot screen	8.2 - 9.8	27.0 - 32.0

Appendix A. Logs of lithologic description obtained during drilling of observation-monitoring piezometers, in the Abbotsford-Sumas Aquifer, British Columbia--Continued

Lithological description	Depth interval below land surface	
	(meters)	(feet)
Piezometer: 94-SR-29; completed 1994		
Brown sandy clay	0.0 - 2.7	0.0 - 9.0
Brown sand and gravel	2.7 - 3.7	9.0 - 12.0
Grey sand with clay lenses	3.7 - 5.5	12.0 - 18.0
Silty sand and gravel	5.5 - 6.1	18.0 - 20.0
Brown clay and sand	6.1 - 14.9	20.0 - 49.0
Sandy brown clay with pebbles	14.9 - 22.9	49.0 - 75.0
Sandy grey clay with pebbles	22.9 - 24.7	75.0 - 81.0
Sand and gravel	24.7 - 29.0	81.0 - 95.0
Dirty coarse sand with clay lenses	29.0 - 29.6	95.0 - 97.0
Number 10 slot screen	--	--