

**NUTRIENTS, METALS, BACTERIA AND ORGANIC COMPOUNDS IN  
GROUNDWATER EXPOSED TO AGRICULTURAL ACTIVITIES  
IN THE LOWER FRASER VALLEY, BRITISH COLUMBIA**

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## ABSTRACT

As part of the Georgia Basin Ecosystem Initiative, Environment Canada conducted a survey of groundwater quality in 1998 at selected Lower Fraser Valley (LFV) sites. The survey included areas of intensive agricultural use (impacted sites) as well as those with no known agricultural activities (reference sites). Twenty sites (16 impacted and 4 reference) in several LFV aquifers were sampled for nutrients, bacteriological parameters, metals, organic contaminants, and estrogen/androgen screening tests.

Nitrate + nitrite concentrations were elevated at four impacted sites; two were over 3 milligrams nitrogen per litre (mg N/L) and another two also exceeded the 10 mg N/L Canadian Water Quality Guideline for Drinking Water. The nitrate + nitrite concentrations at reference sites were all less than 1 mg N/L. Total and fecal coliform and *Escherichia coli* counts were zero at reference sites and positive at four impacted sites, with total coliform counts ranging from 2 to 1300 colonies per 100 mL. Many trace metals concentrations were within the acceptable limits of the Canadian Council for Ministers of the Environment (CCME) guidelines for drinking, irrigation, protection of fresh water aquatic life and livestock watering. Other trace metals like copper, iron and manganese exceeded some of these guidelines. Not all the organic compounds analyzed were detected in the survey. All the detected organic compounds had concentrations below CCME guidelines, where they have been established, for drinking or protection of freshwater life. Few pesticides were detected in groundwater however endosulphan was detected at several impacted sites but at none of the reference sites. Organic compounds not necessarily associated with agriculture such as PAHs and some sterols (cholesterol and  $\beta$ -sitosterol) were detected at many of the impacted and reference sites. Two screening tests were used to detect substances in the water that mimic estrogen or androgen hormones. The results showed no significant estrogenic or androgenic activity.

This survey of groundwater quality in the Lower Fraser Valley showed that agricultural activities can result in an increase in bacterial, nutrient, and pesticide levels and possibly sterol levels (in shallow wells). However, groundwater in the Lower Fraser Valley is affected by more than just agricultural land activity; it is affected also by other activities and land uses related to general human presence.

## RÉSUMÉ

Dans le cadre de l'Initiative de l'écosystème du bassin de Georgia, Environnement Canada a mené en 1998 une enquête sur les eaux souterraines d'un certain nombre de sites sélectionnés de la vallée du bas Fraser (VBF). Cette étude portait sur des zones d'agriculture intensive (sites perturbés) ainsi que sur des zones pour lesquelles aucune activité agricole n'était connue (sites de référence). Vingt sites (16 perturbés et 4 de référence) dans plusieurs aquifères de la VBF ont été étudiés par prélèvement d'échantillons afin d'analyser les nutriments, les paramètres bactériologiques, les métaux, les contaminants organiques et effectuer des tests de dépistage d'oestrogènes/d'androgènes.

Les concentrations en nitrate + nitrite étaient élevées sur quatre sites perturbés ; deux résultats donnaient plus de 3 milligrammes d'azote par litre (mg N/L) et deux autres dépassaient les Recommandations pour la qualité de l'eau potable au Canada qui sont de 10 mg N/L. Les concentrations en nitrate + nitrite sur les sites de référence étaient toutes inférieures à 1 mg N/L. La numération totale de coliformes ainsi que celle des coliformes fécaux et de *Escherichia coli* étaient de zéro sur les sites de référence et positives sur quatre sites perturbés : les numérations totales de coliformes allaient de 2 à 1300 colonies par 100 mL. De nombreuses concentrations en métaux-traces étaient dans les limites acceptables des recommandations du Conseil canadien des ministres de l'environnement (CCME) pour l'eau potable, l'irrigation, la protection de la vie aquatique en eau douce et l'abreuvement des animaux d'élevage. D'autres métaux-traces comme le cuivre, le fer et le manganèse dépassaient certaines de ces recommandations. Tous les composés organiques analysés n'ont pas été détectés lors de cette enquête. Tous ceux qui ont été détectés avaient des concentrations inférieures aux recommandations du CCME pour l'eau potable ou la protection de la vie aquatique en eau douce. Peu de pesticides ont été détectés dans les eaux souterraines, cependant de l'endosulphan a été détecté sur plusieurs sites perturbés mais sur aucun des sites de référence. Des composés organiques pas forcément associés à l'agriculture, comme par exemple les HAP et certains stéroïdes (cholestérol et  $\beta$ -sitostérol) ont été décelés sur de nombreux sites perturbés et de référence. Deux tests de dépistage ont été utilisés pour détecter des substances dans l'eau qui imitent les hormones androgènes ou oestrogènes. Les résultats obtenus n'indiquent pas d'activité androgénique ou oestrogénique significative.

Cette étude de la qualité des eaux souterraines dans la vallée du bas Fraser indique que les activités agricoles peuvent entraîner une augmentation des niveaux en bactéries, nutriments et pesticides ainsi qu'une possible croissance des niveaux en stéroïdes (dans les puits peu profonds). Cependant, l'eau souterraine dans la vallée du bas Fraser est affectée par plus que l'agriculture de surface. Elle subit également les conséquences générales de la présence humaine.

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## 1.0 INTRODUCTION

Land-use activities can have a significant impact on groundwater quality, especially in shallow and unconfined aquifers. Many aquifers in the Lower Fraser Valley (LFV), British Columbia are exposed to agricultural activities and with recent increases in urbanization, significant portions of these aquifers are also exposed to urban activities.

One of the common agricultural activities in the LFV is the application of livestock manure on agricultural fields. The effect of this application on stream water quality and underlying groundwater is not fully known; nor is it known if the run-off has the potential to cause endocrine disrupting effects in organisms living in the groundwater-fed streams. It is expected that manure can contain natural and synthetic hormones (Environment Canada, 1998) that have the potential to cause endocrine-like effects in exposed organisms. As well, some organochlorine pesticides have been shown to cause endocrine disrupting effects in birds and amphibians (Hayes *et. al.*, 2002). It is unknown if these contaminants are of concern in groundwaters of the LFV.

Contaminants of potential concern, especially for human health, in LFV aquifers are nitrate + nitrite and pesticides that have been detected in aquifers like the Abbotsford and Columbia Valley aquifers (Liebscher *et. al.*, 1992; Carmichael *et. al.*, 1995; Grove *et. al.*, 1998; Cox and Liebscher, 1999; Hii *et. al.*, 1999; Zubel, 2000). Many of these groundwaters are used for consumption and irrigation. In the Abbotsford aquifer, which is probably the most studied aquifer in the LFV, it was found that the main source of nitrate + nitrite to the groundwater is from agricultural activities (Wassenaar, 1995). In 1997, Cox and Liebscher (1999) detected 27 organic compounds in the aquifer.

Over 150 aquifers in the LFV have been delineated and classified according to a vulnerability index (Kreye and Wei, 1994) and they have been grouped into classes which are based on ranking criteria including productivity, vulnerability to contamination, size, demand, type of use, and quality/quantity concerns. A Class 1A aquifer is highly vulnerable and highly productive. There are four aquifers in the LFV that belong to this class, including the Abbotsford and Chilliwack aquifers.

The Abbotsford, Chilliwack and several other aquifers in the LFV are unconfined and they are mainly composed of unconsolidated surficial materials that were deposited during the Fraser glaciations about 12,000 years ago. These materials are close to the surface and the water table forms their uppermost boundary. The surficial materials have been sub-divided into hydrostratigraphic units (Halstead, 1986) and those that are permeable (i.e., transmit significant quantities of water) are composed of sand and gravel materials. Contaminants such as nitrate, originating from land-use activities, can easily leach to groundwater through these permeable deposits and be transported with groundwater flow.

As part of the Georgia Basin Ecosystem Initiative (GBEI), Environment Canada conducted a survey in 1998 of groundwaters at selected sites in the LFV. The survey was conducted in Abbotsford/Matsqui and Chilliwack and it included areas of intensive agricultural use as well as those with no known agricultural activities. Most of these areas overlay several important aquifers (Figure 1), which are significant in terms of groundwater use (Table A1) and very susceptible to land-based contamination. The objective of the survey was to determine the concentrations of nutrients, bacteria, metals and organic compounds in groundwater exposed to agricultural activities. A second objective was to conduct a pilot screening for the presence of endocrine disrupting substances in the groundwaters using screening assays. Sampling was conducted in late summer to capture the effect of manure application to fields.

## **2.0 METHODS**

### **2.1 Site Selection**

In August 1998, 20 wells or piezometers (Table 1) in the Lower Fraser Valley were sampled for organic contaminants, inorganic variables, nutrients, bacteriological parameters and estrogen/androgen screening tests. Sixteen sampling locations (Figure 2), including piezometers, and domestic and production wells were selected as sites that are potentially impacted by agricultural activities in Abbotsford and Chilliwack. Most of these impacted sites are in unconfined aquifers, in the vicinity of one or more creeks that are likely affected by agricultural run-off, and/or down gradient of areas of intensive agricultural land use. Fourteen of these sites are in the vulnerable Class 1A aquifers – Abbotsford and Chilliwack. Four sampling sites were chosen as reference sites and are located in different aquifers. These sites are located in the vicinity or down gradient of creeks which appeared to have minimal effects from human activities.

In Chilliwack, eight wells exposed to agricultural activities and four reference wells were sampled. Five piezometers in the Abbotsford aquifer, that have been regularly monitored for nutrients for over 10 years, and three wells from the Matsqui area were also sampled. These wells are also primarily exposed to agricultural activities. At each site, a questionnaire regarding well type, location and surrounding activities was completed at the time of sampling. This information is summarized in Table 1.

### **2.2 Aquifers in the Study Area**

#### **2.2.1 *Abbotsford aquifer***

The Abbotsford aquifer is situated south of Abbotsford and it extends across the Canada/US Border into Whatcom County in Washington State. It is mainly unconfined, composed of permeable sand and gravel deposits which can store large quantities of water.



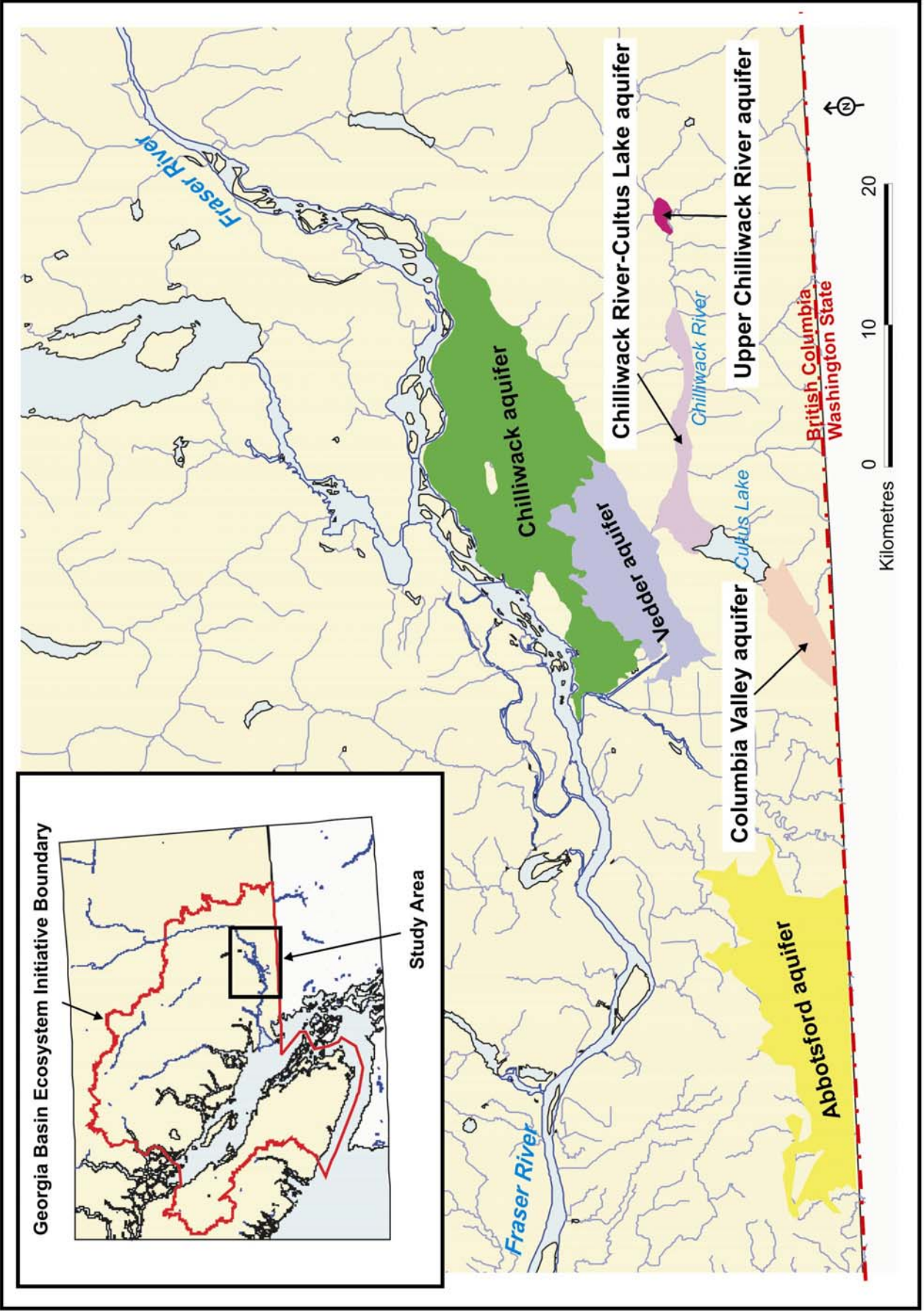


Figure 1. Important aquifers of the Lower Fraser Valley, British Columbia.

Table 1. Description of sample locations, sampling dates, well and piezometer information and land use.

Location ID	Sampling Date	X Easting	Y Northing	Well Depth (m bgl)	Depth to Water (m bgl)	Shallow/ Deep Piezometer/ Well	Aquifer / Type	Nearby Creek/River	Groundwater Use	Upgradient Land Use
ABT1	8/17/1998	543643	5428422	19	4	deep piezometer	Abbotsford / unconfined sand & gravel	Fishtrap Creek	Sampling and Monitoring	Greenhouse, Raspberry
ABT2	8/17/1998	545989	5429371	16	5	deep piezometer	Abbotsford / unconfined sand & gravel		Sampling and Monitoring	Airport, Raspberry
ABT3	8/17/1998	543570	5428549	8	3	shallow piezometer	Abbotsford / unconfined silt lenses	Fishtrap Creek	Sampling and Monitoring	Raspberry, Residential
ABT4	8/17/1998	548419	5430276	15	14	shallow piezometer	Abbotsford / unconfined upper aquifer		Sampling and Monitoring	Raspberry, hobby farm
ABT5	8/17/1998	548419	5428361	18	13	shallow piezometer	Abbotsford / unconfined sand & gravel		Sampling and Monitoring	Dairy, Raspberry
MAT1E	8/17/1998	554060	5438497	20		likely deep well	Abbotsford / unconfined sand & gravel	Clayburn Creek	Irrigation	Nursery
MAT2E	8/17/1998	547137	5437216	5	0	shallow well	other / semi-confined	McLennan Creek	Livestock watering	Poultry, Raspberry
MAT3E	8/17/1998	553468	5440716	6		likely shallow well	other / sand point	Matsqui Slough Fraser River	Irrigation	Dairy, railway, grass
CHW1E	8/20/1998 9/24/1998	576161	5448456	13		likely deep well	Chilliwack / silty sand	Hope Slough	Irrigation	Nursery, Residential
CHW2E	8/20/1998	581071	5447695	6		likely shallow well	Chilliwack / type unknown	Elk Brook	Irrigation	Dairy, corn
CHW3E	8/20/1998	589893	5448477	55		likely deep well	Chilliwack / type unknown		Irrigation	Nursery, gravel parking lot
CHW4E	8/21/1998 9/24/1998	583921	5448007	14	3	deep well	Chilliwack / type unknown	Hope Slough	Drinking - domestic	Hobby farm, pasture
CHW5E REP 1 REP 2 REP 3	9/24/1998 8/27/1998 8/27/1998 8/27/1998	583766	5447957	12	3	intermediate well	Chilliwack / type unknown	Hope Slough	Drinking - domestic	Hobby farm, pasture
CHW6E	8/21/1998	574918	5439647	45	16	deep well	Vedder / unconfined sand & gravel		Drinking - production	Residential
CHW7E	8/27/1998	583614	5446385	18		likely deep well	Chilliwack / type unknown	Elk Creek	Livestock watering	Dairy, pasture
CHW8E	8/27/1998	580251	5446650	9	5	deep well	Chilliwack / type unknown	Elk Brook	Livestock watering	Hog farm, Raspberry
CHW1R*	8/20/1998 9/24/1998	595087	5437551	118		likely deep well	Upper Chilliwack / type unknown	Chilliwack River	Aeration & fish production	Forest
CHW2R*	8/27/1998	575524	5434231	41		likely deep well	other / unconfined locally	Cultus Lake	Drinking - public campground	Forest
CHW3R*	8/27/1998	603350	5467926	35		likely deep well	other / type unknown	Hunter Creek	Sanitation -Public rest stop	Forest
CHW4R*	8/27/1998	601130	5467980	12		likely deep well	other / type unknown	Ruby Creek	Drinking - community	Forest

m bgl = metres below ground level; shallow well=well depth is <5m below water table; deep well=well depth is >10m below water table; \*denotes reference site

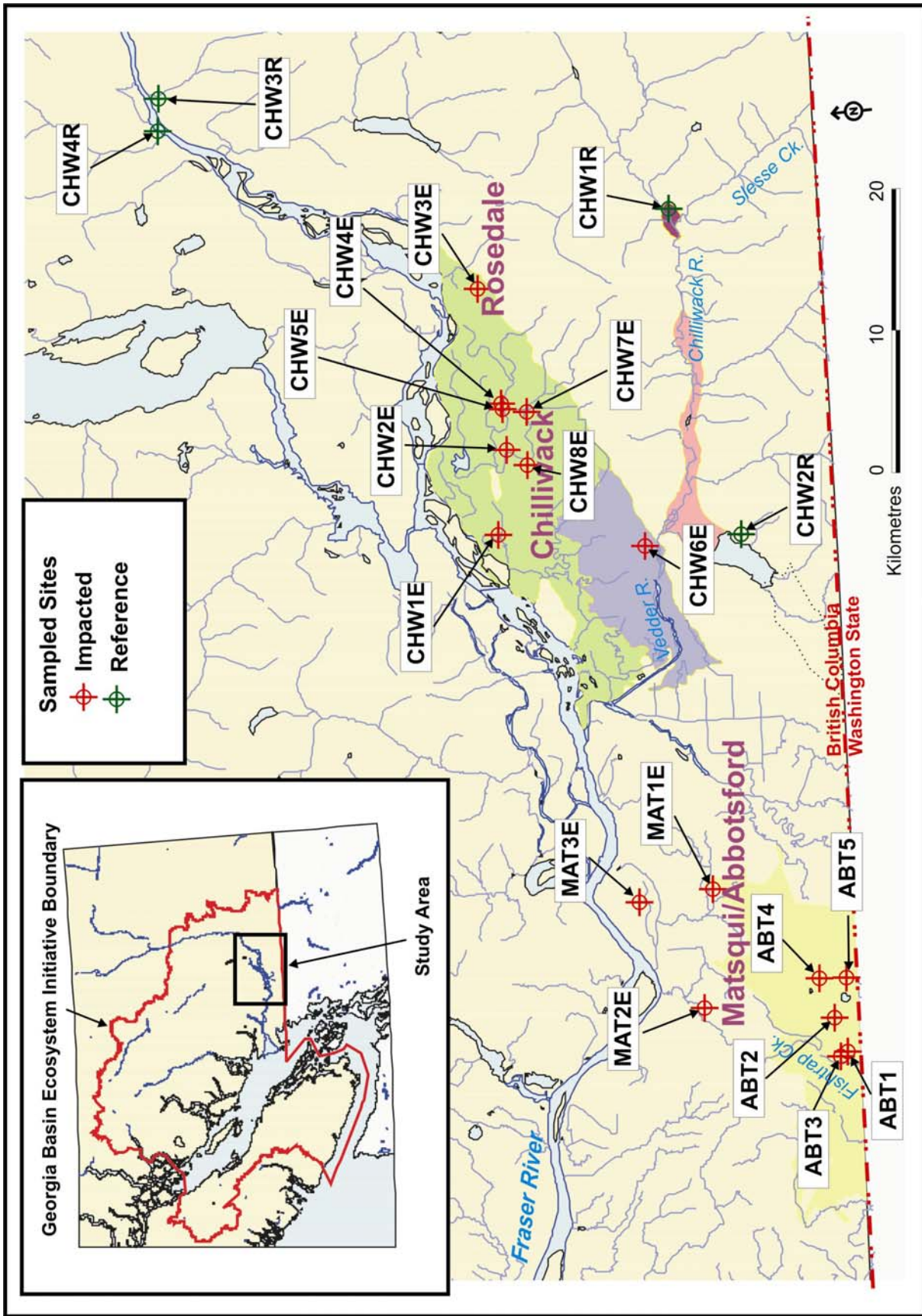


Figure 2. Sites sampled for groundwater quality in the Lower Fraser Valley.

The groundwater flow in the aquifer is radial with significant discharges to the southwest, south and southeast. A significant amount of withdrawal is through pumping of production wells that are mainly clustered in the southeast corner of the aquifer. The aquifer is recharged by direct precipitation and some surface waters via run-offs. Fishtrap Creek also contributes to the recharge at certain months of the year. Six impacted sites were located in this aquifer.

### **2.2.2 Vedder aquifer**

The Vedder aquifer is located just northeast of the Sumas Prairie floodplain. It is an unconfined aquifer that is composed of a very permeable sandy, gravel deposit which is thickest at the southeast edge and thins out across the Vedder River towards the north and west. The aquifer is recharged by precipitation and leakage from the perched bed of the Vedder River. A significant amount of withdrawal is through pumping of wells for irrigation, drinking and production. One of the two production wells owned by the City of Chilliwack in the study area was used as a sample site.

### **2.2.3 Chilliwack aquifer**

The Chilliwack aquifer is not as highly developed as the Vedder aquifer. It is composed of mainly river channel deposits with some underlying glaciofluvial sediments in the areas west and north of Rosedale. Coarse sand and gravel alluvium are found in the former Fraser River channels. In areas where groundwater flushing has prevented a buildup of dissolved iron in the sediments, high yielding wells (> 50 L/s) can be developed to produce potable water (Atwater *et. al.*, 1991). However, south and west of Rosedale, where organic content in the aquifer is higher and flushing rates are lower, the groundwater typically has high dissolved iron content and is generally not potable. There were seven sample sites located in this aquifer.

### **2.2.4 Upper Chilliwack aquifer**

This is a deep (150 m) and confined sandy, gravel aquifer that probably extends for many kilometres along the Chilliwack River valley, west from its confluence with Slesse Creek (Atwater *et. al.*, 1991). The full extent of this aquifer has not been explored. The Chilliwack Salmon Hatchery well field has three artesian wells; free flow is about 30 L/s and pumped yields from two of the wells are greater than 120 L/s (Piteau & Associates, 1985). One reference site was located here.

### **2.2.5 Other aquifers**

Other aquifers in the LFV, according to the aquifer classification system designed by Kreye and Wei (1994) are relatively less important in terms of groundwater vulnerability, use and development. Two impacted sites and three reference sites are located in these other aquifers. MAT2E may be in the top aquifer of two or three overlapping aquifers and two of the reference sites (CHW3R and CHW4R) appear to be in alluvial fan aquifers which are recharged by upgradient streams.

## **2.3 Sample Collection and Analysis**

### **2.3.1 Inorganic and Bacteriological Parameters**

Sample bottles for analysis of major ions (bromide, chloride, fluoride, sulphate, calcium, potassium, magnesium and silicon), water hardness, nitrogen, total phosphorus, total dissolved phosphorus and total metals (aluminum, arsenic, silver, barium, beryllium, cadmium, cobalt, chromium, copper, iron, lithium, manganese, mercury, molybdenum, nickel, lead, strontium, selenium, vanadium and zinc) were rinsed three times with sample water, prior to collecting the sample. The total dissolved phosphorus sample was filtered on-site with a syringe filter set-up using a 0.45 µm Acrodisc filter. All sample bottles for specific analyses were acquired from the analytical laboratory. Preservatives were added to total metals, mercury and total dissolved phosphorus samples after they were collected and filtered (total dissolved phosphorus) (Table 2).

Samples for bacteriological parameters (*Escherichia coli*, fecal coliforms and total coliforms) were collected in bottles prepared by the analytical laboratory and were not rinsed.

### **2.3.2 Organic compounds**

Eight 4 L amber bottles, pre-washed and rinsed 3 times with acetone and hexane, were used to collect 32 L of groundwater from each site for organic compounds analyses including polycyclic aromatic hydrocarbons (PAHs), pesticides and their degradation products, chlorinated benzenes, polychlorinated biphenyl (PCB) aroclors and sterols. The presence of endocrine disrupting contaminants was investigated using estrogen and androgen screening tests.

Water was collected from wells via the household tap and from piezometers via dedicated pumps. Special care was taken not to touch the bottle mouth during collection. The amber bottles were rinsed with sample water three times prior to collection. The bottles were kept cool for up to six hours after collection until the solid phase extraction (SPE) procedure.

Prior to extraction, the SPE discs were cleaned with 5 mL of dichloromethane via vacuum filtration. With the vacuum off, the discs were then 'conditioned' with 5 mL of methanol. The vacuum was turned on to allow only a small amount of the methanol through the disc; thus leaving a thin layer of methanol on the disc for the addition of the first aliquot of sample under vacuum suction.

Table 2. Field sampling procedure and analytical method for analysis of inorganic and bacteriological parameters in groundwater samples collected in the Lower Fraser Valley.

Parameter	Field Sampling Procedure	Analytical Method & Laboratory
<u>Total metals</u> (Ag, Al, Ba, Be, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, V, Zn)	Samples were collected in 500 mL non-pigmented, low density, polyethylene bottles (pre- washed in 25% v/v nitric acid for 2 hr, rinsed with deionized water and air dried).  2 mL 50% nitric acid were added to each sample immediately after collection. Samples were refrigerated before analysis.	Inductively Coupled Plasma-Optical Emission Spectrometry ( <b>ICP-OES</b> ) (Acid-Digested)  NLET
<u>Total arsenic/ selenium</u> (As/Se)	Samples were collected in 250 mL non-pigmented, low density, polyethylene bottles (pre- washed in 25% v/v nitric acid for 2 hr, rinsed with deionized water and air dried).  Samples were refrigerated before analysis.	<b>ICP-OES</b> (Acid-Digested)  NLET
<u>Total mercury</u> (Hg)	Samples were collected in 100 mL Teflon bottles (pre-washed in 25% v/v nitric acid for 2 hr, rinsed with deionized water and air dried).  2 mL sulphuric/dichromic acid were added to each sample immediately after collection. Samples were refrigerated before analysis.	Cold-Vapour Atomic Absorption Spectrophotometry  NLET
<u>Metals total</u> (Ca, Na, K, Mg, Si) and water hardness	Samples were collected in 1L non-pigmented, low density, polyethylene bottles.  Samples were refrigerated and analyzed within 28 days.	<b>ICP-OES</b> (Direct Aspiration)  PESC
<u>Major anions</u> (Br, Cl, F, SO <sub>4</sub> , NO <sub>2</sub> , NO <sub>3</sub> )	Samples were collected in 1L non-pigmented, low density, polyethylene bottles.  Samples were refrigerated and analyzed within 5 days.	Dionex DX500 Ion Chromatography  PESC
Alkalinity	Samples were collected in 1L non-pigmented, low density, polyethylene bottles.  Samples were refrigerated and analyzed within 14 days.	Automated potentiometric titration  PESC
pH	Samples were collected in 1L non-pigmented, low density, polyethylene bottles.  Samples were refrigerated and analyzed within 3 days.	Electrometric measurement using glass electrode  PESC
Conductivity	Samples were collected in 1L non-pigmented, low density, polyethylene bottles.  Samples were refrigerated and analyzed within 28 days.	Immersion type conductivity cell, 25° C, automated  PESC
<u>Nitrogen</u> (NO <sub>2</sub> +NO <sub>3</sub> , NO <sub>2</sub> )	Samples were collected in 250 mL non-pigmented, low density, polyethylene bottles.  Samples were refrigerated and analyzed within 28 days.	Colourimetric, automated Cadmium/Copper Reduction  PESC
Total phosphorus	Samples were collected in 1L non-pigmented, low density, polyethylene bottles.  Samples were refrigerated and analyzed within 5 days.	Automated colourimetric  PESC
Total dissolved phosphorus	Total dissolved phosphorus samples were collected separately in 50 mL borosilicate glass bottles with Teflon liners. Each sample was filtered in the field through 0.45 µm filter and preserved with 20 µL of H <sub>2</sub> SO <sub>4</sub> .  Samples were refrigerated and analyzed within 14 days.	
Total and fecal coliforms, <i>E. coli</i>	Samples were added directly to 500 mL polyethylene bottles (supplied by CanTest) containing EDTA and sodium thiosulphate.  Samples were refrigerated and analyzed within 24 hr	Multiple-Tube Fermentation Technique (MPN)  CanTest Lab., Burnaby, BC

PESC – Pacific Environmental Science Centre, North Vancouver, BC  
NLET – National Laboratory for Environmental Testing, Burlington, ON

A 24 L volume of sample water (six 4 L amber bottles) was required for organic compound analysis. The sample water was pre-filtered through a 1.2 µm glass fiber filter

under vacuum pressure to remove any solids. The filtered sample was transferred to a flask to which 5 mL of methanol was added for every 1 L of sample water. The organic contaminants from this 'conditioned' sample were then extracted through solid phase extraction discs (Supelco - Envi-disk™) under vacuum pressure using a vacuum manifold such that six discs could extract the entire 24 L sample at one time.

The exact volume of sample water passing through each disc was recorded (4 to 6 L). The discs were changed, cleaned and conditioned when filtering became slow. After filtration, each disc was transferred into a petri dish lined with baked aluminum foil and placed in the freezer. All the discs filtered through with sample water from one site were composited at the analytical laboratory (AXYS Analytical, Sidney, BC) and extracted for organic analysis.

All filtering glassware and amber collection bottles were cleaned between samples. The bottles were washed with nonylphenol-free soap and rinsed in distilled water. All glassware was then rinsed three times with acetone to remove the water and then three times with hexane to remove acetone and other organic compounds. The glassware was left to air-dry before starting the next sample at which time the glassware was rinsed with a small amount of the filtered sample water to remove any remaining solvent.

A total of 23 samples, including replicates (see Section 2.4 for Quality Assurance/Quality Control), were analyzed for pesticides and chlorinated benzenes. Twelve randomly selected sets of the samples were submitted for PAHs and sterols analyses. Organic contaminants were analysed by AYSX Analytical Services (Sidney, BC). Chlorinated pesticides, their degradation products, chlorinated benzenes, and PCB aroclors were analysed using gas chromatography-mass spectrometry/gas chromatography with electron capture detection (GC-MS/GC-ECD). Polycyclic aromatic hydrocarbons and sterols were analysed using GC-MS.

### **2.3.3. Estrogen/Androgen Screening Tests**

Sample water from one 4 L amber bottle was used for each of the screening tests to detect the presence of substances in the water that might mimic estrogen or androgen hormones. The extraction procedure was the same as that for organics, except that the SPF discs were not cleaned with dichloromethane but they were conditioned with 5 mL of methanol. One disc was usually sufficient to extract 4 L of sample water, but in some cases, two discs were used. The sampled discs were transferred into petri dishes lined with baked aluminum foil and then frozen.

Analysis for potential androgen activity was conducted by the Toxicology Research Division, Health Products and Foods Branch, Food Directorate, Health Canada (Schrader and Cooke, 2003) using a human androgen receptor gene assay. The Yeast Estrogenicity Screen Bioassay (YES) was conducted at the Aquatic Ecosystem Protection Research Branch, National Water Research Institute, Environment Canada (Burnison et al., 2003).

Table 3. Organic compounds analysed in groundwater samples collected from the Lower Fraser Valley.

Pesticides and degradation products, chlorinated benzenes, PCB aroclors	Polycyclic Aromatic Hydrocarbons (PAHs)	Sterols
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Pesticides and degradation products, chlorinated benzenes, PCB aroclors	Polycyclic Aromatic Hydrocarbons (PAHs)	Sterols
1,2-Dichlorobenzene	Acenaphthylene	Desogestrel
1,3/1,4-Dichlorobenzene	Acenaphthene	Mestranol
1,2,3-Trichlorobenzene	Fluorene	Norethindrone
1,2,4-Trichlorobenzene	Phenanthrene	Estrone
1,3,5-Trichlorobenzene	Anthracene	Equilin
1,2,3,4-Tetrachlorobenzene	Fluoranthene	Norgestrel
1,2,3,5/1,2,4,5-Tetrachlorobenzene	Pyrene	Testosterone
Pentachlorobenzene	Benz(a)anthracene	Ethynylestradiol
Hexachlorobenzene	Chrysene	17 $\alpha$ -Estradiol
Hexachlorobutadiene	Benzo(a)fluoranthene	17 $\beta$ -Estradiol
Aldrin	Benzo(e)pyrene	$\beta$ -Estradiol 3-benzoate
Dieldrin	Benzo(a)pyrene	$\alpha$ -Zearalanol
Endrin	Perylene	Coprostanol
Chlordane, alpha (cis)	Dibenz(ah)anthracene	Epicoprostanol
Chlordane, gamma (trans)	Indeno(1,2,3-cd)pyrene	Cholesterol
oxy-Chlordane	Benzo(ghi)perylene	Cholestanol
o,p'-DDD	C1-Phenanthrene/Anthracene	Desmosterol
p,p'-DDD	C2-Phenanthrene/Anthracene	Ergosterol
o,p'-DDE	C3-Phenanthrene/Anthracene	Stigmasterol
p,p'-DDE	C4-Phenanthrene/Anthracene	$\beta$ -Sitosterol
o,p'-DDT	Retene	
p,p'-DDT	Dibenzothiophene	
$\alpha$ -Endosulphan (I)	C1-Dibenzothiophenes	
$\beta$ -Endosulphan (II)	C2-Dibenzothiophenes	
Endosulphan Sulphate		
$\alpha$ -HCH		
$\beta$ -HCH		
$\gamma$ -HCH		
$\delta$ -HCH		
Heptachlor		
Heptachlor Epoxide		
Methoxychlor		
Mirex		
Nonachlor (cis)		
Nonachlor (trans)		
Aroclor 1242		
Aroclor 1254		
Aroclor 1260		

## 2.4 Quality Assurance/Quality Control

Triplicate samples were submitted from one site (CHW5E) to assess the analytical precision. Three samples were collected by filling approximately  $\frac{1}{4}$  of each sample bottle consecutively, repeating the cycle until the bottles were full and submitted as 'blind' replicates (REP1, REP2 and REP3) for analyses. Four wells (CHW1E, CHW4E, CHW5E and CHW1R) were sampled in August and in September to look at short-term temporal variability for selected inorganic and bacteriological parameters.

## 3.0 RESULTS



### 3.1 Nutrients and Bacteriological Parameters

Nitrate + nitrite was detected at nearly every site and the concentrations ranged from <0.002 to 30.11 mg N/L (Table A2). More of the higher concentrations were measured at impacted sites. The mean concentration was higher at impacted sites (4.5 mg/L) compared with reference sites (0.15 mg/L; Table 4). Two samples from two impacted sites (MAT2E, MAT3E; Figure 3) had concentrations exceeding the 10 mg N/L Canadian guideline maximum acceptable concentration (MAC) for drinking water (Table A3). Nitrite was detected in six samples from impacted sites and two of these samples (0.28 mg N/L at ABT5 in Abbotsford and 0.2 mg N/L at CHW4E in Chilliwack) were above the Canadian water quality guideline (WQG) of 0.06 mg N/L for the protection of fresh water aquatic life (CCME 2002).

Total phosphorus (detection limit = 0.05 mg/L) was detected at only two sites: one impacted site (0.09 mg/L at ABT2) and one reference site (0.13 mg/L at CHW1R in September) (Table A2). The reference site CHW1R did not have a detectable concentration of phosphorus when it was sampled in August. Total dissolved phosphorus (detection limit = 0.002 mg/L) was detected at all sites sampled (Table A2) and on average it tended to be higher at impacted sites (Table 4).

Bacterial counts were positive at four impacted sites (ABT4, MAT1E, MAT2E, CHW7E; Figure 3), with total coliform counts ranging from 2 to 1300 colonies per 100 ml (Table A2). Total coliforms, fecal coliforms and *Escherichia coli* counts were all detected at MAT2E. Only total coliforms were detected at the other three sites. Coliforms and *E. coli* were not detected at the reference sites.

### 3.2 Metals and Major Ions

The concentrations of common ions and trace elements were often higher at impacted sites than at reference sites (Table 4). However, most variables at both impacted and reference sites were at relatively low concentrations (conductivities < 300  $\mu$ S/cm). Calcium was the most prevalent cation while sulphate was the most prevalent anion in both impacted and reference wells (Table 4). Fluorides were detected at all sites except for one (MAT2E). One impacted site (MAT1E) in Abbotsford/Matsqui exceeded the fluoride MACs for drinking and WQGs for irrigation and livestock uses (Figure 3).

Most trace metals were found in higher concentrations at impact sites than at reference sites (Table 4). The exceptions were for arsenic, selenium, copper and zinc. Arsenic and selenium concentrations were similar in reference and impact samples (Table 4; Table A2). Copper and zinc concentrations were variable in both reference and impact samples. Most trace metals concentrations were within the acceptable limits of the CCME guidelines for drinking, irrigation, livestock watering and protection of freshwater life (Table A3). However copper exceeded guidelines at 11 sites (Table A2) and some other metals' concentrations (selenium, aluminum, iron, manganese, lead and zinc) were above guideline MACs and/or WQGs for various uses in at least one well in both impacted and reference areas. Figure 4 presents the number of metals exceedances at each site.

Table 4. Summary of inorganic, nutrient and bacteriological concentrations in groundwater sampled in the Lower Fraser Valley.

Parameters (units in mg/L unless otherwise stated)	Impacted Sites					Reference Sites				
	# above DL/total # sampled	Average <sup>1</sup>	Standard Deviation	Min	Max	# above DL/total # sampled	Average <sup>1</sup>	Standard Deviation	Min	Max
Bromide	0 /16	< 0.05				0 /4	< 0.05			
Chloride	15 /16	5.84	± 4.78	< 0.1	15.00	4 /4	2.02	± 1.64	0.43	4.3
Fluoride	15 /16	0.23	± 0.55	< 0.01	2.30	4 /4	0.08	± 0.07	0.02	0.19
Nitrate + Nitrite as Nitrogen total	14 /16	4.50	± 8.99	< 0.002	30.10	4 /4	0.15	± 0.09	0.042	0.268
Nitrite as Nitrogen	5 /16	0.027	± 0.073	< 0.005	0.280	0 /4	< 0.005			
Total Phosphorus	1 /16	< 0.05	± 0.023	< 0.05	0.090	1 /4	0.016	± 0.033	< 0.05	0.065
Phosphorus total dissolved	16 /16	0.062	± 0.176	0.002	0.720	4 /4	0.038	± 0.062	0.003	0.13
Sulphate	15 /16	23.35	± 18.00	< 0.05	70.00	4 /4	19.53	± 21.97	1.7	50
Conductivity ( $\mu$ S/cm)	16 /16	267	± 110	99	430	4 /4	137	± 108	27	253
pH ( <i>relative units</i> )	N/A	7.18	± 0.66	5.99	8.03	N/A	7.31	± 0.68	6.68	8.22
Residue filterable	16 /16	190	± 85	65	360	4 /4	98	± 64	30	170
Arsenic	16 /16	0.0009	± 0.0016	0.0001	0.0058	2 /4	0.0018	± 0.0032	< 0.0001	0.0066
Selenium	10 /16	0.0003	± 0.0003	< 0.0001	0.0009	4 /4	0.0006	± 0.0010	0.0001	0.0021
Silver	1 /15	< 0.0001	± <0.0001	< 0.0001	0.0001	0 /4	< 0.0001			
Aluminum	11 /15	0.1926	± 0.6863	< 0.002	2.6700	2 /4	0.0015	± 0.0019	< 0.002	0.004
Barium	15 /15	0.0387	± 0.0335	0.0021	0.1040	4 /4	0.0101	± 0.0070	0.0049	0.0205
Beryllium ( $\mu$ g/L)	1 /15	0.0053	± 0.0207	< 0.05	0.0800	0 /4	< 0.05			
Cadmium	5 /15	0.0001	± 0.0001	< 0.0001	0.0005	0 /4	< 0.0001			
Cobalt	12 /15	0.0004	± 0.0007	< 0.0001	0.0022	0 /4	< 0.0001			
Chromium	9 /15	0.0010	± 0.0024	< 0.0001	0.0093	1 /4	0.0002	± 0.0004	< 0.0001	0.0007
Copper	15 /15	0.008	± 0.014	0.0002	0.047	4 /4	0.018	± 0.021	0.0004	0.0461
Iron	15 /15	0.522	± 1.066	0.002	3.610	4 /4	0.017	± 0.012	0.0073	0.0347
Mercury ( $\mu$ g/L)	0 /16	< 0.05				0 /4	< 0.05			
Lithium	14 /15	0.0010	± 0.0008	< 0.0001	0.0032	3 /4	0.0008	± 0.0010	< 0.0001	0.0022
Manganese	15 /15	0.1429	± 0.1969	0.0002	0.6750	4 /4	0.0019	± 0.0022	0.0003	0.0051
Molybdenum	15 /15	0.0008	± 0.0007	0.0001	0.0025	4 /4	0.0021	± 0.0033	0.0002	0.007
Nickel	10 /15	0.0022	± 0.0032	< 0.0003	0.0096	1 /4	0.0001	± 0.0002	< 0.0003	0.0003
Lead	10 /15	0.0005	± 0.0006	< 0.0002	0.0021	4 /4	0.0005	± 0.0003	0.0002	0.0009
Strontium	15 /15	0.1779	± 0.1236	0.0441	0.4140	4 /4	0.1363	± 0.1406	0.0168	0.317
Vanadium	13 /15	0.0012	± 0.0022	< 0.0001	0.0076	3 /4	0.0002	± 0.0003	< 0.0001	0.0006
Zinc	15 /15	0.0088	± 0.0102	0.0010	0.0408	4 /4	0.0270	± 0.0175	0.0013	0.0404
Calcium	16 /16	35.34	± 18.36	11.70	80.60	4 /4	21.63	± 19.45	2.9	42.8
Potassium	16 /16	1.74	± 1.07	0.70	4.20	4 /4	1.31	± 0.76	0.7	2.25
Magnesium	16 /16	8.63	± 4.55	1.55	16.90	4 /4	2.30	± 1.64	0.8	4.6
Sodium	16 /16	7.75	± 9.31	1.55	41.50	4 /4	3.93	± 2.58	1.2	6.6
Silicon	16 /16	10.27	± 3.92	3.85	16.80	4 /4	5.55	± 1.26	3.66	6.24
Hardness	16 /16	124	± 57	42	234	4 /4	64	± 55	10.2	126
E coli (MPN/100mL)	1 /16	1	± 6	0	22	0 /4	0			
Total Coliform (MPN/100mL)	4 /16	139	± 385	0	1300	0 /4	0			
Fecal Coliform (MPN/100mL)	1 /16	5	± 20	0	79	0 /4	0			

<sup>1</sup>Average of all sample results including those below detection limits (DL) (treated as zeros). Replicate values were averaged to represent the site (CHW1E, CHW4E, CHW5E, CHW1R); thus maximum and minimum values may not match the sample values in Table A2.  
N/A = not applicable

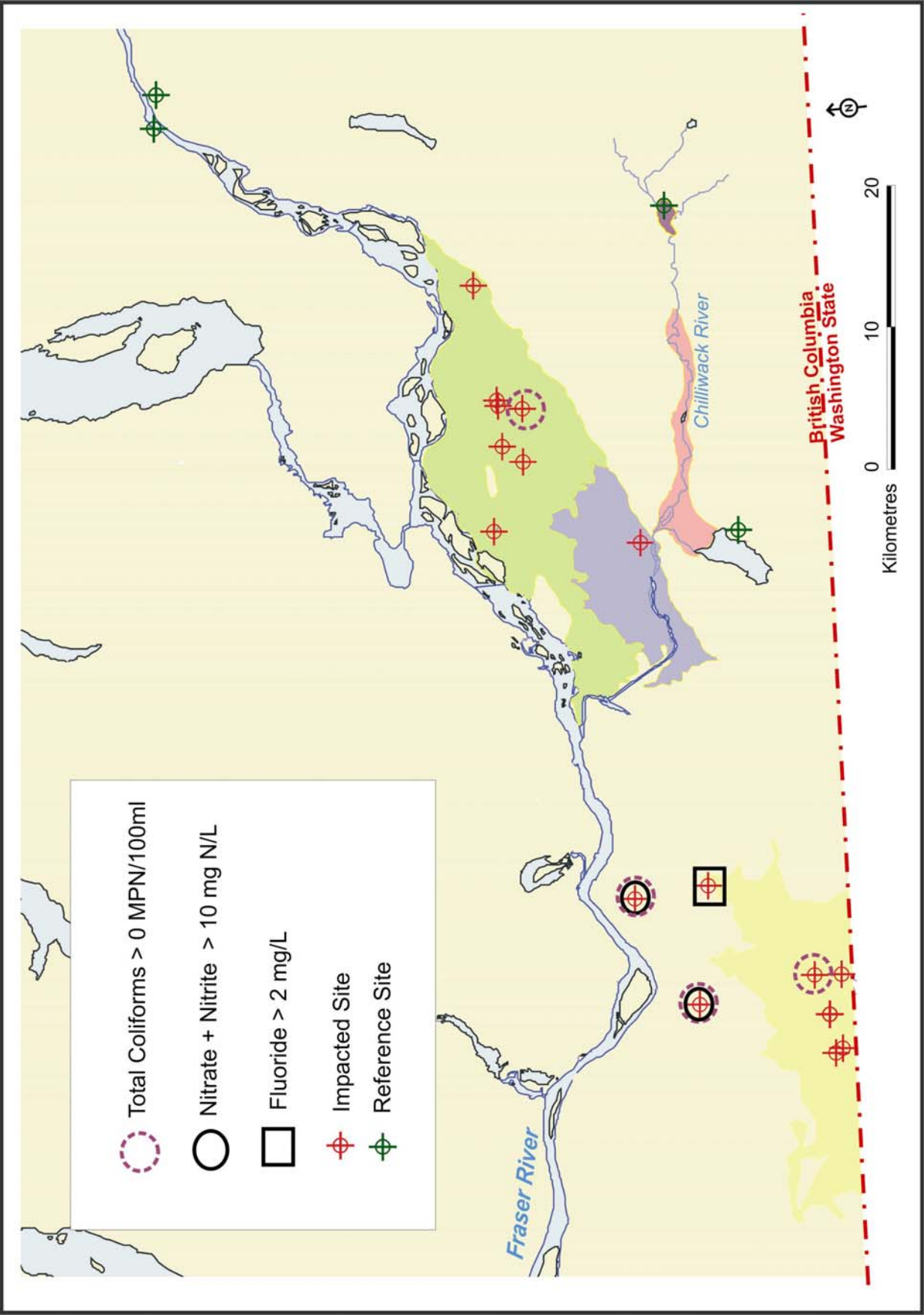


Figure 3. Sample sites with fluoride, nitrate + nitrite and total coliforms exceeding CCME guidelines.

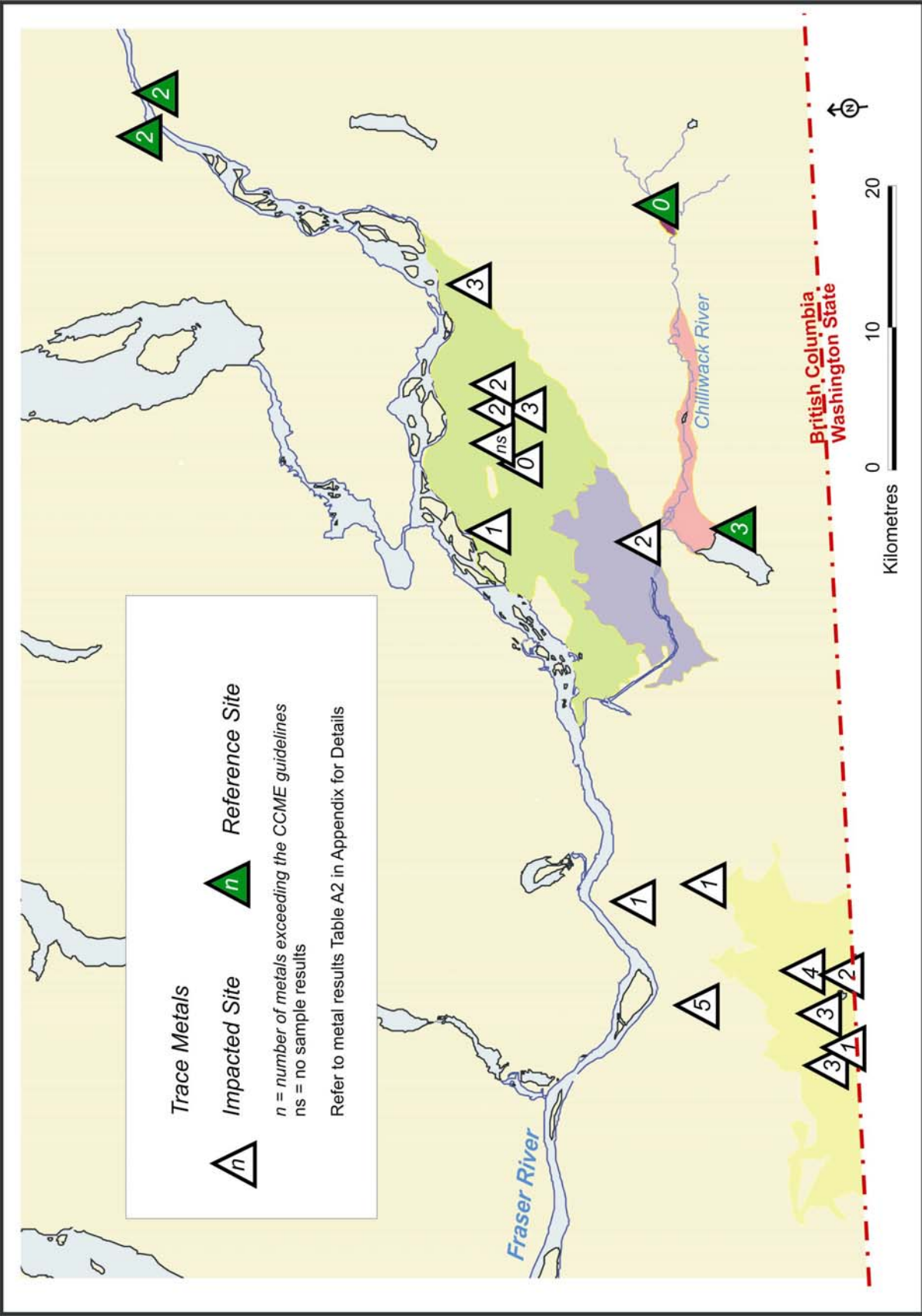


Figure 4. Number of trace metals exceeding the CCME guidelines at sample sites.

The pH values from three sites in the Abbotsford/Matsqui area were lower than the Canadian guideline MACs' range for drinking and WQGs' range for the protection of fresh water aquatic life.

### **3.3 Organic Compounds**

The results for all organic compounds including pesticides, their degradation products, chlorinated benzenes, PCB Aroclors, PAHs and sterols are found in the Appendix (Table A4). All the concentrations were blank corrected and those concentrations with a detected peak that did not meet quantification criteria have been reported and flagged. A comparison of the number of detected compounds at impacted sites versus reference sites is shown in Tables 5a and 5b. All concentrations are below available CCME guidelines MACs for drinking water and WQGs for the protection of freshwater life where they exist (Table A3).

#### **3.3.1 Pesticides, Chlorinated benzenes and PCB Aroclors**

Pesticides, their degradation products, chlorinated benzenes and PCB aroclors were analysed for all samples. Isomers of dichlorobenzene and trichlorobenzene were detected in nearly all quantifiable samples (Table A4). Chlorinated benzenes were most commonly detected in the piezometers (ABT1-5; Table 5a). The compounds, 1,2,3-trichlorobenzene, tetrachlorobenzene and pentachlorobenzene, were found only in impacted wells at levels very close to the sample detection limits (Table A4).

The pesticide related compounds,  $\delta$ -HCH,  $\gamma$ -HCH and DDE, were detected at reference and impacted sites (Table 5b). Pesticides were not detected at several impacted sites (ABT1, ABT5, MAT2E, MAT3E, CHW4E, and CHW5E) and two reference wells (CHW1R and CHW4R; Table 5b)

Endosulphan compounds, DDT, DDE, DDD and methoxychlor were detected at impacted sites but not at reference sites (Table 5b).  $\beta$ -Endosulphan (II) was the most commonly detected pesticide; it was found at six of the 16 sites exposed to agriculture, followed by  $\alpha$ -Endosulphan, which was found at four of the impacted sites. PCB aroclors were only detected at one site (CHW3R, Table 5) at a concentration close to the detection limit for that sample (0.31 ng/L).

#### **3.3.2 Polycyclic Aromatic Hydrocarbons (PAHs)**

Nine randomly chosen sites from impacted areas were analysed for PAHs as well as one replicate sample (REP1). PAHs were detected at all these sites except at ABT4 (Table 5a). The maximum number of detections at the impacted sites was found in CHW3E. Fluoranthene and pyrene were the most common PAHs found at the impacted sites (Table 5b).

Only two of the four reference wells were analysed for PAHs. The maximum number of detections and the highest concentrations were all measured at the CHW1R reference site, in the Upper Chilliwack aquifer (Table 5a). Phenanthrene, pyrene, C1-phenanthrene/anthracene and C2-phenanthrene/anthracene were observed in both reference wells. CHW1R generally had higher levels of several PAHs (Table A4) however none exceeded available WQGs for the protection of aquatic life or MACs for drinking water (Table 4).

### **3.3.3 Sterols**

A total of 10 of the 20 sterols tested were detected at the 11 sites sampled for sterols (Table 5b). Detectable concentrations were found at each site sampled, including the two reference sites. ABT3 and MAT2E had the greatest number of detectable sterol concentrations (Table 5b). The highest concentrations were measured at MAT2E, close to the Abbotsford aquifer. Equilin, testosterone, ethynylestradiol, coprostanol, cholestanol, desmosterol and stigmaterol were detected in impacted wells but not in reference wells (Table 5b). Cholesterol was found in all samples with the highest concentration occurring at MAT2E (Table A4). Generally, the reference wells had a similar range of cholesterol and  $\beta$ -sitosterol concentrations as the impacted wells (Table A4), with the exception of MAT2E.

### **3.4 Androgen and Estrogen Screening Tests**

Results of all samples analyzed for potential androgen activity were negative. Nine of the 23 samples exhibited very weak estrogenic activity with sample CHW6E having the highest level of activity (26.8% of maximum estradiol activity when compared to the positive estradiol control, Table A5).

### **3.5 Quality Assurance / Quality Control**

Triplicate samples (REP1, REP2 and REP3) collected at CHW5E were taken “simultaneously” to assess analytical precision. Most inorganic parameters had low coefficients of variation, with the exception of copper and zinc (Table 6). These metals had coefficients of variation of 139.7% and 80.5%, respectively.

Analytical precision of organic results was assessed only for pesticides, chlorinated benzenes and PCB aroclors because two of the three splits (REP2 and REP3) were not analysed for PAHs or sterols (Table A4). Five chlorinated benzene compounds were found in at least one of the triplicate samples. The concentrations were either similar or close to the detection limit (Table A4).

PAHs and sterols were measured in REP3 and compared with CHW5E for site variability. Concentrations of PAHs and chlorinated benzenes, as well as their detected compounds, varied in these two samples (Table A4). Cholesterol was detected in both samples and the concentrations were similar.

Table 5a. Number of detected organic compounds in each of the contaminant groups at groundwater sampling locations.

Sample ID	Chlorinated Benzenes	Pesticides	PCB Aroclors	Polycyclic aromatic hydrocarbons	Sterols
Impacted wells					
ABT1	7	0	0	5	1
ABT2	6	1	0	-	-
ABT3	7	4	0	0	5
ABT4	6	3	0	0	3
ABT5	5	0	0	-	-
MAT1E	0 (NQ)	4	0	-	-
MAT2E	0 (NQ)	3	0	3	6
MAT3E	0 (NQ)	0	0	-	-
CHW1E	4	4	0	-	-
CHW2E	5	2	0	3	2
CHW3E	4	2	0	10	1
CHW4E	1	0	0	-	-
CHW5E	3	0	0	10	2
REP1	4	0	0	-	-
REP2	3	0	0	-	-
REP3	3	0	0	1	1
CHW6E	0	2	0	5	4
CHW7E	3	2	0	-	-
CHW8E	4	1	0	5	1
Reference wells					
CHW1R	4	0	0	13	1
CHW2R	4	2	0	-	-
CHW3R	2	1	1	4	3
CHW4R	0 (NQ)	0	0	-	-

NQ = not quantifiable for some contaminants

- = not sampled

Table 5b. Percentage of sites with detectable concentrations of organic compounds at impacted and reference locations.

	<b>Impacted sites</b> n=16	<b>Reference sites</b> n=4		<b>Impacted sites</b> n=9	<b>Reference sites</b> n=2
<b>Chlorinated Benzenes</b>	%	%	<b>PAHs</b>	%	%
1,3/1,4-Dichlorobenzene	62	50	Acenaphthene	55	50
1,2-Dichlorobenzene	69	50	Fluorene	22	50
1,2,3-Trichlorobenzene	6	0	Phenanthrene	55	100
1,2,4-Trichlorobenzene	75	75	Fluoranthene	67	50
1,3,5-Trichlorobenzene	19	25	Pyrene	78	100
1,2,3,5/1,2,4,5-Tetrachlorobenzene	6	0	Chrysene	33	50
1,2,3,4-Tetrachlorobenzene	31	0	Benzo(ghi)perylene	22	50
Pentachlorobenzene	12	0	C1-Phenanthrene/Anthracene	44	100
Hexachlorobenzene	25	50	C2-Phenanthrene/Anthracene	33	100
<b>Pesticides</b>			C3-Phenanthrene/Anthracene	22	0
δ-HCH	12	25	C1-Dibenzothiophenes	22	50
γ-HCH	19	25	C2-Dibenzothiophenes	11	0
pp'-DDE	12	25	<b>Sterols</b>		
op'-DDD	6	0	Equilin	11	0
pp'-DDD	12	0	Testosterone	11	0
pp'-DDT	19	0	Ethynylestradiol	11	0
Dieldrin	6	0	α-Zearalanol	11	0
α-Endosulphan (I)	25	0	Cholestanol	11	0
β-Endosulphan (II)	38	0	Cholesterol	100	100
Endosulphan Sulphate	19	0	Desmosterol	22	0
Methoxychlor	6	0	Ergosterol	11	50
			Stigmasterol	22	0
			β-Sitosterol	67	50



Table 6. Analytical variability in triplicate samples collected at CHW5E.

<b>Parameters</b> <i>(units in mg/L unless otherwise stated)</i>	<b>REP 1</b>	<b>REP 2</b>	<b>REP 3</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Coefficient of Variation</b>
<b>Sample Date</b>	8/27/1998	8/27/1998	8/27/1998			
Bromide	<0.05	<0.05	<0.05	< DL		
Chloride	4	4.1	4.2	4.1	± 0.1	<b>2.4</b>
Fluoride	0.1	0.11	0.11	0.11	± 0.01	<b>5.4</b>
Nitrate + Nitrite as Nitrogen total	0.302	0.302	0.289	0.298	± 0.008	<b>2.5</b>
Nitrite as Nitrogen	<0.002	<0.002	<0.002	< DL		
Total Phosphorus	<0.05	<0.05	<0.05	< DL		
Phosphorus total dissolved	0.02	0.02	0.018	0.019	± 0.001	<b>6</b>
Sulphate	14	14	14	14		<b>0</b>
Conductivity ( $\mu\text{S/cm}$ )	247	245	247	246	± 1	<b>0.5</b>
pH ( <i>relative unit</i> )	7.39	7.42	7.39	7.40	± 0.02	<b>0.2</b>
Residue filterable	170	160	160	163	± 6	<b>3.5</b>
Arsenic	0.0007	0.0008	0.0008	0.0008	± 0.0001	<b>7.5</b>
Selenium	0.0003	0.0003	0.0003	0.0003		<b>0</b>
Silver	<0.0001	<0.0001	0.0001	0.00003	± 0.00006	
Aluminum	<0.002	0.002	<0.002	< DL		
Barium	0.0501	0.047	0.0502	0.0491	± 0.0018	<b>3.7</b>
Beryllium ( $\mu\text{g/L}$ )	<0.05	<0.05	<0.05	< DL		
Cadmium	<0.0001	<0.0001	<0.0001	< DL		
Cobalt	0.0002	0.0002	0.0001	0.0002	± 0.0001	<b>34.6</b>
Chromium	<0.0002	0.0002	0.0003	0.0003	± 0.0001	<b>28.3</b>
Copper	0.0004	0.00473	0.0003	0.0018	± 0.0025	<b>139.7</b>
Iron	0.0072	0.0049	0.0056	0.0059	± 0.0012	<b>20</b>
Mercury ( $\mu\text{g/L}$ )	<0.05	<0.05	<0.05	< DL		
Lithium	0.0013	0.0013	0.0014	0.0013	± 0.0001	<b>4.3</b>
Manganese	0.425	0.432	0.439	0.4320	± 0.007	<b>1.6</b>
Molybdenum	0.0006	0.0005	0.0006	0.0006	± 0.0001	<b>10.2</b>
Nickel	0.0003	0.0004	0.0005	0.0004	± 0.0001	<b>25</b>
Lead	0.0006	<0.0002	0.0005	0.0006	± 0.0001	<b>12.9</b>
Strontium	0.155	0.145	0.156	0.1520	± 0.0061	<b>4</b>
Vanadium	0.0001	0.0001	0.0001	0.0001		<b>0</b>
Zinc	0.0058	0.0181	0.0043	0.0094	± 0.0076	<b>80.5</b>
Calcium	37.3	37.5	37.9	37.6	± 0.3	<b>0.8</b>
Potassium	1.5	1.6	1.6	1.6	± 0.1	<b>3.7</b>
Magnesium	8.1	8.1	8.2	8.1	± 0.1	<b>0.7</b>
Sodium	4.2	4.2	4.1	4.2	± 0.1	<b>1.4</b>
Silicon	12.8	12.8	13	12.9	± 0.1	<b>0.9</b>
Hardness	126	127	128	127	± 1	<b>0.8</b>
E coli (MPN/100mL)	0	0	0	0		
Total Coliform (MPN/100mL)	0	0	0	0		
Fecal Coliform (MPN/100mL)	0	0	0	0		

DL = detection limit

## 4.0 DISCUSSION

### 4.1 Nutrient and Bacterial Contamination

Nitrate + nitrite contamination in certain LFV aquifers has been well documented in previous studies (Liebscher *et al.*, 1992; Carmichael *et al.*, 1995; Hii *et al.*, 1999; Zobel, 2000). Elevated nitrate + nitrite concentrations in groundwater, usually above 3 mg N/L, may indicate contamination from human and/or agricultural activities (Zobel, 2000). Hii *et al.* (1999) indicated that high nitrate concentrations in certain areas of the Abbotsford aquifer were likely due to intense agricultural land-use activities like livestock manure applications on raspberry farms either directly above or up gradient. Wassenaar (1995) showed that the main source of nitrate to the groundwater was agricultural activity.

The two aquifers classified as Class 1A, Abbotsford and Chilliwack, had differing average nitrate + nitrite concentrations. The average concentration for the Abbotsford aquifer was 2.5 mg N/L, whereas it was 0.2 mg N/L for the Chilliwack/Vedder aquifers. One factor that may contribute to this observation is the difference in agricultural activity in the two areas. In 2000, corn, forage grass and pasture comprised over 60 percent of land use in the Chilliwack/Vedder area while raspberry farms accounted for less than one percent (Hii *et al.*, 1999). In contrast, raspberry comprised about 60 percent of land use in the Abbotsford aquifer (Hii *et al.*, 1999). The potential for nitrate + nitrite leaching, relative to crop type, in the LFV is probably in the order of raspberries > corn > grass (Kowalenko, 2000). Raspberry crops are probably more vulnerable to nitrate + nitrite leaching because they are planted in wide rows and require less nitrogen. In a field study on raspberry crops conducted by Dean *et al.* (2000), about 50 percent of the total nitrogen per hectare applied as manure was recovered as soil inorganic nitrogen one month after manure application. The nitrogen up-take in grass, being a perennial crop with active roots all year round, is more than in corn, an annual crop (Kowalenko, 2000).

Another factor that may contribute to the lower nitrate + nitrite concentrations in the Chilliwack area may be the dilution of groundwater due to the seasonal fluctuations of the Fraser River influencing the shallow water table. Hence, the Chilliwack and Vedder aquifers are periodically flushed, whereas dilution in the Abbotsford aquifer is more gradual and mainly results from fall and winter precipitation.

Two sites in the Matsqui area (MAT2E and MAT3E) had the highest nitrate + nitrite concentration. The samples were taken from shallow wells in unconfined aquifers. The groundwater at these sites appears to be exposed to a significant source of nitrogen.

Total coliform bacteria include many bacteria that grow in soil, water and in digestive tracts of animals. Fecal coliforms, including *Escherichia coli*, are a type of coliform bacteria that generally grow and multiply only in the digestive systems of warm-blooded animals, including humans (CCME, 1996). The Canadian Drinking Water Guideline for total coliform is 10 total coliform organisms per 100 mL, and zero for fecal coliform and *Escherichia coli* (CCME, 1996).

Data from a 1992 Environment Canada fecal coliform sampling in the LFV (B. Hii, Environment Canada, unpublished data) indicate that surface water bodies like creeks

and ponds were more susceptible to bacterial contamination than groundwater. Over 90 percent of the surface water samples were contaminated with fecal coliform compared to less than 20 percent of the groundwater samples. The results also show that bacterial contamination in groundwater decreases with increasing depths. No fecal coliforms were found in wells deeper than 20 metres in the Abbotsford aquifer. Bacteria can potentially contaminate shallow wells in unconfined aquifers that are down gradient of septic fields. It was shown in a study of the impact of septic tank effluent on groundwater quality in a LFV aquifer (Environment Canada and BC Ministry of Health, 1994) that groundwater quality down gradient of the effluent source (up to 30 m) likely will be affected by the effluent, and nitrate concentration and coliform counts could potentially be over their respective CCME guidelines.

Bacterial contamination was found in one piezometer (ABT4) and in three domestic wells located in impacted sites (MAT1E, MAT2E in the Abbotsford/Matsqui area and CHW7E in the Chilliwack/Vedder area) during this survey (Figure 3, Table A2). These wells, other than MAT2E, were not shallow but at intermediate depths (14 – 20m; Table 2). However MAT2E was the shallowest well sampled (5m). This site also had elevated nitrate + nitrite and sterols levels which are also indicative of agricultural sources.

### **4.3 Metal Contamination**

The higher concentration of metal contaminants in the impacted sites is probably an indication of the greater likelihood of exposure of these groundwaters to a variety of activities associated with agriculture and general human presence. Nearly all wells in both impacted and reference sites had at least one metal that exceeds a CCME water quality guideline (Figure 4). The most common guideline exceedances were for the protection of freshwater aquatic life and these exceedances may be most meaningful in locations where the groundwater discharges into surface waters. Elevated iron and manganese can occur naturally in groundwater and are the most common elements that exceeded the guidelines. However, some of the elevated metal concentrations (iron, copper and manganese) may also be due to 'biofouling', caused by microbial activity, in the wells' water delivery systems. Biofouling is the process where bacterial colonies form a gel-like slime or biofilm that captures chemicals, minerals and other deposits moving through the well during pumping. Iron and manganese oxides, byproducts associated with bacterial growth, will also become accumulated in the biofilms (Legault, 1999). The sites with positive coliform counts also had iron and manganese concentrations exceeding their respective Canadian water quality MACs for drinking water.

It is suspected that the elevated copper and zinc values may represent the variability due to sampling and analytical procedures (Table 6). Low level analysis of copper, zinc, iron and aluminum is susceptible to contamination, especially if open digestion methods (as used for these analyses) are employed (Gino Sardella, National Laboratory for Environmental Testing, personal communication).

## 4.4 Organic Contamination

### 4.4.1 Pesticides, Chlorinated benzenes and PCB Aroclors

Chlorinated benzenes were detected at most sites. Low concentrations of 1,2 dichlorobenzene and 1,2,4 trichlorobenzene were detected in all quantifiable samples with no marked difference between impacted and reference sites. While other chlorinated benzenes were detected mainly at impacted sites, they were found at very low levels. The sources of these ubiquitous compounds may have been numerous as their primary uses are as fumigants, insecticides, industrial solvents, chemical intermediate and degreasing agents for metals (Government of Canada, 1993).

Other pesticides or their degradation products were detected at fewer sites. Endosulphan was detected at six impacted sites (MAT1E, MAT2E, CHW1E, CHW2E, CHW3E, CHW6E) and it was the most commonly detected pesticide in this survey. It is a broad-use insecticide for fruit, corn, clover, ornamental trees and shrubs (CCREM, 1987). As a result of its broad application, it was observed in wells down gradient from residential, nursery, dairy, poultry and raspberry land use areas. It was not observed down gradient of hobby farms (e.g. CHW4E, CHW5E). This pesticide has relatively high usage in the Fraser Valley based on sales data (Enkon, 2001). Previous studies also detected endosulphan sulphate, a degradation product of endosulphan, in a few groundwater samples from the Abbotsford /Matsqui areas (Liebscher *et. al.*, 1992).

Methoxychlor was detected in one well down gradient from a nursery (CHW1E). It is primarily used for the control of blackfly larvae (CCREM, 1987). DDT, a broad-spectrum insecticide now banned in Canada (Voldner and Ellenton 1987), and its metabolites (DDD and DDE) were found in five wells exposed to raspberry land use and residential activities. These are very persistent compounds and are probably being observed as a result of historical use in the area.

### 4.4.2 Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs were found in almost all impacted and reference wells. PAHs are usually not associated specifically with agricultural activities. Documented PAH sources include natural (such as plant debris, oil seeps and forest fires) and anthropogenic (combustion and fossil fuels) (Yunker and MacDonald, 1995). Possible sources of PAHs in the LFV groundwaters are run-off from highway deposits and atmospheric deposit as well as plant breakdown products. The highest levels of many of the PAHs were detected at the CHW1R reference site located in the relatively undisturbed Upper Chilliwack aquifer. These elevated levels appear to be an anomaly. The concentrations are about one order of magnitude higher than those detected in nearby surface waters (e.g. Fraser River estuary, Sylvestre *et. al.*, 1998). The CHW1R detections may be a result of contamination in field collection or at the analytical lab.

The wells that showed the highest total PAH concentrations were CHW3E and CHW5E. Pyrene was detected at almost all sites sampled and concentrations were elevated relative to fluoranthene in CHW6E and CHW8E. This low fluoranthene/fluoranthene+pyrene ratio suggests that the source of PAHs is likely from

combustion of gasoline and diesel from cars and trucks (Yunker and Macdonald, 2002). Although CHW3E is a deep well, it was located in the middle of a gravel parking lot thus, not surprisingly, petroleum related compounds such as dibenzothiophenes (Berthou and Vignier 1996) were detected also.

The predominance of the alkylated phenanthrene/anthracenes (C1 to C4), relative to their parent PAHs at ABT1, CHW3E, CHW5E and the reference well CHW3R is indicative of petrogenic (natural petroleum) sources (Yunker and Macdonald 1995). The reference well CHW3R is close to the highway at a rest stop, which gets frequent traffic and also had low levels of some PAHs similar to impacted wells. It does not appear to be the farming practices that result in the low concentrations of PAHs, but rather the exposure to general human activity and natural petrogenic sources.

#### **4.4.3 Sterols**

The detections of cholesterol (an animal sterol) and  $\beta$ -sitosterol (a plant sterol) in nearly all wells (nine impacted and two reference sites) sampled for sterols suggest that these two sterols are relatively ubiquitous in LFV groundwater. Equilin (horse estrogen used in hormone replacement therapy, FDA, 1997), ethynylestradiol (synthetic hormone used in oral contraceptives, Schultz *et al.*, 2003), testosterone (natural animal sterol often used as growth promoter in cattle) and  $\alpha$ -zearalanol (fungal estrogen used as a growth promoter in cattle, Le Guevel and Pakdel, 2001) were detected in impacted wells only. Equilin was found down gradient of residential land use. There were no obvious horse farms in the area, thus the presence of it was likely from human sources. Testosterone and ethynylestradiol were detected at ABT3 that is exposed to primarily raspberry land use. As it is a shallow well, it may also have been influenced by anthropogenic effects in Fishtrap Creek through surface water-groundwater exchange. Although  $\alpha$ -zearalanol is a growth hormone for cattle, it is also naturally occurring as a derivative of zearalenone (an estrogen in fungi affecting corn and other grain) and it was found in ABT4. There is no commercial cattle production up gradient of this site but there may have been corn crops and hence a likelihood of the fungus containing this sterol.

The impacted shallow well, MAT2E, which also had elevated nitrate + nitrite and coliform concentrations, had the greatest number of detected sterol compounds and the most elevated concentrations, indicating a nearby source of animal and plant sterols to this well.

While there was little evidence of the wide spread presence of sterols, other than cholesterol and  $\beta$ -sitosterol, the presence of equilin, testosterone and ethynylestradiol indicates that the groundwater in the LFV is affected by all forms of human activity and not only by agricultural land use, despite its intensity in the region.

#### **4.5 Estrogen/Androgen screening**

The pilot screening for estrogenic and androgenic activity in the groundwaters indicates no significant positive results. Although nine samples showed estrogenic activity (10 – 26.8% of maximum estrogenic activity), this activity was very weak. Levels of 10% of maximum estrogenic activity or less are considered negative (K. Burnison, National

Water Research Institute, personal communication). Sample CHW6E produced the highest level of estrogenic activity with a 26.8% positive response in the YES assay. However this sample is still considered to have only a weak response. Nonetheless this site is unlike the other sites as it is primarily exposed to residential land use rather than agriculture.

## 5.0 SUMMARY

- Nitrate + nitrite concentrations were higher in groundwater samples collected from the Abbotsford/Matsqui areas than those from the Chilliwack/Vedder areas.
- Nitrate + nitrite concentrations were higher at sites exposed to agricultural activity (impacted sites) than those at reference sites and might be related to specific land uses.
- Bacterial contamination was found in four of 16 impacted wells; two of these wells also had elevated nitrate + nitrite concentrations.
- Impacted sites generally had more detections and higher concentrations of metals than reference sites.
- Several metals, including iron, manganese, aluminum, copper and zinc, exceeded the CCME guidelines for drinking water, the protection of fresh water aquatic life, irrigation and/or livestock watering, at impacted and reference sites. Some of these elevated levels may have been from contamination by the wells' water delivery systems (e.g., copper pipes) or from sampling or analytical procedures.
- Pesticides were detected more frequently at impacted sites than at reference sites, but their concentrations were low.
- Endosulphan was the most frequently detected pesticide and it was detected only at impacted sites. This suggests that groundwaters are affected by endosulphan originating from agricultural activity.
- Some PAHs (i.e., dibenzothiophenes, fluoranthene and pyrene ratios) and sterols (i.e., equilin, ethynylestradiol) suggest exposure to anthropogenic activities other than agriculture at some impacted sites.
- Some PAH and sterol compounds (i.e., pyrene, cholesterol,  $\beta$ -sitosterol) appear to have a ubiquitous presence in groundwater at both impacted and reference sites, indicating exposure to general human presence.
- Estrogen/Androgen screening tests did not result in any significant positive activity, with the exception of an indication of weak estrogenic activity at one site.

This survey of groundwater quality in 20 wells and/or piezometers in the Lower Fraser Valley showed that agricultural activities can result in an increase in bacterial, nutrient

and pesticide levels and possible sterol levels (in shallow wells) in groundwater. However, groundwater in the Lower Fraser Valley is also affected by general human presence. Re-sampling is recommended to confirm some detections (e.g., at the reference CHW1R site) and to assess site variability.

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## APPENDIX

Table A1. Groundwater use<sup>1</sup> in 2000 in important Lower Fraser Valley aquifers.

Important LFV Aquifers	District / City / Village / etc.	Population	Population serviced wholly or in part by municipal / community wells	Population serviced by private wells	% Population using groundwater for water supply	Source of Information
Unknown*	Unincorporated areas between Hope and Chilliwack	1,200	0	1,200	100	Fraser Valley Regional District
Chilliwack* Vedder* Upper Chilliwack River* Chilliwack River/Cultus Lake* Columbia Valley	Chilliwack	70,000	50,000	20,000	100	District of Chilliwack
Abbotsford* Matsqui Slough	Abbotsford	120,000	40,000	10,000	42	City of Abbotsford

<sup>1</sup>groundwater use data from Marc Zubel, BC Ministry of Water, Land and Air Protection.

\* groundwater sample(s) taken in this aquifer during 1998 GBEI survey.

Table A2. Concentrations of inorganic and bacteriological parameters in groundwater collected from the Lower Fraser Valley. (mg/L unless otherwise stated)

Sampling Site	ABT1	ABT2	ABT3	ABT4	ABT5	MAT1E	MAT2E	MAT3E	CHW1E	CHW1E
Sampling Date	8/17/1998	8/17/1998	8/17/1998	8/17/1998	8/17/1998	8/17/1998	8/17/1998	8/17/1998	8/20/1998	9/24/1998
Bromide	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chloride	3.5	15	1.6	3.2	11	10	<0.1	15	0.91	0.82
Fluoride	0.08	0.19	0.06	0.08	0.27	<b>2.3</b> <sup>1,2,4</sup>	<0.1	0.07	0.03	0.02
Nitrate + Nitrite as Nitrogen total	0.009	0.019	2.72	0.577	7.83	4.02	<b>23.3</b> <sup>1</sup>	<b>30.1</b> <sup>1</sup>	0.238	0.192
Nitrite as Nitrogen	<0.005	<0.005	<0.005	0.006	<b>0.28</b> <sup>1,3</sup>	<0.005	<0.005	0.023	<0.005	<0.005
Total Phosphorus	<0.05	0.09	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Phosphorus total dissolved	0.028	0.02	0.008	0.008	0.004	0.72	0.073	0.022	0.006	ns
Sulphate	20	<0.05	3.7	8	70	27	30	46	7.5	7.4
Conductivity ( $\mu\text{S}/\text{cm}$ )	174	353	99	161	374	309	326	430	113	110
pH ( <i>relative unit</i> )	8.03	7.57	7.02	7.54	<b>6.06</b> <sup>1,3</sup>	6.66	<b>5.99</b> <sup>1,3</sup>	<b>6.33</b> <sup>1,3</sup>	7.46	7.55
Residue filterable	110	230	90	120	280	220	280	360	60	70
Arsenic	0.0058	0.0015	0.0004	0.0039	0.0001	0.0001	0.0001	0.0001	0.0003	0.0002
Selenium	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	0.0005	<0.0001	0.0006	0.0001	0.0004
Silver	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ns	<0.0001
Aluminum	0.004	<b>0.009</b> <sup>3</sup>	<b>0.02</b> <sup>3</sup>	<b>0.142</b> <sup>3</sup>	<b>0.014</b> <sup>3</sup>	<0.002	<b>2.67</b> <sup>3</sup>	<b>0.013</b> <sup>3</sup>	ns	0.003
Barium	0.0193	0.0333	0.0021	0.0166	0.104	0.0263	0.0296	0.0305	ns	0.0112
Beryllium ( $\mu\text{g}/\text{L}$ )	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	ns	<0.05
Cadmium	<0.0001	0.0003	<0.0001	<0.0001	0.0002	<0.0001	0.0005	0.0001	ns	<0.0001
Cobalt	0.0001	0.0001	0.0001	0.0002	0.0005	0.0002	0.0021	0.0022	ns	<0.0001
Chromium	<0.0002	0.0004	0.0021	0.0005	<0.0002	0.0019	0.0093	0.0004	ns	<0.0002
Copper	0.0009	<0.0002	<b>0.0028</b> <sup>3</sup>	<b>0.0036</b> <sup>3</sup>	0.001	<b>0.0076</b> <sup>3</sup>	<b>0.005</b> <sup>3</sup>	0.0009	ns	<b>0.0472</b> <sup>3</sup>
Iron	0.105	<b>2.32</b> <sup>1,3</sup>	<b>0.0361</b> <sup>1,3</sup>	<b>0.345</b> <sup>1,3</sup>	0.0635	0.0101	<b>3.61</b> <sup>1,3</sup>	0.0712	ns	0.0044
Mercury ( $\mu\text{g}/\text{L}$ )	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lithium	0.0008	0.0004	0.0003	0.0005	<0.0001	0.0015	0.0012	0.0012	ns	0.0001
Manganese	<b>0.143</b> <sup>1,2</sup>	<b>0.111</b> <sup>1,2</sup>	0.0017	<b>0.0508</b> <sup>1,2</sup>	<b>0.263</b> <sup>1,2</sup>	0.038	<b>0.0731</b> <sup>1,2</sup>	0.0027	ns	0.0012
Molybdenum	0.001	0.0018	0.0003	0.0008	0.0001	0.0003	0.0005	<0.0001	ns	0.0007
Nickel	<0.0002	<0.0002	0.0007	0.0005	0.0005	0.0084	0.0096	0.0052	ns	<0.0002
Lead	<0.0002	<0.0002	<0.0002	0.0003	0.0002	0.0006	<b>0.0021</b> <sup>3</sup>	<0.0002	ns	0.0004
Strontium	0.0629	0.108	0.0441	0.0847	0.197	0.165	0.368	0.242	ns	0.0759
Vanadium	0.0001	0.0008	0.0007	0.0012	<0.0001	0.0006	0.0076	0.0002	ns	0.0005
Zinc	0.0019	0.008	0.0191	0.0134	0.001	0.0084	0.0077	0.0034	ns	0.0083
Calcium	25.2	24.2	11.7	18.1	49.9	31.2	37.9	48.8	19	18
Potassium	1.6	2.5	0.7	2.7	3.9	1.2	4.2	1.7	0.9	0.5
Magnesium	4	9.2	3	5.7	9.8	16.9	8.4	14.12	1.6	1.5
Sodium	4.7	41.5	2.8	6.6	8.4	8.5	8.2	9.5	1.7	1.4
Silicon	8.73	16.8	10	8.61	7.21	12.6	8.37	14.1	3.94	3.99
Hardness	79.2	98.1	41.8	68.5	165	147	129	180	54	51.1
E coli (MPN/100mL)	0	0	0	0	0	0	<b>22</b>	0	0	0
Total Coliform (MPN/100mL)	0	0	0	<b>1300</b>	0	<b>7</b>	<b>920</b>	0	0	0
Fecal Coliform (MPN/100mL)	0	0	0	0	0	0	<b>79</b>	0	0	0

Guideline exceedances are shown in bold; refer to Table A3 for guideline values

<sup>1</sup> over MAC for drinking water

<sup>2</sup> over WQG for irrigation

<sup>3</sup> over WQG for the protection of freshwater aquatic life

<sup>4</sup> over WQG for livestock

ns = no sample

Table A2 (cont'd). Concentrations of inorganic and bacteriological parameters in groundwater collected from the Lower Fraser Valley. (mg/L unless otherwise stated)

Sampling Site	CHW2E	CHW3E	CHW4E	CHW4E	CHW5E	CHW5E	REP 1	REP 2	REP 3	CHW2E
Sampling Date	8/20/1998	8/20/1998	8/21/1998	9/24/1998	8/21/1998	9/24/1998	8/27/1998	8/27/1998	8/27/1998	8/20/1998
Bromide	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chloride	5.3	2.7	7.3	6.7	4.4	3.8	4	4.1	4.2	5.3
Fluoride	0.11	0.09	0.09	0.08	0.13	0.11	0.1	0.11	0.11	0.11
Nitrate + Nitrite as Nitrogen total	<0.002	0.613	0.769	0.566	0.287	0.231	0.302	0.302	0.289	<0.002
Nitrite as Nitrogen	<0.005	<0.005	0.2	0.019	0.025	0.01	<0.002	<0.002	<0.002	<0.005
Total Phosphorus	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Phosphorus total dissolved	0.007	0.006	0.01	ns	0.013	ns	0.02	0.02	0.018	0.007
Sulphate	22	30	26	25	14	12	14	14	14	22
Conductivity ( $\mu\text{S}/\text{cm}$ )	274	380	276	264	249	239	247	245	247	274
pH ( <i>relative unit</i> )	7.22	8.03	6.83	6.97	7.29	7.43	7.39	7.42	7.39	7.22
Residue filterable	180	230	180	180	170	160	170	160	160	180
Arsenic	0.0005	0.0003	0.0001	0.0001	0.0008	0.0008	0.0007	0.0008	0.0008	0.0005
Selenium	<0.0001	0.0009	<0.0001	0.0003	0.0002	0.0005	0.0003	0.0003	0.0003	<0.0001
Silver	ns	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0001	ns
Aluminum	ns	<0.002	<b>0.01</b> <sup>3</sup>	0.002	<b>0.005</b> <sup>3</sup>	<0.002	<0.002	0.002	<0.002	ns
Barium	ns	0.0092	0.0891	0.0833	0.0503	0.0467	0.0501	0.047	0.0502	ns
Beryllium ( $\mu\text{g}/\text{L}$ )	ns	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	ns
Cadmium	ns	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ns
Cobalt	ns	<0.0001	0.0007	0.0006	0.0001	0.0001	0.0002	0.0002	0.0001	ns
Chromium	ns	0.0003	<0.0002	<0.0002	0.0002	<0.0002	<0.0002	0.0002	0.0003	ns
Copper	ns	<b>0.0220</b> <sup>3</sup>	0.0004	0.0006	0.001	0.001	0.0004	0.00473	0.0003	ns
Iron	ns	0.0043	0.0309	0.0155	0.0118	0.0216	0.0072	0.0049	0.0056	ns
Mercury ( $\mu\text{g}/\text{L}$ )	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lithium	ns	0.0032	0.0017	0.0017	0.0013	0.0011	0.0013	0.0013	0.0014	ns
Manganese	ns	0.0002	<b>0.683</b> <sup>1,2</sup>	<b>0.667</b> <sup>1,2</sup>	<b>0.458</b> <sup>1,2</sup>	<b>0.379</b> <sup>1,2</sup>	<b>0.425</b> <sup>1,2</sup>	<b>0.432</b> <sup>1,2</sup>	<b>0.439</b> <sup>1,2</sup>	ns
Molybdenum	ns	0.0025	0.0004	0.0004	0.0006	0.0005	0.0006	0.0005	0.0006	ns
Nickel	ns	0.0003	0.0046	0.0043	0.0006	0.0002	0.0003	0.0004	0.0005	ns
Lead	ns	<b>0.0015</b> <sup>3</sup>	<0.0002	<0.0002	0.0008	<b>0.0018</b> <sup>3</sup>	0.0006	<0.0002	0.0005	ns
Strontium	ns	0.397	0.162	0.156	0.155	0.148	0.155	0.145	0.156	ns
Vanadium	ns	0.005	<0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	ns
Zinc	ns	<b>0.0408</b> <sup>3</sup>	0.002	0.0034	0.0113	0.006	0.0058	0.0181	0.0043	ns
Calcium	40	64	35.2	32.9	37.7	35.4	37.3	37.5	37.9	40
Potassium	1.2	0.8	1.4	1.4	1.6	1.5	1.5	1.6	1.6	1.2
Magnesium	10.4	13.2	11.7	11	8.5	8.1	8.1	8.1	8.2	10.4
Sodium	4.3	5.4	6.1	5.2	4.2	3.5	4.2	4.2	4.1	4.3
Silicon	15.3	5.46	12	11.6	12.7	12.6	12.8	12.8	13	15.3
Hardness	142	214	136	127	129	122	126	127	128	142
E coli (MPN/100mL)	0	0	0	0	0	0	0	0	0	0
Total Coliform (MPN/100mL)	0	0	0	0	0	0	0	0	0	0
Fecal Coliform (MPN/100mL)	0	0	0	0	0	0	0	0	0	0

Guideline exceedances are shown in bold; refer to Table A3 for guideline values

<sup>1</sup> over MAC for drinking water

<sup>2</sup> over WQG for irrigation

<sup>3</sup> over WQG for the protection of freshwater aquatic life

<sup>4</sup> over WQG for livestock

ns = no sample

Table A2 (cont'd). Concentrations of inorganic and bacteriological parameters in groundwater collected from the Lower Fraser Valley. (mg/L unless otherwise stated)

Sampling Site	CHW6E	CHW7E	CHW8E	CHW1R	CHW1R	CHW2R	CHW3R	CHW4R	No of sites with samples not meeting Guidelines
Sampling Date	8/21/1998	8/27/1998	8/27/1998	8/20/1998	9/24/1998	8/27/1998	8/27/1998	8/27/1998	
Bromide	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0
Chloride	0.87	7.4	5.9	1.8	2.1	1.4	0.43	4.3	0
Fluoride	0.03	0.11	0.11	0.06	0.07	0.19	0.02	0.06	1 <sup>1,2,4</sup>
Nitrate + Nitrite as Nitrogen total	0.225	<0.002	1.47	0.005	0.079	0.268	0.169	0.134	2 <sup>1</sup>
Nitrite as Nitrogen	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	1 <sup>1,3</sup>
Total Phosphorus	<0.05	<0.05	<0.05	<0.05	0.13	<0.05	<0.05	<0.05	0
Phosphorus total dissolved	0.002	0.045	0.015	0.13	ns	0.003	0.007	0.011	0
Sulphate	7.3	40	23	21	21	50	1.7	5.4	0
Conductivity ( $\mu\text{S}/\text{cm}$ )	110	413	237	203	201	253	27	67	0
pH ( <i>relative unit</i> )	7.58	7.99	7.14	8.33	8.11	7.42	6.68	6.91	3 <sup>1,3</sup>
Residue filterable	80	280	170	130	130	170	30	60	0
Arsenic	0.0002	0.0006	0.0001	0.0071	0.0061	<0.0001	<0.0001	0.0004	0
Selenium	0.0002	0.0001	0.0009	<0.0001	0.0001	<b>0.0021</b> <sup>3</sup>	0.0001	0.0002	1 <sup>3</sup>
Silver	<0.0001	<0.0001	<0.0001	ns	<0.0001	<0.0001	<0.0001	<0.0001	0
Aluminum	<b>0.005</b> <sup>3</sup>	0.003	<0.002	ns	0.004	0.002	<0.002	<0.002	9 <sup>3</sup>
Barium	0.0113	0.102	0.0502	ns	0.0205	0.0049	0.0076	0.0075	0
Beryllium ( $\mu\text{g}/\text{L}$ )	<0.05	<0.05	<0.05	ns	<0.05	<0.05	<0.05	<0.05	0
Cadmium	<0.0001	0.0002	<0.0001	ns	<0.0001	<0.0001	<0.0001	<0.0001	0
Cobalt	<0.0001	0.0001	0.0002	ns	<0.0001	<0.0001	<0.0001	<0.0001	0
Chromium	0.0002	0.0002	<0.0002	ns	<0.0002	<0.0002	<0.0002	0.0007	0
Copper	<b>0.0283</b> <sup>3</sup>	<b>0.0033</b> <sup>3</sup>	0.0006	ns	0.0004	<b>0.0032</b> <sup>3</sup>	<b>0.0461</b> <sup>3</sup>	<b>0.0227</b> <sup>3</sup>	11 <sup>2,3</sup>
Iron	0.0016	<b>1.2</b> <sup>1,3</sup>	0.019	ns	0.0127	0.0073	0.0347	0.014	5 <sup>1,3</sup>
Mercury ( $\mu\text{g}/\text{L}$ )	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0
Lithium	0.0002	0.001	0.0014	ns	0.0006	0.0022	<0.0001	0.0002	0
Manganese	0.0008	<b>0.313</b> <sup>1,2</sup>	0.0427	ns	0.0051	0.0003	0.0013	0.0009	8 <sup>1,2</sup>
Molybdenum	0.0009	0.002	0.0002	ns	0.007	0.0009	0.0004	0.0002	0
Nickel	<0.0002	<0.0002	0.0033	ns	<0.0002	<0.0002	<0.0002	0.0003	0
Lead	0.0008	0.0005	0.0003	ns	0.0005	0.0009	0.0002	0.0003	3 <sup>3</sup>
Strontium	0.0785	0.414	0.12	ns	0.178	0.317	0.0168	0.0333	0
Vanadium	0.0005	0.0001	0.0001	ns	<0.0001	0.0001	0.0002	0.0006	0
Zinc	0.0055	0.0023	0.001	ns	0.0013	<b>0.0339</b> <sup>3</sup>	<b>0.0324</b> <sup>3</sup>	<b>0.0404</b> <sup>3</sup>	4 <sup>3</sup>
Calcium	18.6	80.6	25.5	33.5	33.1	42.8	2.9	7.5	0
Potassium	0.8	1.7	1.1	2.3	2.2	0.7	0.7	1.6	0
Magnesium	1.6	7.9	12.7	2.2	2.2	4.6	0.8	1.6	0
Sodium	1.6	5.2	6.1	7	6.2	5.6	1.2	2.3	0
Silicon	3.85	11.1	13.6	5.76	6.43	6.24	3.66	6.22	0
Hardness	52.8	234	116	92.8	91.8	126	10.2	25.5	0
E coli (MPN/100mL)	0	0	0	0	0	0	0	0	1 <sup>1</sup>
Total Coliform (MPN/100mL)	0	<b>2</b>	0	0	0	0	0	0	4 <sup>1</sup>
Fecal Coliform (MPN/100mL)	0	0	0	0	0	0	0	0	1 <sup>1</sup>

Guideline exceedances are shown in bold; refer to Table A3 for guideline values

<sup>1</sup> over MAC for drinking water

<sup>2</sup> over WQG for irrigation

<sup>3</sup> over WQG for the protection of freshwater aquatic life

<sup>4</sup> over WQG for livestock

ns = no sample

Table A3. Health Canada drinking water guidelines<sup>1</sup> and CCME guidelines<sup>2</sup> for water uses and for the protection of freshwater aquatic life.

Parameters (units in mg/L unless otherwise stated)	Drinking Water		Irrigation	Protection of Fresh Water Aquatic Life	Livestock Drinking
	MAC	AO			
Chloride		250	100 - 700 <sup>c</sup>		
Fluoride	1.5		1		1 - 2
Nitrate + Nitrite as Nitrogen total	10			3	100
Nitrite as Nitrogen	1 <sup>a</sup>			0.06	10
Sulphate		500			1000
Conductivity ( $\mu\text{S/cm}$ )					
pH (relative unit)	6.5 - 8.5			6.5 - 9.0	
Arsenic	0.025 (IMAC)		0.1	0.005	0.025
Selenium	0.01		0.02 - 0.05	0.001	
Silver				0.0001	
Aluminum	0.01 <sup>b</sup>		5	0.005 - 0.1	5
Barium	1				
Beryllium ( $\mu\text{g/L}$ )			0.1		0.1
Cadmium	0.005		0.0051	0.000017 <sup>d</sup>	0.08
Cobalt			0.05		
Chromium	0.05				1
Copper		1	0.2 - 1	0.002 - 0.004 <sup>e</sup>	0.5 - 5
Iron		0.3	5	0.3	
Lithium			2.5		
Manganese		0.05	0.2		
Molybdenum			0.01 - 0.05	0.073	0.5
Nickel			0.2	0.025 - 0.15 <sup>f</sup>	1
Lead	0.01		0.2	0.001 - 0.007 <sup>g</sup>	0.1
Strontium (Becquerel/L)	5				
Vanadium			0.1		0.1
Zinc		5	1 - 5	0.03	50
Calcium					1000
Sodium		200			
Total Coliform (MPN/100mL)			1000		
Fecal Coliform (MPN/100mL)			100		

MAC = maximum acceptable concentration

IMAC = interim maximum acceptable concentration

AO = aesthetic objective only

<sup>a</sup> where nitrate and nitrite are determined separately, levels of nitrite should not exceed 3.2 mg nitrite/L or 1 mg N/L.

<sup>b</sup> the drinking water guideline for aluminum is not a MAC or a health-based guideline.

<sup>c</sup> the drinking water guideline for chloride varies according to crops and the commercial part of the plant being protected.

<sup>d</sup> the cadmium guideline is the lower of 2 values: (i) 0.000017 mg/L or (ii)  $10^{(0.86(\log(\text{hardness})) - 3.2)}$  mg/L

<sup>e</sup> depending on hardness, the copper guideline is 0.002 mg/L (0 - 120 mg CaCO<sub>3</sub>), 0.003 mg/L (120 - 180 mg CaCO<sub>3</sub>) or 0.004 mg/L (> 180 mg CaCO<sub>3</sub>).

<sup>f</sup> depending on hardness, the nickel guideline is 0.025 mg/L (0 - 60 mg CaCO<sub>3</sub>), 0.065 mg/L (60 - 120 mg CaCO<sub>3</sub>), 0.11 mg/L (120 - 180 mg CaCO<sub>3</sub>) or 0.15 mg/L (> 180 mg CaCO<sub>3</sub>).

<sup>g</sup> depending on hardness, the lead guideline is 0.01 mg/L (0 - 60 mg CaCO<sub>3</sub>), 0.02 mg/L (60 - 120 mg CaCO<sub>3</sub>), 0.04 mg/L (120 - 180 mg CaCO<sub>3</sub>) or 0.07 mg/L (> 180 mg CaCO<sub>3</sub>).

<sup>1</sup> Health Canada Drinking Water Guidelines, 2003

<sup>2</sup> CCME Canadian Environmental Quality Guidelines, 2002

Table A3 (cont'd). Health Canada drinking water guidelines<sup>1</sup> and CCME guidelines<sup>2</sup> for water uses and the protection of freshwater aquatic life.

<b>Parameters</b> <i>(units in ng/L unless otherwise stated)</i>	<b>Drinking Water</b> MAC	<b>Irrigation</b>	<b>Protection of Fresh</b> <b>Water Aquatic Life</b>	<b>Livestock Drinking</b>
1,3-Dichlorobenzene			150000	
1,4-Dichlorobenzene	5000		26000	
1,2-Dichlorobenzene	200000		700	
1,2,4-Trichlorobenzene			24000	
1,2,3-Trichlorobenzene			8000	
1,2,3,4-Tetrachlorobenzene			1800	
Pentachlorobenzene			6000	
Hexachlorobenzene				520
α-HCH			10	
β-HCH			10	
δ-HCH			10	
γ-HCH			10	
Heptachlor			no EQG	
Aldrin	700		no EQG	
Chlordane (trans)			no EQG	
Chlordane (cis)			no EQG	
o,p'-DDT			no EQG	
p,p'-DDT			no EQG	
Acenaphthylene			5800	
Fluorene			3000	
Phenanthrene			400	
Anthracene			12	
Fluoranthene			40	
Pyrene			25	
Benz(a)anthracene			18	
Benzo(a)pyrene	10		15	

MAC = maximum acceptable concentration

no EQG = no Environmental Quality Guideline is recommended.

<sup>1</sup> Health Canada Drinking Water Guidelines, 2003

<sup>2</sup> CCME Canadian Environmental Quality Guidelines, 2002



Table A4. Organic contaminant concentrations (ng/L) in groundwater collected from the Lower Fraser Valley.

Sample ID	ABT1	ABT2	ABT3	ABT4	ABT5	MAT1E	MAT2E	MAT3E	CHW1E	CHW2E	CHW3E	CHW4E
<b>Chlorinated Benzenes and Pesticides</b>												
Hexachlorobutadiene	<0.01	<0.01	<0.01	<0.02	<0.01	NQ	NQ	NQ	<0.04	<0.02	<0.03	<0.05
1,3/1,4-Dichlorobenzene	<b>31.5*</b>	<b>15.5*</b>	<b>24.5*</b>	<b>16.5*</b>	<b>23.5*</b>	NQ	NQ	NQ	<b>22.5*</b>	<b>26.5*</b>	<b>9*</b>	NQ
1,2-Dichlorobenzene	<b>15.4*</b>	<b>5.9*</b>	<b>14.4*</b>	<b>8.5*</b>	<b>11.4*</b>	NQ	NQ	NQ	<b>9.1*</b>	<b>13.4*</b>	<b>7.3*</b>	NQ
1,3,5-Trichlorobenzene	<0.08r*	<0.02r*	<0.02r*	<b>0.09r*</b>	<0.03r*	NQ	NQ	NQ	<b>0.24r*</b>	<b>0.05r*</b>	<0.05	<0.12
1,2,4-Trichlorobenzene	<b>0.71*</b>	<b>0.37*</b>	<b>0.67*</b>	<b>0.21*</b>	<b>0.50*</b>	NQ	NQ	NQ	<b>0.50*</b>	<b>0.51*</b>	<b>0.26*</b>	<b>0.46*</b>
1,2,3-Trichlorobenzene	<b>0.14</b>	<b>0.13</b>	<b>0.11</b>	<0.02	<b>0.08r</b>	NQ	NQ	NQ	<0.02	<b>0.21</b>	<b>0.08</b>	<0.12
1,2,3,5/1,2,4,5-Tetrachlorobenzene	<0.01	<0.01	<b>0.02*</b>	<0.01	<0.01	NQ	NQ	NQ	<0.04	<0.02	<0.02	<0.04
1,2,3,4-Tetrachlorobenzene	<b>0.04</b>	<b>0.02</b>	<b>0.04</b>	<b>0.03</b>	<b>0.02r</b>	NQ	NQ	NQ	<0.04	<0.02	<0.03	<0.05
Pentachlorobenzene	<b>0.03r*</b>	<0.04r*	<b>0.04r*</b>	<0.04r*	<0.05r*	<0.13	<0.10	<0.11	<0.07r*	<0.05r*	<0.05r*	<0.07r*
Hexachlorobenzene	<b>0.09</b>	<b>0.06</b>	<0.05	<b>0.03</b>	<0.04	<0.05	<0.06	<0.08	<0.09	<0.07	<0.07	<0.12
α-HCH	<0.09	<0.1	<0.06	<0.16	<0.08	<0.2	<0.27	<0.17	<0.23	<0.19	<0.11	<0.19
β-HCH	<0.12	<0.13	<0.08	<0.21	<0.11	<0.29	<0.39	<0.24	<0.3	<0.24	<0.15	<0.26
δ-HCH	<0.09	<0.1	<0.06	<0.16	<0.08	<b>0.74</b>	<b>0.11r</b>	<0.15	<0.22	<0.18	<0.15	<0.04
γ-HCH	<0.09	<0.1	<0.06	<b>0.38r</b>	<0.08	<0.3	<0.40	<0.15	<0.22	<0.18	<0.11	<0.19
Heptachlor	<0.25	<0.57	<0.55	<1.1	<0.64	<0.41	<0.66	<0.45	<1.4	<1.4	<0.75	<0.63
Aldrin	<0.11	<0.05	<0.11	<0.15	<0.03	<0.19	<0.15	<0.2	<0.2	<0.23	<0.16	<0.13
Oxy-chlordane	<0.04	<0.16	<0.18	<0.17	<0.17	<0.77	<0.74	<1.4	<0.49	<0.23	<1.2	<1.2
Chlordane (trans)	<0.14	<0.09	<0.18	<0.15	<0.13	<0.08	<0.11	<0.09	<0.09	<0.19	<0.13	<0.08
Chlordane (cis)	<0.12	<0.08	<0.16	<0.14	<0.12	<0.07	<0.09	<0.08	<0.08	<0.17	<0.12	<0.08
o,p'-DDE	<0.04	<0.04	<0.04	<0.05	<0.03	<0.06	<0.05	<0.05	<0.04	<0.03	<0.06	<0.04
p,p'-DDE	<0.03	<0.03*	<b>0.10*</b>	<b>0.13*</b>	<0.03*	<0.05	<0.04	<0.05	<0.04	<0.03	<0.05	<0.04r*
Nonachlor (trans)	<0.11	<0.08	<0.16	<0.1	<0.06	<0.04	<0.06	<0.08	<0.09	<0.19	<0.07	<0.06
Nonachlor (cis)	<0.08	<0.06	<0.11	<0.07	<0.04	<0.03	<0.04	<0.05	<0.06	<0.13	<0.05	<0.04
o,p'-DDD	<0.02	<b>0.01</b>	<0.04	<0.03	<0.01	<0.02	<0.04	<0.03	<0.05	<0.04	<0.03	<0.03
p,p'-DDD	<0.02	<0.01	<b>0.04</b>	<0.03	<0.01	<0.02	<0.04	<0.03	<0.06	<0.04	<0.04	<0.04
o,p'-DDT	<0.02	<0.02	<0.03	<0.03	<0.03	<0.06	<0.06	<0.06	<0.07	<0.04	<0.04	<0.03
p,p'-DDT	<0.03	<0.02	<b>0.18</b>	<b>0.07</b>	<0.04	<0.09	<0.08	<0.08	<0.09	<0.05	<0.05	<0.03
Mirex	<0.02	<0.03	<0.02	<0.03	<0.03	<0.06	<0.06	<0.07	<0.08	<0.04	<0.06	<0.06
Heptachlor Epoxide	<0.02	<0.03	<0.04	<0.04	<0.02	<0.02	<0.02	<0.02	<0.07	<0.01	<0.03	<0.04
α-Endosulphan (I)	<0.02	<0.07	<0.06	<0.04	<0.09	<b>0.68</b>	<0.02	<0.02	<b>37</b>	<b>0.24</b>	<b>0.25</b>	<0.09
Dieldrin	<0.01	<0.03	<b>0.09</b>	<0.04	<0.02	<0.02	<0.02	<0.02	<0.06	<0.01	<0.02	<0.03
Endrin	<0.06	<0.1	<0.08	<0.14	<0.06	<0.06	<0.02	<0.05	<0.15	<0.05	<0.09	<0.12
β-Endosulphan (II)	<0.03	<0.05	<0.03	<0.05	<0.03	<b>0.53</b>	<b>0.08</b>	<0.03	<b>32</b>	<b>0.14</b>	<b>0.08</b>	<0.05
Endosulphan Sulphate	<0.03	<0.05	<0.04	<0.06	<0.03	<b>0.12</b>	<b>0.26</b>	<0.06	<b>9.4</b>	<0.02	<0.04	<0.05
Methoxychlor	<0.11	<0.2	<0.16	<0.25	<0.11	<0.09	<0.08	<0.08	<b>2.1</b>	<0.09	<0.15	<0.21
<b>PCBs</b>												
AROCLOR 1242	<1.3	<1.5	<1.7	<1.8	<1.3	<0.46	<0.80	<1.1	<2.5	<1.5	<1	<0.84
AROCLOR 1254	<0.97	<1.4	<2.3	<3.4	<0.51	<1.2	<1.5	<1.4	<2.2	<1	<3	<1.3
AROCLOR 1260	<1.2	<1.3	<1.8	<1.9	<1.1	<0.72	<0.80	<1.4	<3.5	<4	<1.2	<0.82
<b>Polycyclic Aromatic Hydrocarbons (PAHs)</b>												
Acenaphthylene	<0.16	NA	<0.18	<0.14	NA	NA	<0.29	NA	NA	<0.2	<0.13	NA
Acenaphthene	<0.11	NA	<0.13	<0.1	NA	NA	<b>0.24</b>	NA	NA	<b>0.15</b>	<b>0.16r</b>	NA
Fluorene	<0.33*	NA	<0.36	<0.29	NA	NA	<0.24	NA	NA	<0.39	<b>0.115r*</b>	NA

NA = not analysed; NQ = not quantifiable; r=peak detected but did not meet quantification criteria; \*=blank corrected

Table A4 (cont'd). Organic contaminant concentrations (ng/L) in groundwater collected from the Lower Fraser Valley.

Sample ID	ABT1	ABT2	ABT3	ABT4	ABT5	MAT1E	MAT2E	MAT3E	CHW1E	CHW2E	CHW3E	CHW4E
Phenanthrene	<b>0.46</b>	NA	<0.15	<0.14	NA	NA	<0.15r*	NA	NA	<b>0.24*</b>	<b>0.615r*</b>	NA
Anthracene	<0.15	NA	<0.16	<0.15	NA	NA	<0.15	NA	NA	<0.16	<0.07	NA
Fluoranthene	<b>0.17r*</b>	NA	<0.08r*	<0.08r*	NA	NA	<b>0.16</b>	NA	NA	<0.08r*	<b>0.19</b>	NA
Pyrene	<b>0.22r*</b>	NA	<0.07r*	<0.07r*	NA	NA	<b>0.18</b>	NA	NA	<b>0.10r*</b>	<b>0.26</b>	NA
Benz(a)anthracene	<0.06	NA	<0.05	<0.05	NA	NA	<0.10	NA	NA	<0.04	<0.11	NA
Chrysene	0.1	NA	<0.05	<0.05	NA	NA	<0.10	NA	NA	<0.04	<0.11	NA
Benzo(a)fluoranthene	<0.1	NA	<0.09	<0.09	NA	NA	<0.10	NA	NA	<0.07	<0.07	NA
Benzo(e)pyrene	<0.1	NA	<0.09	<0.09	NA	NA	<0.25	NA	NA	<0.08	<0.06	NA
Benzo(a)pyrene	<0.11	NA	<0.1	<0.1	NA	NA	<0.30	NA	NA	<0.08	<0.08	NA
Perylene	<0.12	NA	<0.1	<0.98	NA	NA	<0.33	NA	NA	<0.08	<0.08	NA
Dibenz(ah)anthracene	<0.22	NA	<0.18	<0.2	NA	NA	<0.86	NA	NA	<0.14	<0.11	NA
Indeno(1,2,3-cd)pyrene	<0.18	NA	<0.15	<0.16	NA	NA	<0.59	NA	NA	<0.12	<0.10	NA
Benzo(ghi)perylene	<b>0.32r*</b>	NA	<0.12	<0.13	NA	NA	<0.48	NA	NA	<0.1	<0.08	NA
C1-Phenanthrene/Anthracene	<b>0.76r*</b>	NA	<0.24r*	<0.23r*	NA	NA	<0.31	NA	NA	<0.24r*	<b>1.4</b>	NA
C2-Phenanthrene/Anthracene	<0.26	NA	<0.4	<0.41	NA	NA	<0.32	NA	NA	<0.04	<b>0.2</b>	NA
C3-Phenanthrene/Anthracene	<0.43	NA	<0.43	<0.44	NA	NA	<0.39	NA	NA	<0.41	<b>0.27</b>	NA
C4-Phenanthrene/Anthracene	<0.32	NA	<0.32	<0.33	NA	NA	<0.45	NA	NA	<0.31	<0.2	NA
Retene	<0.32	NA	<0.32	<0.33	NA	NA	<0.45	NA	NA	<0.31	<0.2	NA
Dibenzothiophene	<0.14	NA	<0.14	<0.13	NA	NA	<0.14	NA	NA	<0.14	<0.08	NA
C1-Dibenzothiophenes	<0.22	NA	<0.22	<0.21	NA	NA	<0.17	NA	NA	<0.22	<b>0.13</b>	NA
C2-Dibenzothiophenes	<0.24	NA	<0.24	<0.23	NA	NA	<0.12	NA	NA	<0.24	<b>0.09</b>	NA
<i>Total PAHs</i>	<i>2.03</i>		<i>&lt;DL</i>	<i>&lt;DL</i>			<i>0.58</i>			<i>0.49</i>	<i>3.43</i>	
<i>fluoranthene/ fluoranthene+pyrene</i>	<i>0.44</i>		<i>&lt;DL</i>	<i>&lt;DL</i>			<i>0.47</i>			<i>&lt;DL</i>	<i>0.42</i>	
<i>Phenanthrene+anthracene/ Phenanthrene+anthracene+C1- C4-Phenanthrene/anthracene</i>	<i>0.38</i>		<i>&lt;DL</i>	<i>&lt;DL</i>			<i>&lt;DL</i>			<i>1.0</i>	<i>0.25</i>	
<b>Sterols</b>												
Desogestrel	<2.5	NA	<6.8	<3.2	NA	NA	<16	NA	NA	<2.4	<4.2	NA
Mestranol	<1.1	NA	<1.5	<0.86	NA	NA	<0.75	NA	NA	<0.97	<0.60	NA
Norethindone	<8.3	NA	<13	<12	NA	NA	<6.4	NA	NA	<6.4	<2.9	NA
Estrone	<0.18	NA	<0.35	<0.13	NA	NA	<0.41	NA	NA	<0.24	<0.19	NA
Equilin	<0.49	NA	<0.45	<0.52	NA	NA	<0.44	NA	NA	<0.61	<0.52	NA
Norgestrel	<6.8	NA	<8.5	<2.2	NA	NA	<3.5	NA	NA	<4.6	<2.4	NA
Testosterone	<3.3	NA	<b>21.4*</b>	<2.6	NA	NA	<1.2	NA	NA	<2.3	<1.5r*	NA
Ethynylestradiol	<1.2	NA	<b>3.8r</b>	<1.2	NA	NA	<2.0	NA	NA	<1.6	<0.96	NA
17 $\alpha$ -Estradiol	<0.4	NA	<0.43	<0.28	NA	NA	<0.39	NA	NA	<0.40	<0.24	NA
17 $\beta$ -Estradiol	<0.18	NA	<0.28	<0.11	NA	NA	<0.31	NA	NA	<0.19	<0.19	NA
$\alpha$ -Zearalanol	<0.69	NA	<0.68	<b>0.75r</b>	NA	NA	<1.1	NA	NA	<0.73	<0.44	NA
Coprostanol	<1.8	NA	<1.7r*	<0.89	NA	NA	<3.8	NA	NA	<0.64	<1.4	NA
Epicoprostanol	<0.56	NA	<2.2	<0.51	NA	NA	<2.0	NA	NA	<0.54	<0.88	NA
Cholesterol	<b>6*</b>	NA	<b>19*</b>	<b>4*</b>	NA	NA	<b>171.4*</b>	NA	NA	<b>24*</b>	<b>9*</b>	NA
Cholestanol	<0.48	NA	<0.46	<0.36r	NA	NA	<b>10.6r*</b>	NA	NA	<0.68	<1.1	NA
Desmosterol	<3.9	NA	<4.2	<2.1	NA	NA	<b>9.0r</b>	NA	NA	<2.7	<1.7	NA
Ergosterol	<2	NA	<2.8	<2	NA	NA	<b>68</b>	NA	NA	<3.7	<2.3	NA
Stigmasterol	<2.2	NA	<b>1.7r</b>	<2.1	NA	NA	<b>33</b>	NA	NA	<1.6	<5.0	NA
$\beta$ -Estradiol 3-benzoate	<0.15r*	NA	<0.22	<0.13	NA	NA	<0.66	NA	NA	<0.26	<0.76	NA
$\beta$ -Sitosterol	<1.4	NA	<b>6.5r</b>	<b>2.9r</b>	NA	NA	<b>187.6*</b>	NA	NA	<b>3.8r</b>	<1.2r*	NA

NA = not peak detected but did not meet quantification criteria; \* = blank corrected analysed; NQ = not quantifiable; r = peak detected but did not meet quantification criteria; \* = blank corrected

Table A4 (cont'd). Organic contaminant concentrations (ng/L) in groundwater collected from the Lower Fraser Valley.

Sample ID	CHW5E	REP1	REP2	REP3	CHW6E	CHW7E	CHW8E	CHW1R	CHW2R	CHW3R	CHW4R
<b>Chlorinated Benzenes and Pesticides</b>											
Hexachlorobutadiene	<0.03	<0.03	<0.05	<0.17	NQ	<0.02	<0.03	<0.01	<0.01	<0.03	NQ
1,3/1,4-Dichlorobenzene	<0.38*	<b>8*</b>	<b>16*</b>	<b>16*</b>	NQ	<b>7*</b>	<b>3*</b>	<b>13.5*</b>	<b>24.5*</b>	NQ	NQ
1,2-Dichlorobenzene	<b>4.8*</b>	<b>8.2*</b>	<b>8.17*</b>	<b>11.07*</b>	NQ	<b>6.7*</b>	<b>6.9*</b>	<b>8.3*</b>	<b>11.4*</b>	NQ	NQ
1,3,5-Trichlorobenzene	<0.08	<0.09	<b>0.23r*</b>	<0.23	NQ	<0.12	<0.06	<b>0.04r*</b>	<0.02r*	<0.09	NQ
1,2,4-Trichlorobenzene	<b>0.17*</b>	<b>0.22*</b>	<0.19*	<b>0.50*</b>	NQ	<b>0.19*</b>	<b>0.23*</b>	<b>0.27*</b>	<b>0.29*</b>	<b>0.25*</b>	NQ
1,2,3-Trichlorobenzene	<0.08	<0.09	<0.18	<0.24	NQ	<0.13	<b>0.09</b>	<0.02	<0.02	<0.1	NQ
1,2,3,5/1,2,4,5-Tetrachlorobenzene	<0.03	<0.03	<0.04	<0.14	NQ	<0.02	<0.02	<0.01	<0.01	<0.03	NQ
1,2,3,4-Tetrachlorobenzene	<0.03	<0.03	<0.05	<0.17	NQ	<0.02	<0.03	<0.02	<0.01	<0.03	NQ
Pentachlorobenzene	<0.05*	<0.06r*	<0.08	<0.16	<0.05r*	<0.06*	<0.07r*	<0.06r*	<0.02r*	<0.04r*	NQ
Hexachlorobenzene	<b>0.07</b>	<b>0.07</b>	<0.05	<0.15	<0.07	<0.06	<0.11	<0.06	<b>0.06</b>	<b>0.04</b>	<0.06
α-HCH	<0.14	<0.11	<0.19	<0.31	<0.05	<0.06	<0.19	<0.08	<0.15	<0.14	<0.19
β-HCH	<0.19	<0.15	<0.28	<0.45	<0.07	<0.09	<0.25	<0.1	<0.19	<0.19	<0.26
δ-HCH	<0.02	<0.03	<0.17	<0.28	<0.09	<0.08	<0.11	<0.08	<b>0.45r</b>	<0.06	<0.03
γ-HCH	<0.13	<0.11	<0.3	<0.40	<0.05	<b>0.1r*</b>	<b>0.1r*</b>	<0.08	<0.14	<b>0.2r*</b>	<0.19
Heptachlor	<0.34	<0.4	<0.61	<0.82	<0.21	<0.21	<0.30	<0.78	<0.73	<0.15	<0.42
Aldrin	<0.11	<0.11	<0.24	<0.21	<0.07	<0.07	<0.08	<0.08	<0.16	<0.05	<0.13
Oxy-chlordane	<0.85	<0.66	<0.95	<1.7	<0.65	<0.29	<0.53	<0.14	<0.24	<0.29	<0.41
Chlordane (trans)	<0.07	<0.09	<0.16	<0.09	<0.05	<0.03	<0.1	<0.12	<0.17	<0.03	<0.056
Chlordane (cis)	<0.06	<0.09	<0.14	<0.08	<0.04	<0.03	<0.1	<0.11	<0.15	<0.03	<0.051
op'-DDE	<0.07	<0.05	<0.09	<0.08	<0.03	<0.04	<0.04	<0.05	<0.04	<0.03	<0.044
pp'-DDE	<0.06	<0.04	<0.08	<0.07	<0.02r	<0.03*	<0.03*	<0.04	<b>0.01*</b>	<0.03r*	<0.04
Nonachlor (trans)	<0.09	<0.05	<0.10	<0.09	<0.03	<0.02	<0.03	<0.11	<0.06	<0.03	<0.055
Nonachlor (cis)	<0.06	<0.04	<0.06	<0.06	<0.02	<0.02	<0.03	<0.08	<0.04	<0.02	<0.04
op'-DDD	<0.03	<0.03	<0.04	<0.04	<0.01	<0.01	<0.03	<0.02	<0.01	<0.02	<0.019
pp'-DDD	<0.03	<0.03	<0.04	<0.04	<b>0.02</b>	<0.01	<0.03	<0.02	<0.01	<0.02	<0.02
op'-DDT	<0.03	<0.02	<0.07	<0.05	<0.02	<0.02	<0.03	<0.03	<0.04	<0.02	<0.021
pp'-DDT	<0.03	<0.02	<0.11	<0.07	<0.02	<b>0.03r</b>	<0.03	<0.03	<0.05	<0.02	<0.025
Mirex	<0.08	<0.07	<0.09	<0.09	<0.06	<0.03	<0.04	<0.03	<0.06	<0.04	<0.07
Heptachlor Epoxide	<0.02	<0.02	<0.04	<0.04	<0.02	<0.02	<0.02	<0.04	<0.02	<0.02	<0.03
α-Endosulphan (I)	<0.09	<0.02	<0.04	<0.04	<0.08	<0.03	<0.02	<0.04	<0.03	<0.02	<0.04
Dieldrin	<0.01	<0.01	<0.03	<0.04	<0.02	<0.02	<0.01	<0.03	<0.02	<0.02	<0.03
Endrin	<0.05	<0.05	<0.08	<0.1	<0.06	<0.08	<0.05	<0.12	<0.08	<0.07	<0.1
β-Endosulphan (II)	<0.02	<0.02	<0.06	<0.06	<b>0.04</b>	<0.03	<0.02	<0.05	<0.04	<0.03	<0.05
Endosulphan Sulphate	<0.02	<0.02	<0.1	<0.10	<0.03	<0.04	<0.02	<0.05	<0.04	<0.03	<0.05
Methoxychlor	<0.09	<0.09	<0.13	<0.16	<0.10	<0.13	<0.08	<0.21	<0.15	<0.11	<0.17
<b>PCBs</b>											
AROCLOR 1242	<1.3	<1.4	<1.2	<1.1	<0.47	<0.65	<0.89	<1.9	<1.7	<b>0.33</b>	<0.59
AROCLOR 1254	<1.7	<1.5	<2	<1.8	<1.3	<0.81	<0.80	<1.5	<4.1	<0.48	<1
AROCLOR 1260	<0.64	<1.4	<1.1	<1.2	<0.51	<0.61	<0.70	<1.9	<3.6	<0.39	<0.71
<b>Polycyclic Aromatic Hydrocarbons (PAHs)</b>											
Acenaphthylene	<0.18	NA	NA	<0.32	<0.15	NA	<0.41	<0.18	NA	<0.21	NA
Acenaphthene	<b>0.18</b>	NA	NA	<0.13	<b>0.11</b>	NA	<0.16	<b>12</b>	NA	<0.15	NA
Fluorene	<0.35*	NA	NA	<0.27	<0.03*	NA	<b>0.35</b>	<b>15.5*</b>	NA	<0.42	NA

NA = not analysed; NQ = not quantifiable; r=peak detected but did not meet quantification criteria; \*=blank corrected

Table A4 (cont'd). Organic contaminant concentrations (ng/L) in groundwater collected from the Lower Fraser Valley.

Sample ID	CHW5E	REP1	REP2	REP3	CHW6E	CHW7E	CHW8E	CHW1R	CHW2R	CHW3R	CHW4R
Phenanthrene	<b>0.46*</b>	NA	NA	<0.18r*	<b>0.27*</b>	NA	<0.19r*	<b>23.46*</b>	NA	<b>0.25*</b>	NA
Anthracene	<0.15	NA	NA	<0.19	<0.17	NA	<0.20	<b>5</b>	NA	<0.22	NA
Fluoranthene	<b>0.09r*</b>	NA	NA	<0.12	<b>0.09r*</b>	NA	<b>0.22</b>	<b>5.38r*</b>	NA	<0.10r*	NA
Pyrene	<b>0.17r*</b>	NA	NA	<b>0.13</b>	<b>1.4r*</b>	NA	<b>1.1</b>	<b>4.5r*</b>	NA	<b>0.17r*</b>	NA
Benz(a)anthracene	<0.04	NA	NA	<0.10	<0.06	NA	<0.09	<b>0.24</b>	NA	<0.07	NA
Chrysene	<b>0.05</b>	NA	NA	<0.11	<b>0.54</b>	NA	<0.09	<b>0.27</b>	NA	<0.07	NA
Benzo(a)anthracene	<0.06	NA	NA	<0.26	<0.1	NA	<0.24	<0.09	NA	<0.12	NA
Benzo(e)pyrene	<0.06	NA	NA	<0.26	<0.11	NA	<0.24	<0.09	NA	<0.12	NA
Benzo(a)pyrene	<0.06	NA	NA	<0.32	<0.12	NA	<0.29	<0.1	NA	<0.14	NA
Perylene	<0.06	NA	NA	<0.34	<0.12	NA	<0.32	<0.1	NA	<0.14	NA
Dibenz(ah)anthracene	<0.1	NA	NA	<1.0	<0.22	NA	<0.88	<0.23	NA	<0.27	NA
Indeno(1,2,3-cd)pyrene	<0.1	NA	NA	<0.65	<0.19	NA	<0.58	<0.16	NA	<0.22	NA
Benzo(ghi)perylene	<b>0.11</b>	NA	NA	<0.52	<0.15	NA	<0.47	<b>0.18r</b>	NA	<0.17	NA
C1-Phenanthrene/Anthracene	<b>0.96r*</b>	NA	NA	<0.38	<0.26r*	NA	<b>0.8</b>	<b>1.26r*</b>	NA	<b>0.66r*</b>	NA
C2-Phenanthrene/Anthracene	<b>0.99</b>	NA	NA	<0.36	<0.46	NA	<b>0.35</b>	<b>0.98</b>	NA	<b>1.1</b>	NA
C3-Phenanthrene/Anthracene	<b>0.64</b>	NA	NA	<0.45	<0.49	NA	<0.38	<0.45	NA	<0.55	NA
C4-Phenanthrene/Anthracene	<0.28	NA	NA	<0.52	<0.37	NA	<0.44	<0.34	NA	<0.42	NA
Retene	<0.28	NA	NA	<0.52	<0.37	NA	<0.44	<0.34	NA	<0.42	NA
Dibenzothiophene	<0.13	NA	NA	<0.17	<0.16	NA	<0.18	<b>1.9</b>	NA	<0.19	NA
C1-Dibenzothiophenes	<b>0.39</b>	NA	NA	<0.22	<0.24	NA	<0.23	<b>0.23</b>	NA	<0.3	NA
C2-Dibenzothiophenes	<0.23	NA	NA	<0.15	<0.27	NA	<0.16	<0.25	NA	<0.34	NA
<i>Total PAHs</i>	<i>4.04</i>				<i>2.41</i>		<i>2.82</i>	<i>70.9</i>		<i>2.18</i>	
<i>fluoranthene/ fluoranthene+pyrene</i>	<i>0.35</i>				<i>0.06</i>		<i>0.17</i>	<i>0.54</i>		<i>0</i>	
<i>Phenanthrene+anthracene/ Phenanthrene+anthracene+ C1-C4-Phenanthrene/anthracene</i>	<i>0.15</i>				<i>1.0</i>		<i>0</i>	<i>0.93</i>		<i>0.12</i>	
<b>Sterols</b>											
Desogestrel	<4.3	NA	NA	<8.1	<3.0	NA	<9.8	<2	NA	<2.1	NA
Mestranol	<1.2	NA	NA	<0.43	<1.1	NA	<0.80	<1	NA	<1.2	NA
Norethindone	<37	NA	NA	<2.5	<8.5	NA	<3.9	<11	NA	<8.2	NA
Estrone	<0.24	NA	NA	<0.27	<0.19	NA	<0.25	<0.23	NA	<0.25	NA
Equilin	<0.79	NA	NA	<0.29	<b>0.80r</b>	NA	<0.53	<0.96	NA	<0.39	NA
Norgestrel	<8.9	NA	NA	<4	<4.5	NA	<3.0	<5.7	NA	<5.4	NA
Testosterone	<11	NA	NA	<0.73	<2.1r*	NA	<1.4	<2	NA	<1.2	NA
Ethinylestradiol	<2.6	NA	NA	<1.1	<1.2	NA	<0.83	<1.8	NA	<0.93	NA
17 $\alpha$ -Estradiol	<0.74	NA	NA	<0.27	<0.4	NA	<0.19	<0.62	NA	<0.21	NA
17 $\beta$ -Estradiol	<0.19	NA	NA	<0.15	<0.27	NA	<0.24	<0.47	NA	<0.2	NA
$\alpha$ -Zearalanol	<1.6	NA	NA	<0.73	<0.69	NA	<1.1	<1.8	NA	<1	NA
Coprostanol	<0.74	NA	NA	<1.8	<0.96	NA	<2.3	<0.98	NA	<0.33	NA
Epicoprostanol	<1.3	NA	NA	<0.94	<0.48	NA	<1.2	<0.93	NA	<0.61	NA
Cholesterol	<b>18*</b>	NA	NA	<b>19.4*</b>	<b>11*</b>	NA	<b>6.4*</b>	<b>4*</b>	NA	<b>25*</b>	NA
Cholestanol	<0.54	NA	NA	<1.7*	<0.21	NA	<0.14	<1	NA	<0.45	NA
Desmosterol	<3.6	NA	NA	<0.88	<b>3.4r</b>	NA	<1.6	<3.9	NA	<2.4	NA
Ergosterol	<2.7	NA	NA	<1.8	<2.1	NA	<2.5	<3.7	NA	<b>1.9r</b>	NA
Stigmasterol	<2.5	NA	NA	<1.7	<1.1	NA	<2.7	<2.1	NA	<1.6	NA
$\beta$ -Estradiol 3-benzoate	<0.2	NA	NA	<0.48	<0.24	NA	<0.54	<0.41	NA	<0.25r*	NA
$\beta$ -Sitosterol	<b>5.1r</b>	NA	NA	<1.2	<b>3.2r</b>	NA	<1.3r*	<2.6	NA	<b>2.6r</b>	NA

NA = not analysed; NQ = not quantifiable; r=peak detected but did not meet quantification criteria; \*=blank corrected

Table A5. Summary of the yeast estrogen assay screening test on groundwater collected from the Lower Fraser Valley.

Sample	Dose Response	EC50 (mL)	Relative Concentration (ng/L Estradiol-Equivalents)	% of Maximum Estradiol Activity <sup>a</sup>
MAT1E1	+	41.5	0.1	6
MAT1E2	+	41.7	NR	7.2
MAT2E1	-	NA	NA	NA
MAT2E2	-	NA	NA	NA
MAT3E	-	NA	NA	NA
ABT1	+	23.7	0.9	16.5
ABT2	+	43.6	0.4	2.8
ABT3	+	43	0.4	6.9
ABT4	+	43.2	0.5	16.3
ABT5	-	NA	NA	NA
CHW1E	+	41	0.1	7.6
CHW2E1	+	41	0.1	2.1
CHW2E2	-	NA	NA	NA
CHW3E	+	42	0.2	13.1
CHW4E	+	41	<0.1	2.4
CHW5E	+	41.31	0.3	11
REP1	+	26.7	0.5	10.5
REP2	+	41.6	0.4	13.5
REP3	+	42.6	0.4	18.3
CHW6E	+	39.6	0.4	26.8
CHW7E	+	17.1	0.6	6.3
CHW8E	+	18.2	0.6	6.5
CHW1R	-	NA	NA	NA
CHW2R	+	10.6	0.9	4.2
CHW3R	+	44.1	0.2	6.8
CHW4R	+	40.7	0.3	11.5

+ indicates that a dose related response was observed

- indicates no dose response

<sup>a</sup> when compared to positive Estradiol Control

NA = not applicable

NR = no result