Groundwater Quality in the Lower Cowichan River Aquifer Complex

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TABLE OF CONTENTS

Page

Table of Contents i
List of Tables ii
List of Figures ii
Executive Summary iv
Acknowledgements vii
1.0 Introduction 1
1.1 Study Objectives 3
1.2 Climate 3
1.3 Topography and Geology 7
1.4 Description and classification of aquifers in the study area 7
1.4.1 Intrinsic aquifer vulnerability 11
1.4.2 Aquifer and river connectivity 12
1.5 Groundwater monitoring and observation wells 17
1.5.1 Surface water connection 23
1.6 Land use 26
2.0 Methods 27
2.1 Sample locations 28
2.2 Sampling methodology and analytical parameters 29
3.0 Results 30
3.1 Water quality 30
3.2 Quality Assurance and Quality Control 30
3.3 Major Ion Chemistry 32
3.4 Chemical Parameters 34
3.4.1 Chloride 34
3.4.2 Sodium 37
3.4.3 Iron and manganese 40
3.4.4 Nitrate 45
3.5 CCME Water Quality Index 48
4.0 Summary 49
5.0 Recommendations 51
6.0 References 55

APPENDIX A: Well Construction Records 61
APPENDIX B: Sampling program and QA/QC methods and results 81
B.1 Sample collection, laboratory analysis and Quality Assurance/Quality Control 83
B.2 Data Archiving and Analysis 84
B.3 Quality Assurance and Quality Control Results 84
APPENDIX C: Analytical Results.....95
APPENDIX D: CCME Water Quality Index Calculations.....115

LIST OF TABLES

Table 1.1: Summary of aquifer classification and characteristics 11
Table 1.2: Summary of Observation Wells in Study Area 18
Table 1.3: Summary groundwater levels from active observation wells (2002-2011) 22
Table 1.4: Surficial Land Use for Aquifer 186 (1992-1997) (B.C. Integrated Land Management Bureau, 2009) 26
Table 2.1: Summary of well details for study sample sites, including active observation wells 29
Table 3.1: Sample summary, including quality assurance and quality control (QA/QC) 30
Table 3.6: Iron (mg/L) in groundwater samples 42
Table 3.7: Manganese (mg/L) in groundwater samples..... 42
Table 3.8: Nitrate-nitrogen (dissolved) (mg/L) in groundwater samples 46

LIST OF FIGURES

Figure 1.1: Location of the study area in the Cowichan Valley, Vancouver Island..... 2
Figure 1.2: Monthly total precipitation and median daily temperature at the Environment Canada Duncan Kelvin Creek Weather Station (EC1012573) (2002-2011)..... 4
Figure 1.3: Lower Cowichan River aquifers 186, 187 and 188 boundaries and vulnerability classification..... 5
Figure 1.4: Detailed map of study area 6
Figure 1.5: Aquifer Intrinsic Vulnerability of uppermost aquifer in the Lower Cowichan River area. Grid Cells: 100 m x 100 m. 13

Figure 1.6: Cross-Section A-A' (wells labelled by Well Tag Number, study sites and observation wells labelled in brackets) 14

Figure 1.7: Cross-section B-B' (top) and cross-section C-C' (bottom) (wells labelled by Well Tag Number, study sites and observation wells labelled in brackets) 15

Figure 1.8: Long-term hydrograph for observation well 204 (1977-2011)..... 19

Figure 1.9: Long-term hydrograph for observation well 318 (1993-2011)..... 20

Figure 1.10: Long-term hydrograph for observation well 211 (1976-2011)..... 21

Figure 1.11: Cumulative Precipitation Departure from Average, Environment Canada, Cowichan Lake Forestry Station (1977-2006) from (Janicki, 2011) 19

Figure 1.12: Observation Well 204 and 318 daily groundwater levels compared to daily precipitation at Environment Canada Kelvin Creek station (2003-2011) 23

Figure 1.13: Observation Well 204 and 318 water levels compared to Cowichan River discharge measured at the Allenby Bridge (2003-2010) 25

Figure 1.14: Daily precipitation at the Environment Canada Kelvin Creek station compared to Cowichan River discharge at Allenby Bridge (2003-2010) 25

Figure 1.15: Land use in the study area (1992-1997)..... 27

Figure 3.1: Piper Plot showing results of the major ion analyses from all sites in this study and two observation wells. 33

Figure 3.2: Chloride (mg/L) by date 36

Figure 3.3: Chloride (mg/L) by site..... 36

Figure 3.4: Sodium (mg/L) by date 39

Figure 3.5: Sodium (mg/L) by site 39

Figure 3.6: Correlation between sodium and chloride concentration (meq/L) .. 40

Figure 3.7: Iron (mg/L) by date..... 43

Figure 3.8: Iron (mg/L) by site 43

Figure 3.9: Manganese (mg/L) by date 44

Figure 3.10: Manganese (mg/L) by site 44

Figure 3.11: Nitrate plus nitrite (dissolved) (mg/L) by date 47

Figure 3.12: Nitrate-nitrogen (dissolved) mg/L by site..... 48

EXECUTIVE SUMMARY

Groundwater is an important resource in British Columbia. It has been estimated that over 750,000 people in B.C. depend on groundwater as their source of potable drinking water. In the Cowichan Valley region of southern Vancouver Island, groundwater is an essential source of potable water for domestic purposes, including municipal water supplies. It also provides water for industrial, commercial and agricultural purposes and critical baseflow to streams during dry periods. In the lower Cowichan Valley underlying the City of Duncan there are several very productive, layered, sand and gravel aquifers that provide fresh water for the area. As the population of the region increases, the demand on groundwater and these aquifers is expected to increase.

The Lower Cowichan River layered aquifer system is composed of three sand and gravel aquifers known as the Lower Cowichan River aquifers 186, 187 and 188 (also commonly known as the Lower Cowichan Aquifers A, B, and C, referring to the upper, middle and lower aquifers respectively). This layered aquifer complex is found along the lower Cowichan River floodplain and consists of interbedded fluvial and glaciofluvial sand and gravel deposits, variably separated by lower permeability layers of silt, clay, and till.

The two uppermost aquifers have been identified as being highly to moderately vulnerable to potential contamination from surface activities and land-use overlying the aquifer, based on factors including the depth to groundwater and the lithology of the materials overlying the aquifer i.e. the presence or absence and relative thickness of confining low permeability sediments such as clay or till.

The main source of groundwater recharge is likely infiltration of precipitation at the land surface; in addition, the aquifer complex, in particular the upper and middle aquifers, are considered hydraulically connected to the Cowichan River. The river is a source of aquifer recharge and receives groundwater discharge within different reaches and seasonally during the year. Because of this interconnection, water quality in the aquifer has the potential to be impacted by surface water quality, while, equally, production well pumping adjacent to the river may affect river base flow during dry

periods. The latter concerns are to be addressed in separate studies currently being completed in the Cowichan watershed.

In 2002, the B.C. Ministry of Environment initiated this study of the groundwater quality within the Lower Cowichan River aquifer complex, focussing on wells constructed in the uppermost aquifer layers (aquifers 186 and 187). The objectives of this study were to establish a baseline of ambient groundwater chemistry which could be used to evaluate future changes, and to assess seasonal variability and temporal trends in groundwater quality.

Six large-capacity production wells, owned and operated by municipalities or fish hatcheries, were sampled between 2002 and 2011. The majority of the study wells are situated adjacent to the Cowichan River (≤200 m distance), with the exception of site 5 which is located closer to the Koksilah River, approximately 1.5 km south of the Cowichan. Available water chemistry data for the same period from two provincial observation wells constructed in these aquifers were also included in the evaluation.

Groundwater samples were analyzed for water quality parameters including pH, conductivity, alkalinity, turbidity, major anions and cations, and total or dissolved metals. Based on the sampling program, groundwater in the Lower Cowichan River (upper and middle) aquifers was determined to be an immature, calcium-bicarbonate type groundwater without evidence of saltwater intrusion. Compared to the Guidelines for Canadian Drinking Water Quality, the concentrations of all measured chemical parameters were below the maximum acceptable concentrations for all health-based parameters.

There were two exceedences for iron and one exceedence for manganese, both considered naturally occurring aesthetic parameters that affect the taste and appearance of the water. Measured concentrations of chloride at site 6 were below the drinking water guidelines but elevated compared to concentrations at sites 1 to 5, and nitrate-nitrogen concentrations were also higher at site 6 compared to the other production and observation wells. These slightly higher concentrations of chloride and nitrate may be indicative of surface land use impacts and onsite activities, or differences in the aquifer properties at the location.

The Lower Cowichan River aquifer system is a highly productive source of quality drinking water for the City of Duncan, the Municipality of North Cowichan, and the Cowichan Tribes. It is used extensively by agricultural and industrial operations in the area, and provides baseflow to the Cowichan River during dry periods. The groundwater quality is currently very good; however the aquifer is also highly susceptible to anthropogenic impacts making aquifer protection a priority. Although well head protection plans have been developed for essential municipal wells, priority should be placed on aquifer protection, specifically land use decisions, hazard identification, and risk management at both a wellhead and an aquifer level. It is recommended that all levels of government continue to work together to share resources and information to better understand and monitor this important aquifer system. Future studies could include more widespread sampling of domestic and small to medium well users, spatially distributed over the aquifer, in areas at higher risk to contamination due to aquifer properties and the type of land use (e.g. industrial or agricultural use).

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1.0 Introduction

Groundwater is an important resource in British Columbia. It has been estimated that over 750,000 people in B.C. depend on groundwater as their source of potable drinking water (Statistics Canada, 2007a). In the Cowichan Valley region of Vancouver Island, groundwater is used as a source of potable water for domestic purposes, as well as for industrial, commercial and agricultural purposes. It also provides baseflow to streams during dry periods, and thus has a critical importance to salmonids and other fish species.

As the population of the region increases, the demand on groundwater is also expected to increase. Groundwater is an attractive source for drinking water because it is an abundant and easily extracted source of high quality potable water. Groundwater is also considered less vulnerable to contamination compared to surface water because infiltration through sedimentary surface layers can naturally reduce the presence of pathogens and because many pathenogenic organisms found in surface water are short lived in the subsurface or well environment (Cullimore, 2008).

Cowichan Lake receives glacial melt water and surface water runoff from the surrounding mountains, and is the source of the Cowichan River. The Cowichan River flows from its headwaters at Cowichan Lake, through the City of Duncan, and finally discharges into the ocean at Cowichan Bay (Figure 1.1). The Lower Cowichan River layered aquifer system is located adjacent to the lower reach of the Cowichan River between Duncan and the Cowichan Bay estuary. It is comprised of three sand and gravel aquifers referred to as Lower Cowichan River aquifers 186, 187 and 188, also known as the Lower Cowichan River aquifers A, B and C, referring to the upper, middle and deepest aquifers, respectively (Gallo, 1995a, 1995b, and 1995c)(Figure 1.3). The aquifers are separated by lower permeability layers of silt, clay or till; however, especially between the upper (186) and middle (187) aquifers, these confining sediments are not always present, or occur as discontinuous lenses and the aquifers may be considered interconnected, both with each other and with the overlying Cowichan River.

The two uppermost aquifers have been identified as highly productive, and highly to moderately vulnerable to potential contamination from surface activities and overlying land use (Figure 1.3). Aquifer 188 is also highly productive; however, because it is

overlain by a low permeability silt, and clay layer, the vulnerability is considered lower than the surficial and middle aquifers (Gallo, 1995c).

In 2002, the B.C. Ministry of Environment (MOE) initiated this study of the groundwater quality within the Lower Cowichan River aquifer complex, focussing on wells constructed in the uppermost aquifer layers (aquifers 186 and 187), to develop a better understanding of the ambient water quality of the groundwater, including seasonal or temporal variation. Six high capacity municipal and hatchery supply wells and two provincial observations wells (Figure 1.4) completed in aquifer 186 or 187 were selected for sampling over a nine year period, from January 2002 through October 2011, and the results are discussed in this report.

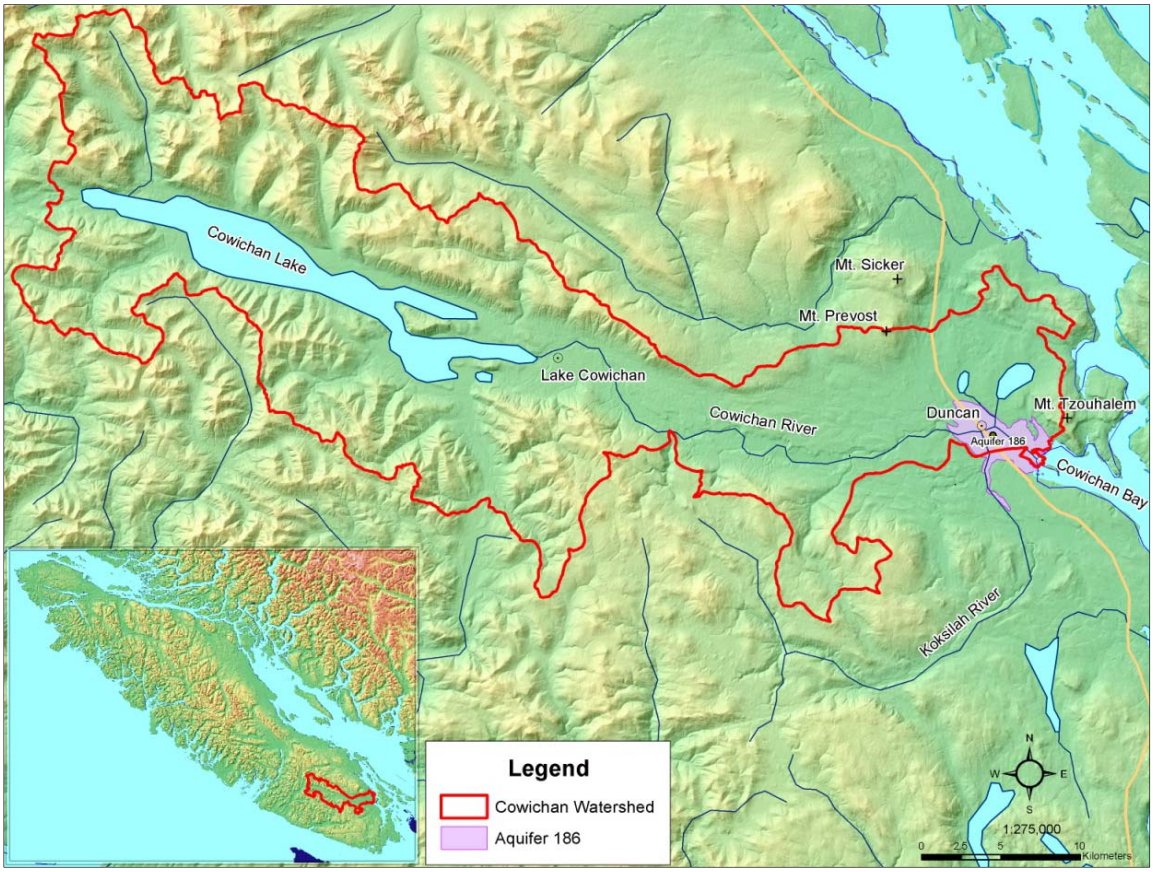

Figure 1.1: Location of the study area in the Cowichan Valley, Vancouver Island

1.1 Study Objectives

The purpose of the study was to assess the ambient groundwater chemistry of aquifer 186 and 187. The objectives of the study were to:

- Obtain and analyze samples of untreated groundwater from different wells in the upper aquifer complex in both the wet (November to April), and the dry (May to October) seasons for a comprehensive list of inorganic chemical constituents commonly found in groundwater (the complete list of parameters is provided in section 2.2 and Appendix C);
- Compare the results of the groundwater sampling to the Guidelines for Canadian Drinking Water Quality;
- Assess both the spatial and temporal distribution and trends in selected groundwater quality parameters in the aquifer;
- Establish the baseline chemistry for aquifer 186 and 187;
- Make the findings available to stakeholders, including local and regional government, researchers and community groups to guide future research directions, and decision-making with respect to land-use and water resource management.

1.2 Climate

The lower Cowichan Valley is located in the Coastal Douglas-fir biogeoclimatic zone, characterized by warm, sunny summers and wet, mild winters (BC Ministry of Forests, 1995). Eastern Vancouver Island is in the rain shadow of the Vancouver Island and Olympic mountains. There are two Environment Canada weather stations in proximity to the study area (Figure 1.4). However they were in operation during different periods. Duncan Kelvin Creek climate station (EC1012573) is located approximately 3.5 km southwest of aquifer 186 and has been in operation from 1987 to the present. Monthly average temperature and precipitation data from this station are shown in Figure 1.2. Daily temperature and precipitation were used for comparison to groundwater hydrographs for this area (Figure 1.12) (Environment Canada, 2008a). The Environment Canada Duncan Forestry station (EC1012570) located approximately 0.5 km southeast of the Cowichan River at observation well 211 was in operation from 1958-1989 and has

been used for determination of published long term (1971-2000) climate normals for this area (Environment Canada, 2008b).

Based on data from the Duncan Kelvin Creek station (EC1012573), during the study period (2002-2011), annual precipitation ranged from a minimum of 1018.2 mm in 2008, to a maximum of 1821.7 mm in 2006, and the annual average precipitation during this period was 1346.8 mm. The annual average daily temperature is 10.0 °C, the average daily maximum temperature is 14.8 °C and the average daily minimum temperature is 5.2 °C. The majority of precipitation in this area falls from November to April (the "wet" season), and the driest months are May to October (the "dry" season).

Historic climate normals (1971 to 2000) from the Duncan Forestry climate station (EC1012570) indicate that the historic average annual precipitation in this area is 1039.2 mm, the annual average daily temperature is 9.4 ºC, the average maximum daily temperature is 14.5 °C and the average minimum daily temperature is 4.3 °C. During the study period there was a higher than average precipitation and higher temperatures were observed, compared to the long-term record.

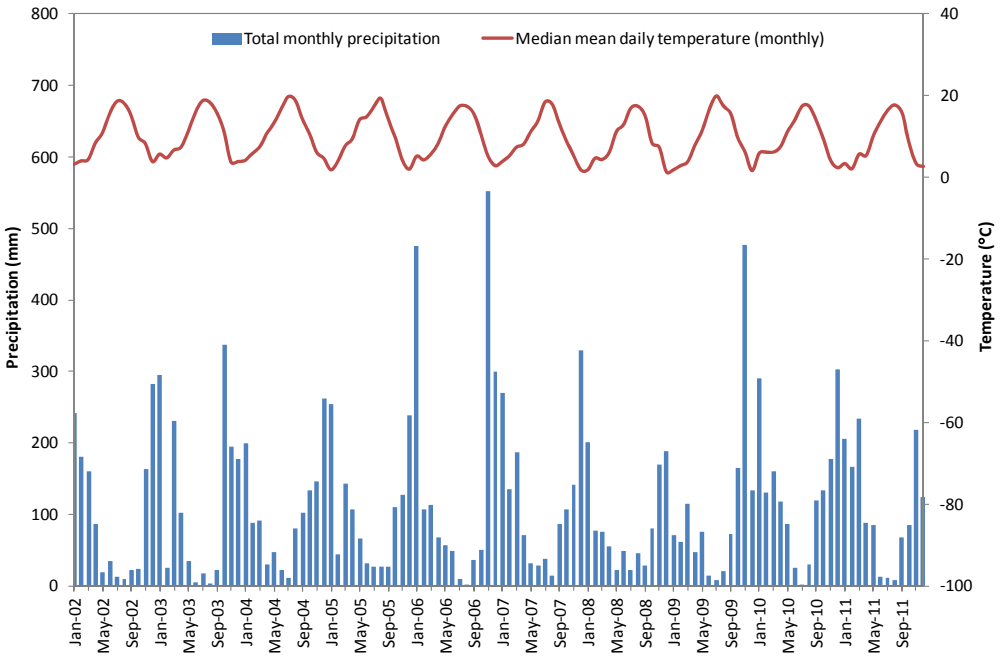

Figure 1.2: Monthly total precipitation and median daily temperature at the Environment Canada Duncan Kelvin Creek Weather Station (EC1012573) (2002-2011)

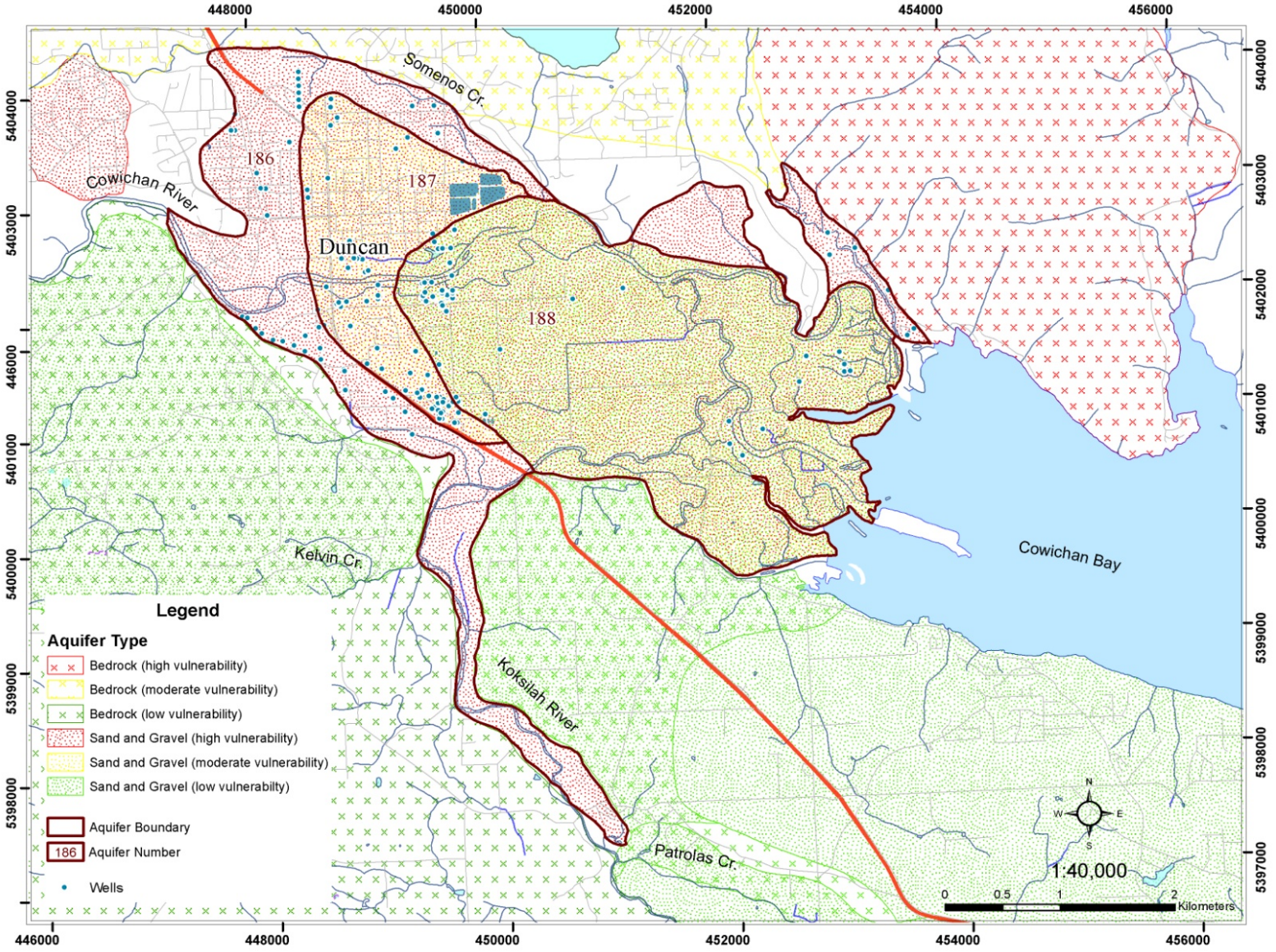

Figure 1.3: Lower Cowichan River aquifers 186, 187 and 188 boundaries and vulnerability classification

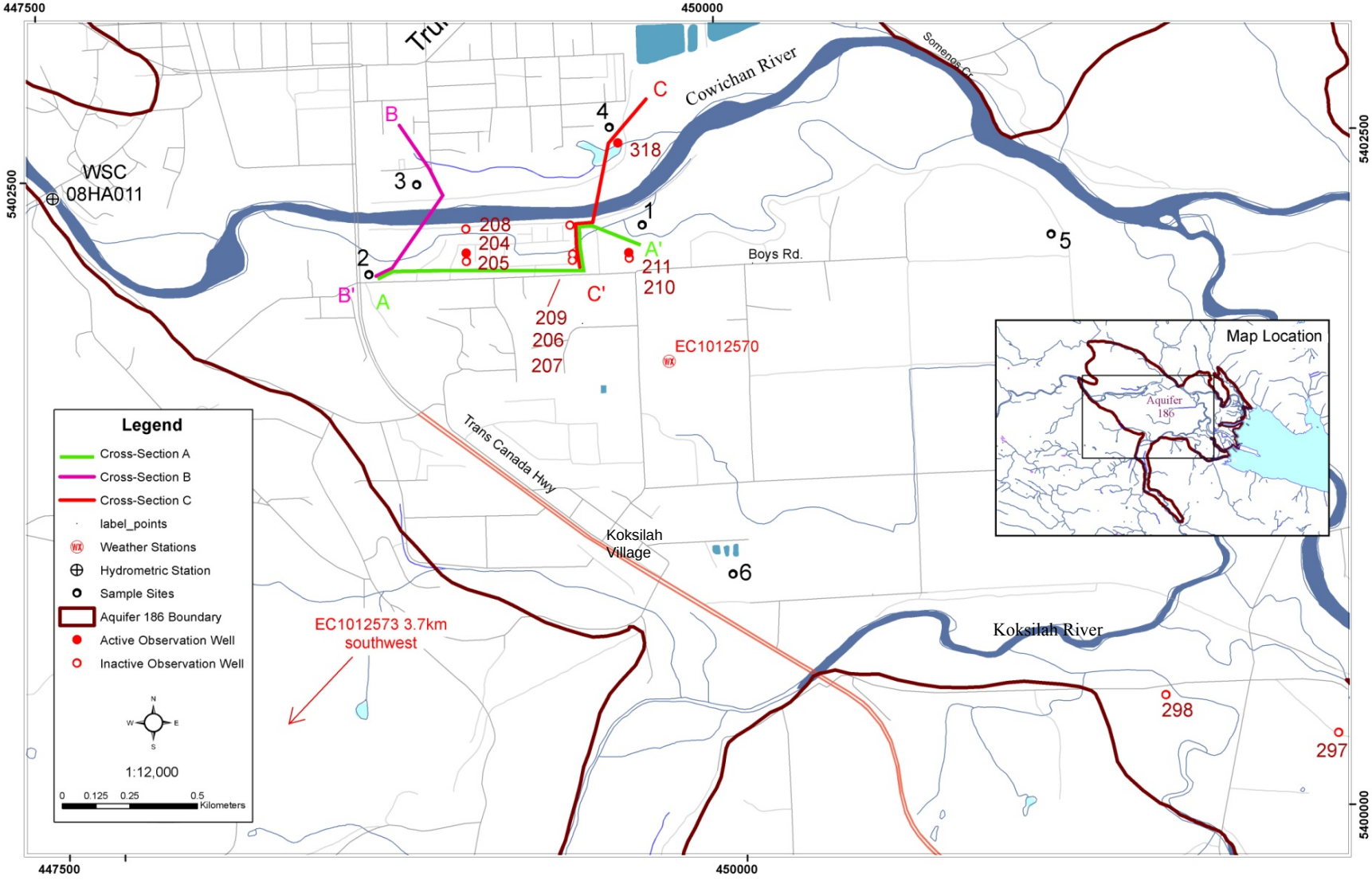

Figure 1.4: Detailed map of the study area

1.3 Topography and Geology

The Cowichan River flows from Cowichan Lake through the Cowichan valley toward Cowichan Bay. The topography increases dramatically on either side of the lake from an elevation of 200 m above sea level (asl) up to 1400 m asl at the crest of the watershed. Aquifers 186, 187, and 188 are situated along the floodplain and estuary of the lower portions of the Cowichan and Koksilah Rivers (Figure 1.3). The area overlying aquifer 186, the largest of the Lower Cowichan aquifers, is flat with an average elevation of 20 m asl and is surrounded by the higher elevation on the flanks of Mount Tzouhalem to the east, Mount Sicker and Mount Prevost in the north, and gently increasing slopes to the south (Figure 1.1 and Figure 1.3).

Bedrock underlying the Cowichan River consists mainly of sedimentary rock including shale, sandstone, and siltstone belonging to the Haslam or Cedar District formations from the Upper Cretaceous Nanaimo group of the Mesozoic Era (Muller, 1977; Massey, 1994).

During the Fraser glaciation (26,000-13,000 years before present (bp)), the lower Cowichan Valley was covered by a valley glacier, the Cowichan Ice tongue (Halstead, 1968; Blyth & Rutter, 1992). Glacial advance, melt, and retreat during various phases of the Fraser glaciations caused the deposition of unconsolidated sediments including till, silt, clay, sand and gravel. The surficial geology along the lower Cowichan River reflects this geologic history, and includes the postglacial Salish sediments deposited in the last ~5000 years of the Quaternary period, including shore, deltaic, and fluvial deposits of gravel, sand, silt, and clay. The Salish sediments can range up to 3000 m in lateral width and 20 meters in thickness within different parts of the Nanaimo and Georgia Lowlands (Ronneseth, Hodge, & Kohut, 1994). Underlying the Salish sediments are glacial to post-glacial Capilano sediments formed from ~13,000 to 5000 years bp including fluvial and deltaic deposits of gravel and sand, and/or glaciomarine or marine deposits of silt, clay, stony clay, and till-like mixtures (Halstead, 1996; Blyth & Rutter, 1992).

1.4 Description and classification of aquifers in the study area

An aquifer is a water-bearing subsurface geological unit that water wells are constructed within, to access groundwater in usable quantities. A proportion of all precipitation enters the subsurface, infiltrates through shallower soil layers and into the sediments or rock below, filling the pore space between unconsolidated sand and gravel grains and the fractures in bedrock. The natural geochemistry of groundwater may change as it flows through the subsurface, and

dissolves and 'picks-up' chemical constituents found in the rock or unconsolidated materials. The chemistry of groundwater may also be affected by land-uses such as surface application of chemicals that can subsequently dissolve into the infiltrating water.

The three aquifers in the study area, aquifers 186, 187, and 188, (Figure 1.3) comprise a layered aquifer system, and studies have shown that the aquifers are in some measure hydraulically interconnected to one another (Thurber Engineering Ltd., 2001; Gallo, 1995a, b, and c).

This aquifer complex is the primary source of municipal water supply for the Cowichan area. The City of Duncan has four drinking water production wells in aquifer 186 (Thurber Engineering, 2001; Maxwell & Wei, 2003) serving a population of 4,986 based on 2006 census data collected by Statistics Canada (Statistics Canada, 2007b). The Municipality of North Cowichan has four production wells in aquifer 186 (Maxwell & Wei, 2003) and has a population of 27,557 of which approximately 21,157 are supplied with groundwater for potable use (CVRD, 2010; Statistics Canada, 2007c). The Cowichan Valley Regional District as a whole has a population of 76,929 (CVRD, 2010).

Other major production wells include those operated by the Freshwater Fisheries Society of B.C., the Cowichan Tribes Hatchery, the Cowichan Indian Reserve and several private aquaculture operations in the area (Thurber Engineering, 2001). In addition to the municipal supplies, utilities and improvement districts, rural areas outside of the City of Duncan and Municipality of North Cowichan service areas utilize groundwater from private domestic wells.

Well head protection plans have been developed for the major production wells in the lower Cowichan aquifer complex, including the Municipality of North Cowichan and City of Duncan municipal wells, Cowichan Tribes water supply and hatchery wells, and the Freshwater Farms and provincial trout hatchery wells (Thurber Engineering, 2001).

The detailed properties of aquifers 186, 187 and 188 are shown in Table 1.1 and have been compiled according to the B.C. aquifer classification system, which uses well data and other information to describe the aquifer characteristics (Kreye, Ronneseth, & Wei, 2001).

Using the aquifer classification system, aquifers are classified based on the level of development and the level of vulnerability to contamination, and further ranked according to factors including productivity, vulnerability, size, degree of water demand, type of water use, and whether quality or quantity concerns have been identified for the aquifer. For example, the level

of aquifer development is designated as heavy (I), moderate (II) or light (III) by considering the demand on the aquifer compared to its productivity. The aquifer vulnerability is designated high (A), moderate (B), or low (C) based on the potential for contamination from the surface, depending on the type, thickness and extent of geologic materials overlying the aquifer, depth to water (or to the top of confined aquifers), and the type of aquifer materials. This vulnerability assessment is based on the aquifer properties and does not consider the type of land use overlying the aquifer, such as might be considered in a well head protection plan or risk analysis. Refer to Berardinucci & Ronneseth (2002) for a more detailed overview of the aquifer classification system. Aquifer classification maps are available from MOE 2011a and 2011b.

Since the classification of these aquifers was completed nearly twenty years ago, there has been more extensive development of wells in the area, therefore the aquifer statistics shown in Table 1.1 may have changed somewhat based on additional well data. At the time that these aquifers were classified there were approximately 120 known wells within the spatial extent of aquifers 186, 187 and 188, compared to 205 wells mapped in the same area in 2012 (a 41% increase).

It is also understood that there is likely to be additional wells not included in the provincial inventory, because submission of well records by well drillers and well owners is voluntary. In B.C. well information is maintained in the WELLS database, a publicly available resource which stores well data including location, lithology, and construction details (B.C. Ministry of Environment, 2011c).

Aquifer 186 is approximately 17.0 km^2 in area, and extends westward from Cowichan Bay roughly to the edge of Government Street in the Duncan city centre. The northwest boundary of the aquifer is close to Somenos Creek, and to the south, the aquifer is found along the Koksilah River. A finger-like extension of the aquifer borders the upper reaches of this river from Koksilah Village to just north of Patrolas Creek.

Aquifer 186 materials are considered to be Salish sediments of the Quaternary Period, Cenozoic Era, and include shore, glaciofluvial, fluvial and deltaic deposits described as thick, porous, layered sand and gravel sequences underlying deposits of channelized and braided cut and fill sands and gravels (Gallo, 1995a; Blyth & Rutter, 1992). Aquifer 186 is considered an unconfined aquifer, meaning that there are no low-permeability sediments such as silt or clay that overlie it. The aquifer productivity is high, and there is an extensive level of groundwater

use, including for municipal water supplies, therefore the aquifer development is considered heavy. Salt water intrusion in the aquifer has been identified as a concern in areas closest to the Cowichan River estuary, related to recharge from tidal flow within distributory channels of the river (Wei, 1985).

Aquifers 187 and 188 are located beneath aquifer 186 and have a smaller spatial extent. Aquifer 187 is approximately 11.4 km^2 in area, and is made up of Capilano sediments of the Cenozoic Era, including deltaic, fluvial and glaciofluvial channel deposits of sand and gravel (Gallo, 1995b).

Aquifer 187 is highly productive and is partially confined by silt, silty sand, clay and glaciomarine till-like sediments. For this reason the aquifer is classified as having a moderate vulnerability to contamination, although the water table is shallow and as previously stated, there appears to be no confining layer between aquifers 186 and 187 in some wells in the Boys Road area, as determined during various drilling campaigns (Brown & Carr, 1967), and as shown in the cross-sections in Figure 1.6 and Figure 1.7 discussed below and in Lapcevic, Gellein, & Ormond (2013).

Aquifer 188 is the deepest of the lower Cowichan River aquifers, and is made up of glaciofluvial deposits of sand and gravel and ground moraine deposits of silty sand known as the Vashon Drift (Gallo, 1995c). Aquifer 188 is roughly 8.7 km^2 in area and thought to be more extensively confined by overlying low permeability sediments, including marine clays (Capilano sediments) and therefore has a lower vulnerability to contamination. Underlying aquifer 188 is thought to be Vashon till (e.g. gravelly clay) deposits (Gallo, 1995c; Blyth & Rutter, 1992). While Table 1.1 suggests that the median estimated well yield for wells constructed in aquifer 188 are lower than for aquifer 187, as has been established in historical studies (Foweraker, 1976), there have been some very high capacity wells constructed in the lower unit, in particular in the more eastern section, closer to the Cowichan Bay estuary (Gallo, 1995c).

It is believed that all three aquifers are hydraulically connected to the Cowichan and Koksilah Rivers (Thurber Engineering Ltd., 2001; Gallo, 1995a, b, and c), as discussed further in sections 1.4.2 and 1.5.1 below. Thus the source of aquifer recharge is believed to be both from infiltration of precipitation from the surficial area overlying the aquifers, as well as infiltration through the riverbank into the hyporheic zone. The regional direction of groundwater flow is southeast towards Cowichan Bay and the Georgia Strait.

Table 1.1: Summary of aquifer classification and characteristics

Parameter		Aquifer 186	Aquifer 187	Aquifer 188
Level of development		I (Heavy)	II (Moderate)	III (Low)
Level of vulnerability		A (High)	B (Moderate)	C (Low)
Productivity		High	High	High
Ranking		14	12	10
Area (km^2)		17.0	11.4	8.7
Well Depth Range (Median)	**m**	2.4 – 22.3 (7.9)	9.4 – 38 (23)	29 – 61 (43)
	ft	8 – 73 (26)	31 – 125 (75)	94 – 200 (140)
	N=	88	17	15
Well yield range (Median)	**L/s**	0.44 – 143 (1.6)	2.2-189 (30)	0.63 – 32 (6.6)
	USgpm	7 – 2260 (25)	35 – 3000 (478)	10 – 500 (104)
	N=	66	16	13
Depth to Static Water Level (Median)	**m bgs**	0.5 – 6.4 (2.4)	0.30 – 4.9 (2.1)	0.6 – 12 (1.4)
	ft bgs	1.5 – 21 (8.0)	1.0 – 16 (7.0)	2.0 – 39 (4.5)
	N=	67	17	10
Transmissivity	**(m^2/d)**	1.9×10^3 – 3.6×10^4	124 – 1.2×10^4	277 – 584
	USgpd/ft	1.5×10^5 – 2.9×10^6	1.0×10^4 – 1.0×10^6	2.2×10^4 – 4.7×10^4
Specific Capacity	**(L/s/m)**	9.3 – 80	1.3 – 38	2.9
	USgpm/ft	45 – 386	6.3 – 182	14

N=number of wells used for aquifer classification and statistical calculations (some records well depth, water depth and estimated yield values whereas data from some records are not available)
bgs=below ground surface

1.4.1 Intrinsic aquifer vulnerability

In 2010 intrinsic aquifer vulnerability maps were completed for Vancouver Island using the DRASTIC method, which assigns a relative, qualitative measure of intrinsic vulnerability to potential contamination from surface sources based on the properties of the aquifer and surficial sediments, and other physiographic factors (Liggett, Lapcevic, & Miller, 2011). Originally developed by the U.S. Environmental Protection Agency (Aller, Bennett, Lehr, Petty, & Hackett, 1987), the methodology DRASTIC acronym stands for

the parameters: Depth to groundwater; Recharge, Aquifer media, Soil Media, Topography, Impact of vadose zone, and hydraulic Conductivity of the aquifer. Using this method, the intrinsic vulnerability mapping was developed for use as a tool in land use decision making, sustainable development planning, source water protection planning, identifying sensitive areas, prioritizing areas for further monitoring or protection, and educating the public. The parameter ratings were based on information extracted from the British Columbia Provincial WELLS Database (B.C. Ministry of Environment, 2011c) and hydrogeological reports completed by various agencies.

An advantage to the intrinsic vulnerability maps is that the DRASTIC method shows variation in vulnerability within different zones in a single aquifer area where parameters such as depth to water, topography, and soil type vary. The resulting maps are based on the properties evaluated for individual 100 x100 m rasters or cells. In comparison the BC aquifer classification system provides a summary of the properties for the entire aquifer polygon, even though the well data may indicate a greater spatial variability.

Within the study area the intrinsic vulnerability map (Figure 1.5) applies to aquifer 186 because DRASTIC can only be used to evaluate the aquifer closest to the ground surface. From this map it is observed that aquifer 186 has a high intrinsic vulnerability and is surrounded by high to medium vulnerability areas.

1.4.2 Aquifer and river connectivity

Aquifers 186 and 187 have been classified as two distinct aquifers separated by a layer of less permeable material, described in well records as brown to grey sandy silt, blue or grey clay with stones or pebbles, or "dense grey till." As shown in Table 1.1 above, there is an overlap in the range of depths noted for the upper and middle aquifer, and an examination of well lithologies indicates that in some cases there is no confining layer present, suggesting that the confining sediments occur as discontinuous lenses in some areas where aquifers 186 and 187 are not discrete units. Also in Table 1.1, median static water levels are within the same range for all three aquifers.

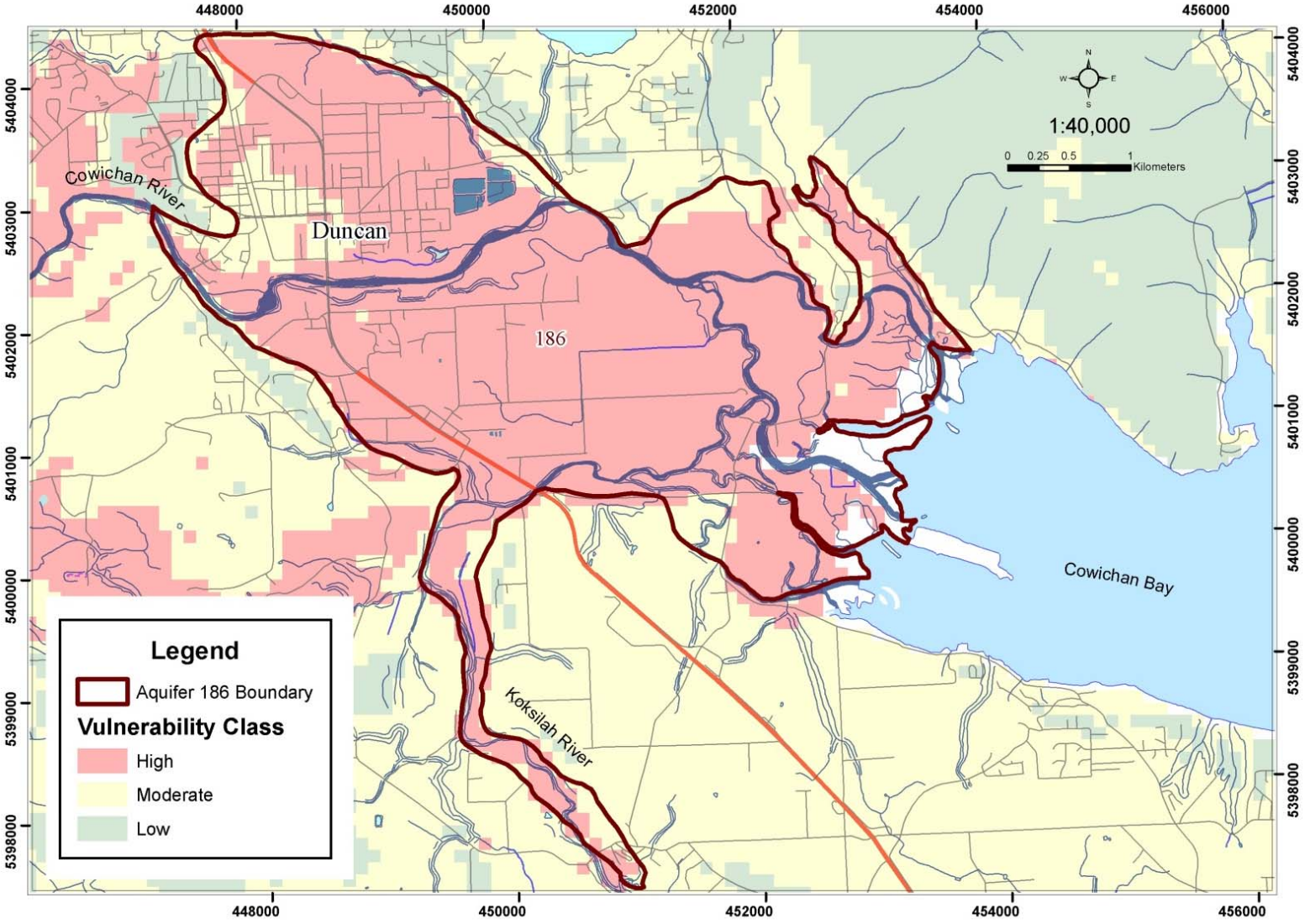

Figure 1.5: Aquifer Intrinsic Vulnerability of uppermost aquifer in the Lower Cowichan River area. Grid Cells: 100 m x 100 m.

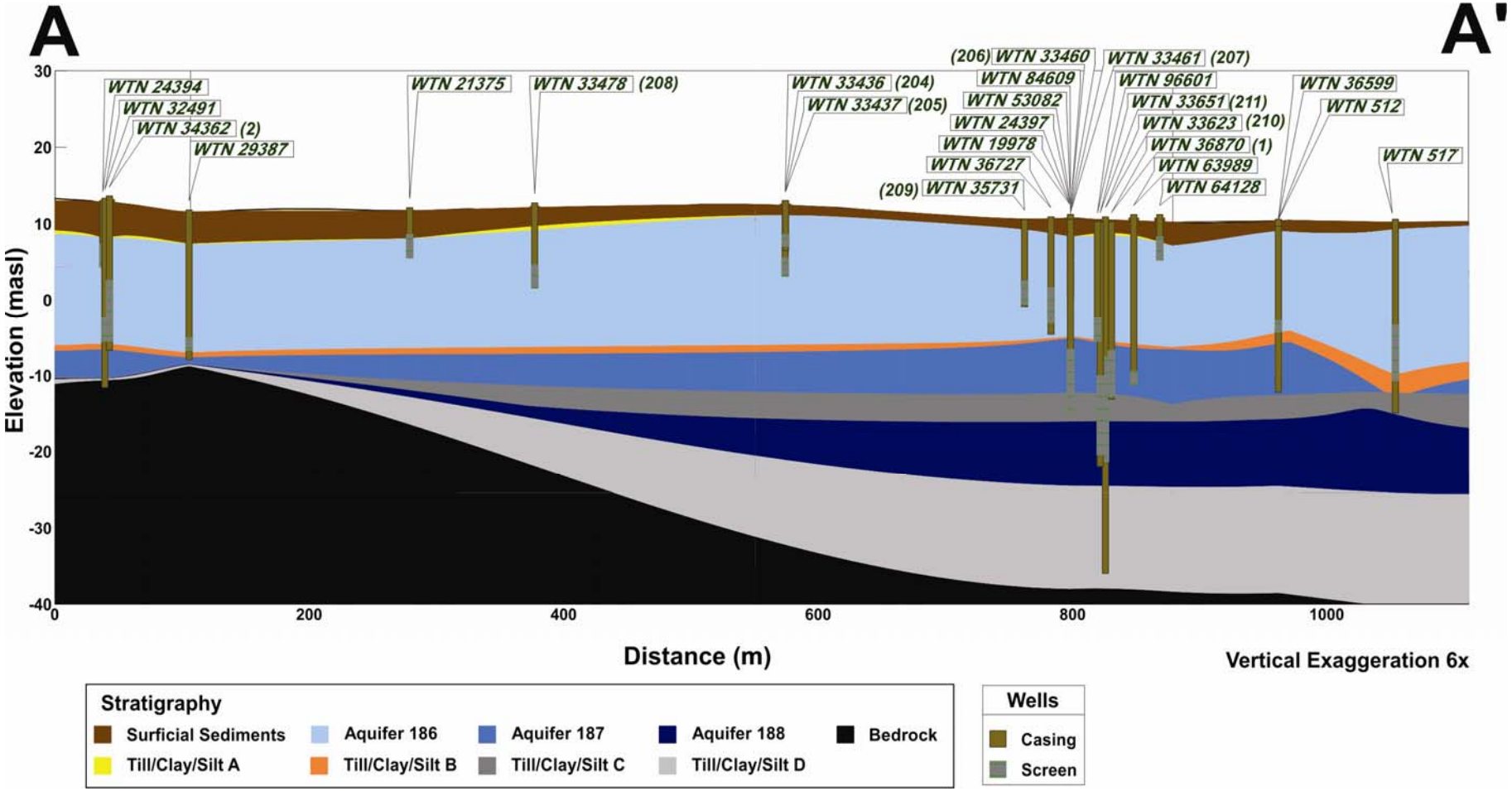

Figure 1.6: Cross-Section A-A' (wells labelled by Well Tag Number, study sites and observation wells labelled in brackets)

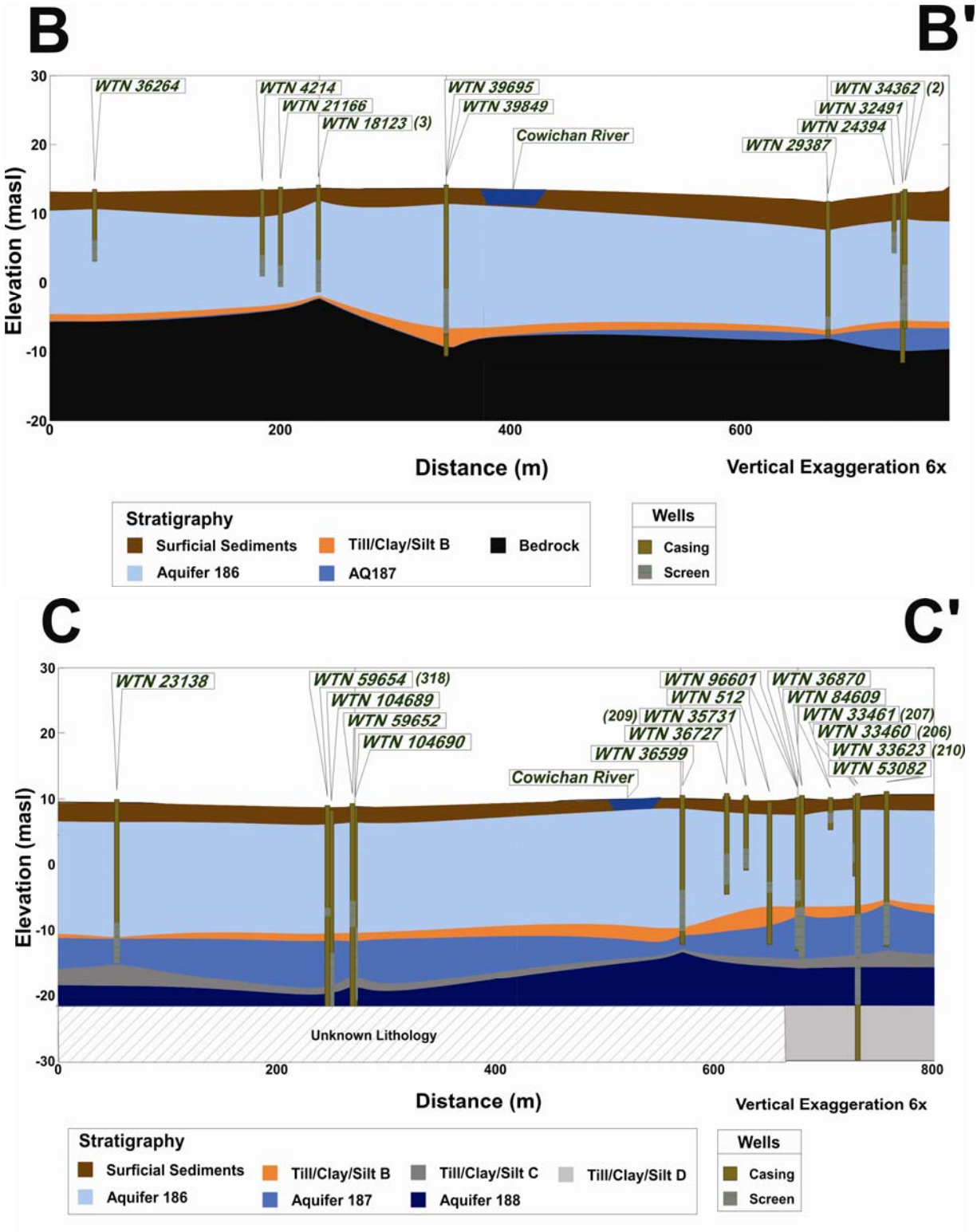

Figure 1.7: Cross-section B-B' (top) and cross-section C-C' (bottom) (wells labelled by Well Tag Number, study sites and observation wells labelled in brackets)

The occurrence and depth of aquifers and confining layers north and south of the Cowichan River, and west of the Trans Canada Highway are shown in a series of cross-sections, Figure 1.6 and Figure 1.7 from (Lapcevic, Gellein, and Ormond, 2013.). The cross-section locations are shown in Figure 1.4. These cross-sections were completed using EnviroInsite software, using data from the provincial WELLS database, and TRIM map elevation converted to a Digital Elevation Model comprised of 2 m x 2 m cells.

Based on the well construction records evaluated to prepare the cross-sections, where present, low permeability confining sediments ("confining layer B") between aquifer 186 and 187 occur at a median depth from approximately 11 to 18 m (35-58 ft), and have a median thickness of 7.0 m. From the cross-sections it is apparent that these confining sediments are reduced in thickness or pinch out in the area of Well Tag Numbers (WTN) 53082 on section A-A' and C-C', and WTN 18123 on section B-B'.

Low permeability confining sediments ("confining layer C") are believed to be thicker and more consistently present overlying aquifer 188, the deepest of the three aquifers. Sections B-B' and C-C' cross the Cowichan River; in this case the location and depth of the river on the cross-section is approximated based on map information, as detailed survey data were not available. Groundwater levels are also not shown on the cross-sections.

Historical studies suggested that there was a strong connection between aquifers 186 and 187 and the Cowichan River, however there was not as strong evidence for connectivity between aquifer 188 and surface water in his study area closer to the Cowichan estuary (Zubel, 1978). More recent studies, including Thurber Engineering (2001) have provided evidence for hydraulic connectivity, to a varying extent, between all three of the sand and gravel aquifers, and the river, based on pumping tests and hydrograph analysis.

Richards (1986) estimated that a significant proportion (80%) of groundwater extracted from the municipal production wells adjacent to the Cowichan River was derived from river flow but that there was also evidence of groundwater recharge from other sources. The river-aquifer connectivity is discussed further below based on recent observation well and river stage height data (see section 1.5.1).

1.5 Groundwater monitoring and observation wells

The MOE and the B.C. Ministry of Forests, Lands, and Natural Resource Operations (MFLNRO) maintain a network of dedicated groundwater observation wells. The Provincial Observation well network is used to monitor groundwater quantity by continuously measuring groundwater levels. Observation wells are also sampled periodically to evaluate ambient water quality. As of December 2012 there were 58 active observation wells located on Vancouver Island and the Gulf Islands, including three in the study area.

Within the lower Cowichan River area, historically there have been 11 different observation wells in operation during various periods, including observation wells 204, 211 and 318 that are currently active. Table 1.2 provides details on the observation well construction, period of record, the aquifer that they are constructed into and the current operational status; the well construction records are included in Appendix A and the locations of key observation wells are shown in Figure 1.4. The water quality results for the active observation wells that were sampled during the period between 2002 and 2011 are included in the geochemical data analysis (section 3).

Figure 1.8, Figure 1.10 and Figure 1.11, show the long-term hydrographs (groundwater level over time) for observation wells 204, and 318, constructed in aquifer 186, and observation well 211 constructed in aquifer 188. A summary of the median water levels from 2002-2011 for observation wells 204, 211, and 318 is shown in Table 1.3.

Observation well 204 has been monitored since January 1977 (Figure 1.8). The groundwater levels in this well show a seasonal fluctuation, with the shallowest water levels observed from November to January and the deepest groundwater levels observed from June to September annually. Based on the long-term record, average groundwater levels in well 204 range between 1.5 m to 2.5 m below ground surface (bgs) over the year. However within the last ten years there is a median difference of 2.4 m between winter high and summer low water levels, a greater annual variation compared to earlier years.

The climate data for the Environment Canada Cowichan Lake Forestry station (EC1012040, located on the southwest end of Cowichan Lake) from 1977 to 2006 shows that there is a long-term variation in precipitation in this area that has an approximately 15 year cyclicity, as shown on the plot of cumulative precipitation departure from average

(Figure 1.9)(Janicki, 2011). The observed cyclicity is thought to be associated with the Pacific Decadal Oscillation (PDO).

Table 1.2: Summary of Observation Wells in Study Area

Observation Well Number	Aquifer Number	Operational Status	Period of record	Well Tag Number (WTN)	Screened Interval (m bgs)	Well Depth (m bgs)
204	186	Active	1975-present	33436	7.0−9.4	9.4
205	186	Inactive	1975-2007	33437	4.0−5.5	6.1
206	186	Inactive	1975-1979	33460	6.7−9.8	11.9
207	186	Inactive	1975-1979	33461	1.8−3.4	4.4
208	186	Inactive	1975-2006	33478	7.6−10.7	10.7
209	186	Inactive	1975-1979	35731	7.6−10.7	11.0
298	186	Inactive	1987-2005	44174	No screen (dug well)	4.3
318	186	Active	1992-present	59654	15.2−16.4	16.5
210	187	Inactive	1975-1979	33623	17.7−21.3	46.3
211	188	Active	1975-present	33651	29.0−30.2	31.7
297	188	Inactive	1987-1997	56954	41.1−42.4	42.7

The PDO is related to fluctuations of sea surface temperature in the northern Pacific that influence long-term climate patterns in North and South America (Mantua & Hare, 2002). Within the Cowichan watershed, these effects are demonstrated by a relatively wetter period, beginning in 1979 and peaking in 1984, followed by a transition to drier conditions that reach a low in May 1994. Subsequently, increasing precipitation is observed relative to the average, corresponding to a wetter period from 1999 to 2006 (Janicki, 2011). A comparison between the cumulative precipitation departure, and groundwater level fluctuations within observation well 204 (Janicki, 2011), indicates that during the early period of record until approximately 1999, there was a very close correlation between groundwater levels and precipitation. Since 1999, although the precipitation has increased

relative to the average (wetter period), the summer groundwater levels have become deeper, suggesting that water levels in the aquifer are being affected by factors other than just recharge, such as well pumping.

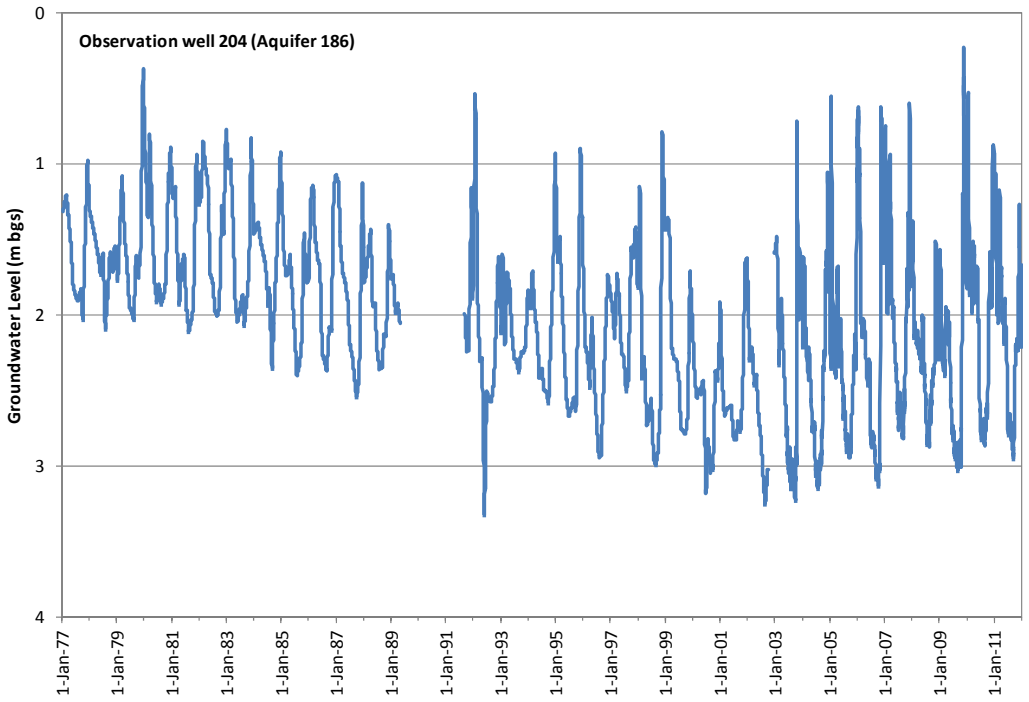

Figure 1.8: Long-term hydrograph for observation well 204 (1977-2011)

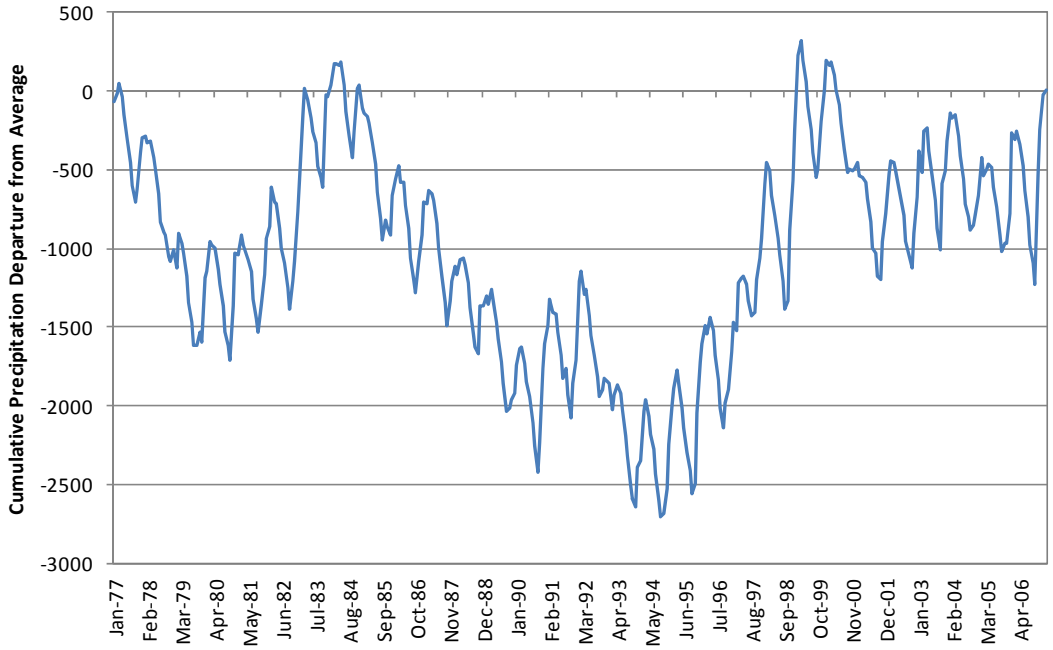

Figure 1.9: Cumulative Precipitation Departure from Average, Environment Canada, Cowichan Lake Forestry Station (1977-2006) from (Janicki, 2011)

Observation well 318, active since 1993, is also constructed in aquifer 186, and is located very close to several high capacity wells operated by the Vancouver Island Trout Hatchery, including one sampled for this study (site 4)(Figure 1.4). Raw (hourly) water level data for well 318 show a significant variation from adjacent pumping interference that is somewhat less evident on the long-term hydrograph (Figure 1.10), which utilizes averaged daily groundwater levels. Based on data over the period of record, average groundwater levels in well 318 range a total of approximately 1.5 m over the year, from roughly 3.5 m below ground surface at the shallowest point (November, May) up to 5.0 m bgs in late winter (January to March). Although late summer (July-September) water levels are also deeper (around 4.5 m bgs), the groundwater levels in this well do not follow a typical seasonal variability, reflecting precipitation inputs to aquifer recharge, and instead appear to reflect periods of high water use in the hatchery (e.g. peak use during salmonid brood rearing season in late winter).

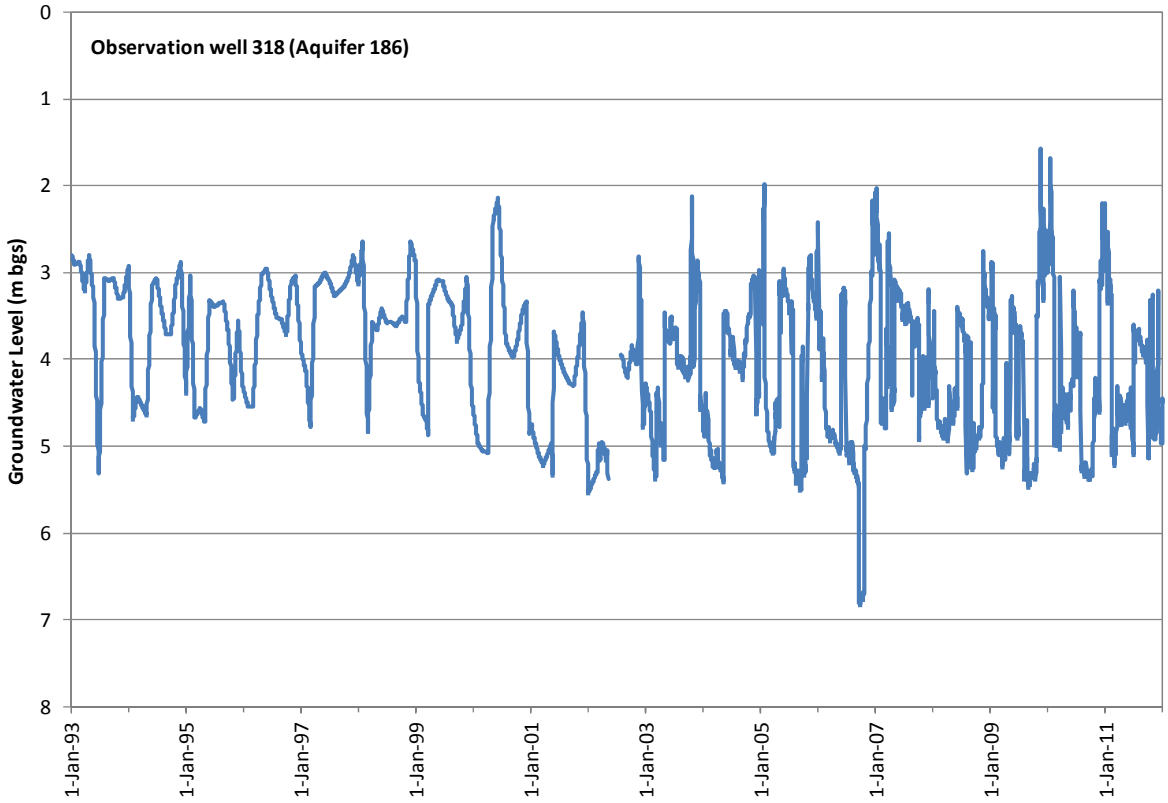

Figure 1.10: Long-term hydrograph for observation well 318 (1993-2011)

Similarly, there is a notable difference between long-term groundwater levels and the cumulative precipitation departure from average (Janicki, 2011), providing further evidence that water levels in the aquifer at this location are influenced by well pumping. Unlike observation well 204, the period record for well 318 is shorter, does not encompass the earlier time before significant aquifer development, and the influence on groundwater levels from long-term climate cycles such as the Pacific Decadal Oscillation is less evident.

For comparison to the observation wells constructed in the shallow aquifer (186), the long-term hydrograph for observation well 211, constructed in aquifer 188, is provided (Figure 1.11). For the whole period or record, the groundwater levels in this well show an annual range of approximately 1.1 m, on average, however since approximately 2003 there has been a noticeable increase in seasonal water level range, to roughly 3 m between fall or winter shallow groundwater levels and summer deep water levels. There has also been a deepening of the low water level of approximately 1 m within the last decade.

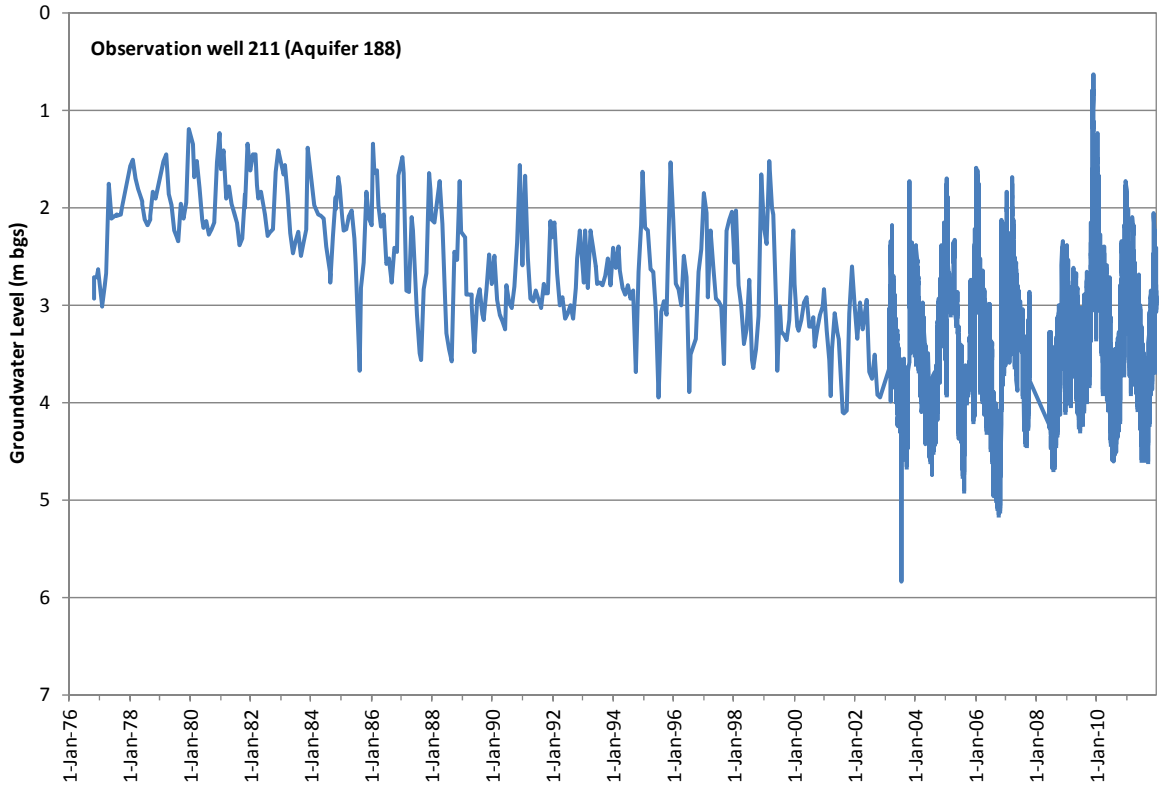

Figure 1.11: Long-term hydrograph for observation well 211 (1976-2011)

Similarly to wells 204 and 318, a comparison between the groundwater level data and the cumulative precipitation departure from average suggests that since approximately 1999, water levels in well 211 are being influenced by factors other than recharge, such as well pumping (Janicki, 2011). Further detailed discussion of the hydrographs for observation wells in the Cowichan aquifer complex is presented in Lapcevic, Gellein and Ormond (2013).

Table 1.3: Summary groundwater levels for active observation wells (2002-2011)

Observation well number	Aquifer	Median annual water depth	Minimum water depth (median 2002-2011)	Maximum water depth (median 2002-2011)	Annual water depth range (Max-Min) (m)
204	186	2.30	0.72	3.13	2.4
318	186	4.08	2.17	5.40	3.1
211	188	3.35	1.64	4.84	3.0

One way to evaluate the observation well response to recharge is to plot the groundwater levels and precipitation together, which has been done for observation well 204 and 318 in Figure 1.12. From this figure, groundwater level response to precipitation is rapid, and can generally be observed within one day.

As previously discussed, the aquifers 186, 187 and 188 are hydraulically connected to the Cowichan River, therefore the groundwater response following precipitation events may also be as a result of recharge due to rising river levels. Detailed surveyed wellhead elevation in comparison to river stage height is not currently available, therefore it is not possible to accurately map the potentiometric (water level) contours for this area.

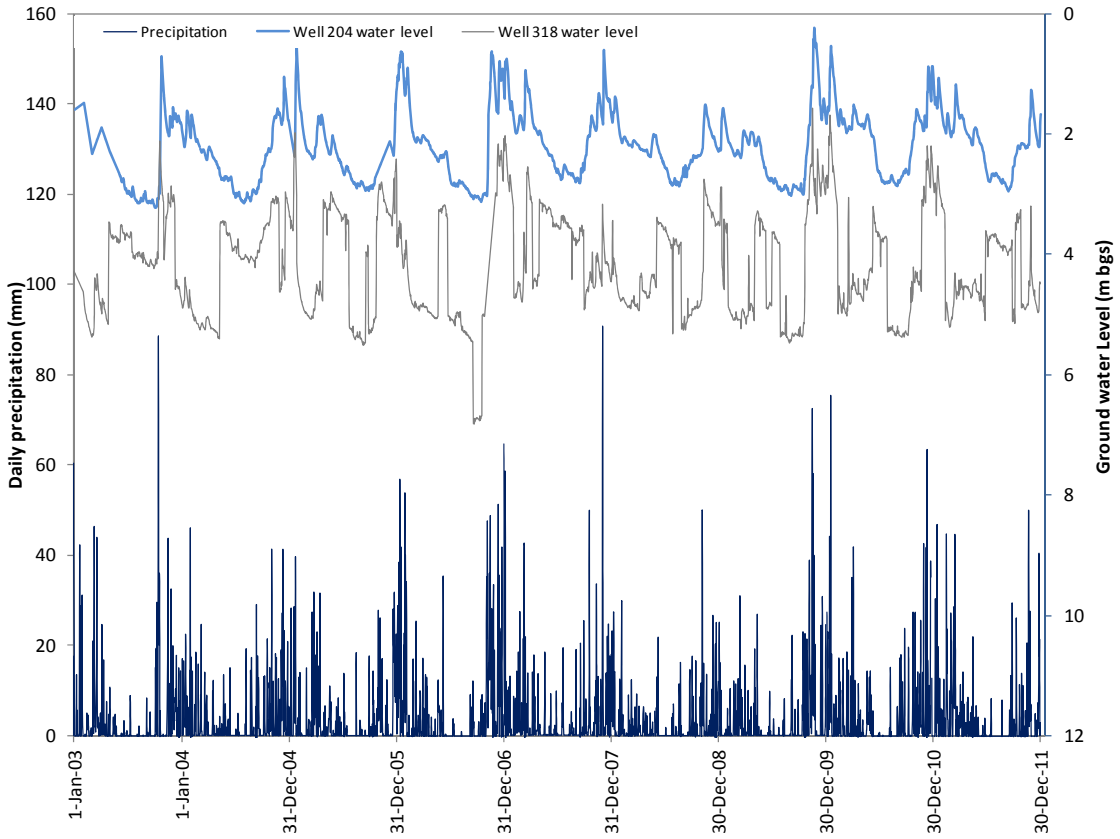

Figure 1.12: Observation Well 204 and 318 daily groundwater levels compared to daily precipitation at Environment Canada Kelvin Creek station (2003-2011)

1.5.1 Surface water connection

The Water Survey of Canada operates a hydrometric station (WSC08HA011) at the Allenby Bridge in Duncan (Figure 1.4) that continuously measures the level (stage) of the Cowichan River (Water Survey of Canada, 2012). A rating curve is used to calculate the discharge corresponding to the height of water at the gauge. The hydrometric station is located approximately 1.5 kilometres upstream from observation well 204, and two kilometres upstream from observation well 318. Observation well 204 is located approximately 100 m from the main channel of the Cowichan River. Observation well 318 is approximately 200 m from the river and within 30 m of an off channel storage lagoon that is connected to the river; however the groundwater levels in well 318 are also impacted by pumping in the nearby fish hatchery production wells.

The groundwater levels in the observation wells can be compared to the river discharge in order to evaluate the groundwater-surface water connection. A comparison of the groundwater level hydrograph for observation wells 204 and 318 to river flow measured

at the Water Survey of Canada gauge (Figure 1.13) indicates that river flow and groundwater levels follow the same trend. There is little to no lag time between peaks in discharge and peaks in groundwater levels. As expected, river flow is also highly correlated to precipitation, with peaks in discharge observed following peak precipitation events Figure 1.14. Because the groundwater hydrographs follow the same pattern, using this coarse data set (daily values) it is not possible to isolate the relative influence of either precipitation or river discharge on groundwater levels. The hydrograph for observation well 318 generally shows the same relationship to river discharge as observation well 204, but the groundwater levels are also subject to interference from nearby pumping. Previous studies have confirmed the link between the groundwater and the river; however this relationship may vary seasonally and spatially in different reaches.

Analysis of temperature data in the Cowichan River and observation wells 204, 211 and 318 indicates that there is an approximately 1 to 3 month time lag between peak river temperature and peak groundwater temperature with the response varying in different wells (Lapcevic, Gellein, & Ormond, 2013). The municipal sources, such as the Municipality of North Cowichan production wells, have not been classified as GUDI (groundwater under direct influence of surface water) based on assessments conducted for the municipality (John MacKay, Municipal Engineer, Municipality of North Cowichan, personal communication, January 2013). Despite this, because the river contributes to groundwater recharge, pollutants in the surface water have a potential to impact nearby wells.

The relationship between river and groundwater quality was not examined within this study. The interactions between surface and groundwater, including the effects of groundwater extraction on river discharge, and the links between water quality in the river and aquifers are the focus of more detailed studies currently being undertaken by the Ministry of Forests, Lands and Natural Resources Operations with other partners, including results reported in (Lapcevic, Gellein, & Ormond, 2013).

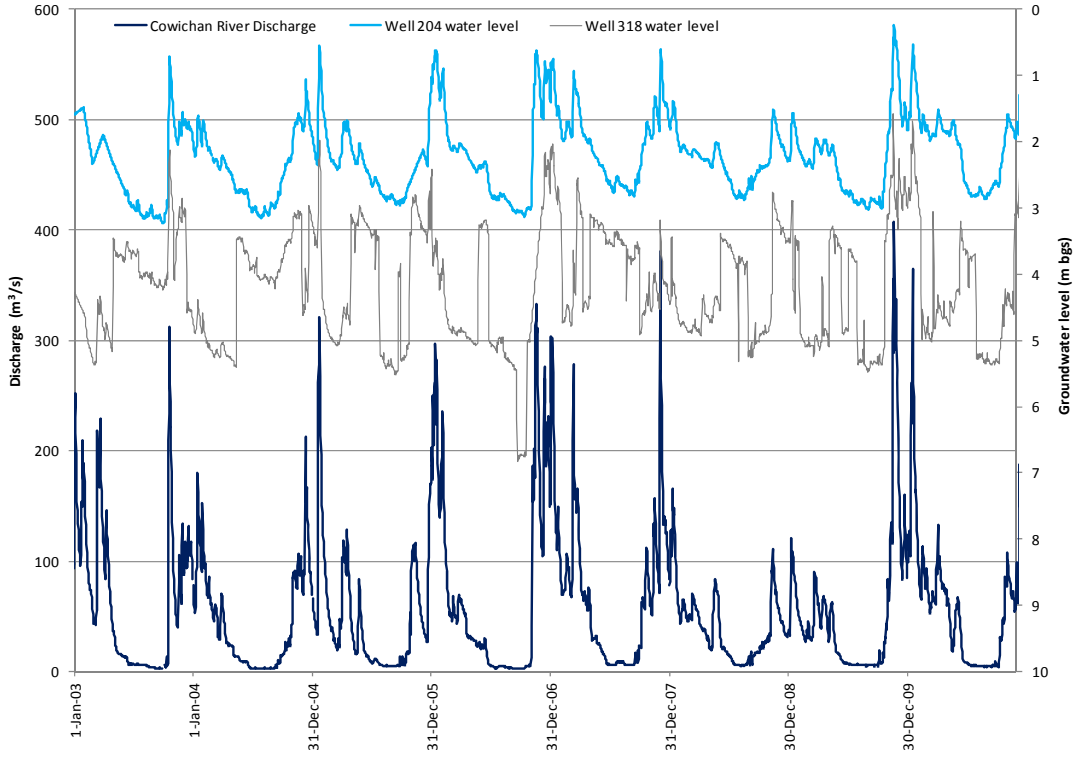

Figure 1.13: Observation Well 204 and 318 water levels compared to Cowichan River discharge measured at the Allenby Bridge (2003-2010)

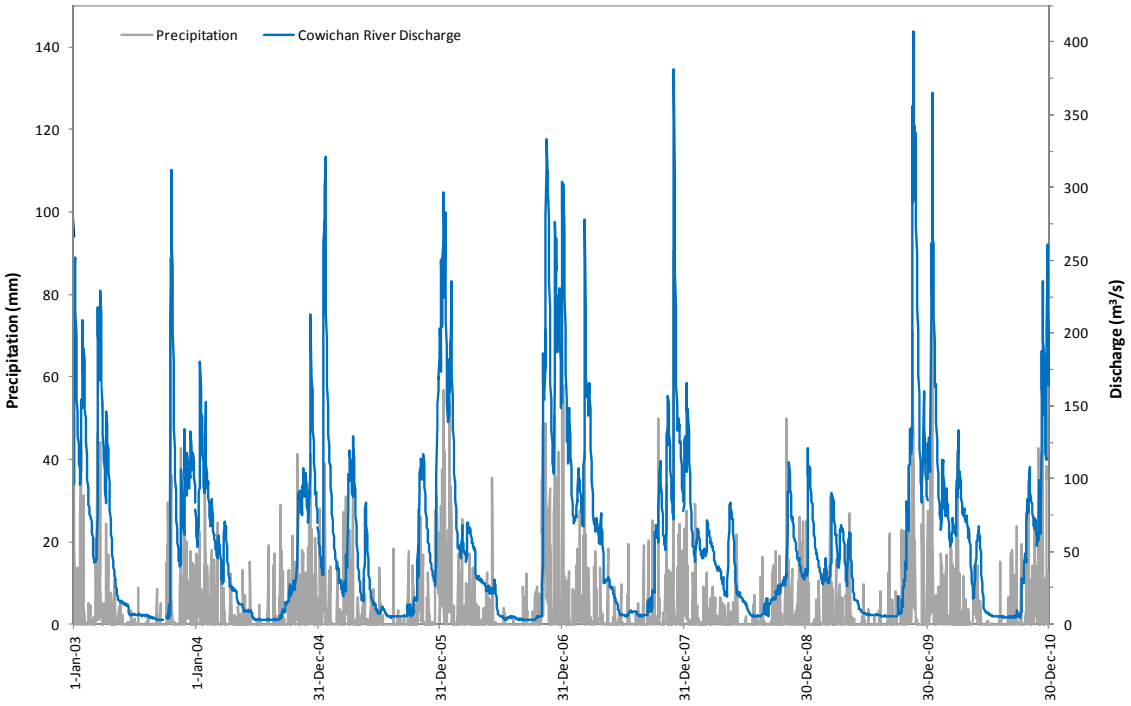

Figure 1.14: Daily precipitation at the Environment Canada Kelvin Creek station compared to Cowichan River discharge at Allenby Bridge (2003-2010)

1.6 Land use

Land use in the Lower Cowichan Valley overlying aquifer 186, which covers the largest area of aquifers in the aquifer complex (total area 16.95 km^2 or 1695 hectares (ha)), is predominantly agriculture and urban development in addition to young forest, residential-agricultural mixture and wetlands as listed in Table 1.4 and shown in Figure 1.15 (B.C. Integrated Land Management Bureau, 2012). The land use determination is based on mapping completed from 1992 to 1997. Although more recent mapping is not available, the main change has been conversion of young forest areas to more urban or rural residential land use. Agricultural land use is greatest along the lower Cowichan River and estuary.

Urban areas such as the City of Duncan, Municipality of North Cowichan and Cowichan Valley Regional District service areas (e.g. Cowichan Bay, Eagle Heights) have sanitary sewer service (CVRD, 2012). Municipal wastewater is treated at the Joint Utilities Board sewage treatment facility off of Lakes Rd. on the north side of the Cowichan River and the effluent is discharged to the Cowichan River downstream of the municipal well fields. Homes in mixed residential-agricultural, and agricultural areas are thought to mostly have individual septic systems for wastewater treatment.

Table 1.4: Surficial Land Use for Aquifer 186 (1992-1997)

Land Use	ha	% of Total
Agriculture	670.6	40
Estuary	17.4	1
Residential-Agriculture Mix	89.9	5
Urban	578.3	34
Wetlands	89.4	5
Young Forest	2.5	15
Total	1695.2	100

Industrial and commercial land use is not included within the surficial mapping categories, however much of the industry/commerce is concentrated south of Duncan city centre, in the area to the west of the Trans Canada Highway, between the Cowichan and Koksilah Rivers, including transport companies, auto repair, construction, gravel extraction, recycling, waste disposal and other industries. As an example, the former Koksilah landfill, closed since 1997, is located in this area, along Koksilah Rd approximately 2.5 km south of Duncan (Piteau Associates Engineering Ltd., 2011).

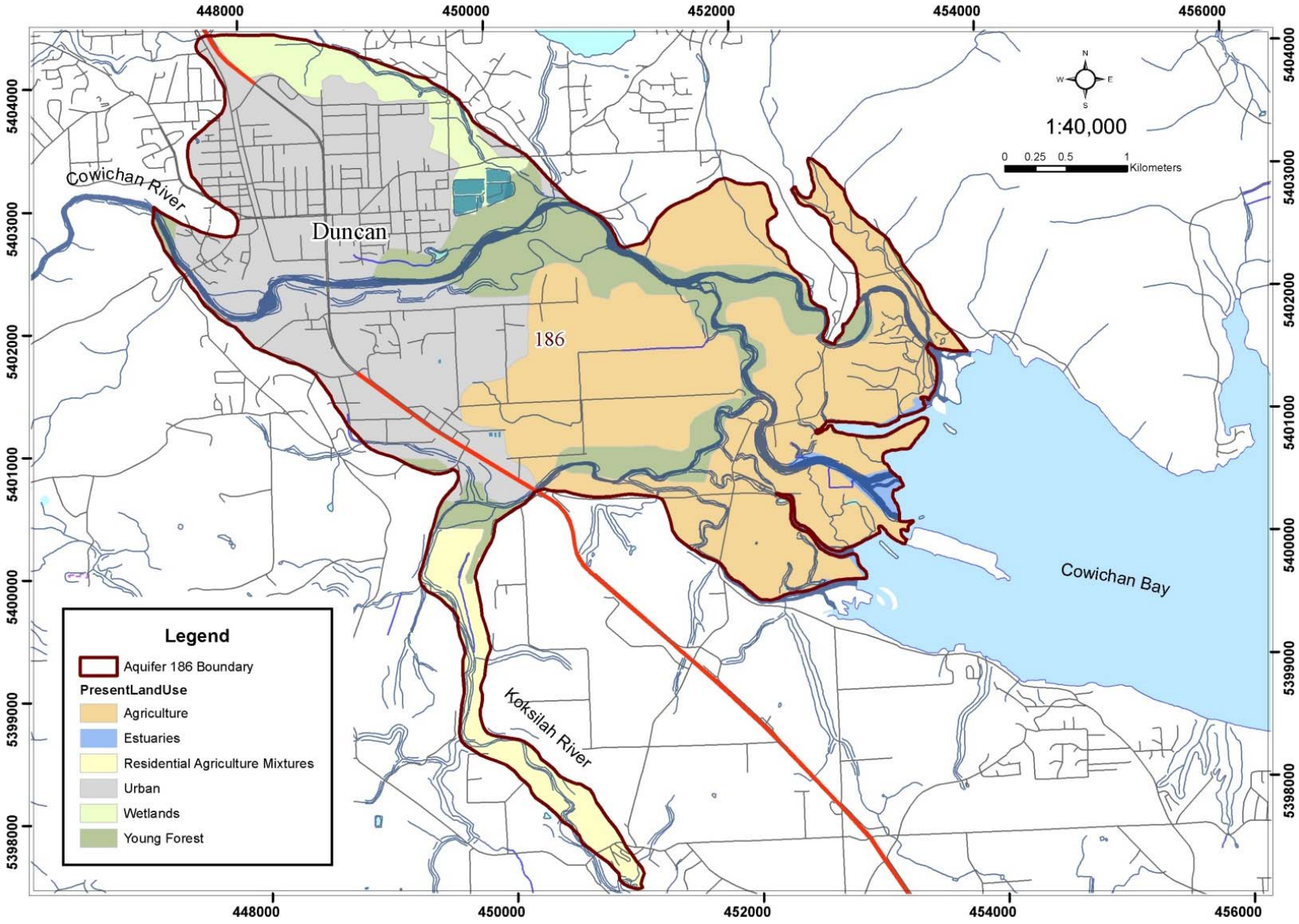

Figure 1.15: Land use in the study area (1992-1997)

2.0 Methods

2.1 Sample locations

Within this study, water quality samples were collected from wells constructed in Lower Cowichan aquifers 186 and 187. Six production wells were selected for inclusion in the sampling program (Figure 1.4):

(1) Municipality of North Cowichan Well 3;

(2) City of Duncan Well 4;

(3) City of Duncan Well 2;

(4) Vancouver Island Trout Hatchery Well 1;

(5) Cowichan Tribes Hatchery Well 4; and

(6) Ocean Farms Hatchery Well 4.

Production wells were selected due to a lower likelihood of ownership changes, regular well use, and good well maintenance practices. Samples were collected twice per year between 2002 and 2007 in the wet season (December to February) and the dry season (July to September). In October 2011, a final sample was collected.

A summary of well details for the sample sites is provided in Table 2.1 and the well construction records are included in Appendix A. The depth of the wells ranged from 15 m to 32 m (49 ft to 104 ft) and the lithology of the aquifers is described as silt and sand transitioning to coarse, sandy gravel. Less permeable material, described as clay, silt or till was observed at the bottom of all of the boreholes, except at site 3 where bedrock was reported. In general drilling was terminated when the less permeable layer was reached, so there is minimal information about the depth of the underlying materials. Information on the current pumping rates of the individual wells is not readily available. For the municipal wells, for example, discharge records are generally kept as monthly totals from all wells in the well field rather than for each individual well.

The results in this report also include data from observation wells 204 and 318, that were sampled during the same study period from 2003-2011, as a part of the MOE/MFLNRO observation well network water quality sampling program.

Table 2.1: Summary of well details for study sample sites, including active observation wells

Site	Well Use Type	Well Tag No. (WTN)	Aquifer	Well Depth (m bgs)	Screen length (m)	Screened interval (m bgs)	Land Use
1	Municipal	36870	186	22.9	6.4	16.5 - 22.9	Urban
2	Municipal	34362	186	19.8	8.0	10.6 – 18.6	Urban
3	Municipal	18123	186	15.1	4.7	10.4 - 15.1	Urban
4	Hatchery	85198	187	26.8	7.6	19.2 - 16.2	Urban
5	Hatchery	65039	187	16.2	Unknown	Unknown	Agriculture
6	Hatchery	85197	187	31.7	6.1	25.6 - 31.7	Urban
204	Observation	33436	186	9.4	2.4	7.0 - 9.4	Urban
318	Observation	59654	186	30.5	4.3	15.2 - 16.4	Young Forest

Notes:
m bgs meters below ground surface

2.2 Sampling methodology and analytical parameters

The sampling methodology followed protocols outlined in B.C. Ministry of Water, Land and Air Protection (2003a and 2003b) and Nielsen & Nielsen (2007), as detailed in Appendix B, along with the information on the quality assurance and quality control measures utilized.

The laboratory analytical parameters included general chemistry (e.g. alkalinity, pH, total hardness, pH, specific conductivity, turbidity, and filterable residue (1.0 μm) also known as total dissolved solids), major ions (ammonia, nitrate, bicarbonate, chloride, fluoride, sulfate, calcium, iron, magnesium, potassium and sodium) and total or dissolved metals (silver, aluminum, arsenic, boron, barium, beryllium, bismuth, bromide, cadmium, cobalt, chromium, copper, iron, fluoride, mercury, lithium, manganese, molybdenum, nickel, lead, sulfur, antimony, selenium, silicon, tin, strontium, tellurium, titanium, thallium, uranium, vanadium, zinc, and zirconium). The parameters chosen for this sampling program include all constituents typically evaluated in a detailed drinking water package for potable water sources. In 2011 the samples were analyzed for dissolved metals whereas previous samples were analyzed for total metals. A complete list of parameters and the sample results for each site are shown in Appendix C.

3.0 Results

3.1 Water quality

A total of 64 samples were collected from all well sites, including the two active observation wells as summarized in Table 3.1. This list also describes the Quality Assurance and Quality Control (QA/QC) samples collected at the same locations (9 samples). The sample dates ranged from December 2002 to October 2011, as shown in Table 3.2. The analytical results from the groundwater samples were compared to the Guidelines for Canadian Drinking Water Quality (Health Canada, 2012), and considered the presence or absence of anthropogenic impacts, and temporal trends.

3.2 Quality Assurance and Quality Control

As shown in Table 3.1, the QA/QC included collection and analysis of replicate samples and field blanks. The charge balance error (CBE) or electroneutrality was also calculated for all results. QA/QC methods are detailed in Appendix B.

Table 3.1: Sample summary, including quality assurance and quality control (QA/QC)

Site	N= number samples	QA/QC samples	Total samples, including QA/QC	CBE> 5%	RPD-1	RPD-2	RPD-2 exceedence parameters
1	8	0	8	1	na	na	-
2	9	1 replicate	10	0	4	1	manganese
3	9	0	9	1	na	na	-
4	9	1 replicate	10	1	4	2	copper, tin
5	9	0	9	0	na	na	-
6	9	0	9	2	na	na	-
204	7	4	11	0	6	0	-
318	4	2 replicates, 1 field blank	7	0	2	0	-
Total	**64**	**9**	**73**	**5**	**16**	**3**	-

Notes: CBE Charge Balance Error (table indicates number of samples with CBE >5%)
RPD Relative Percent Difference
MDL Method Detection Limit
RPD-1 Indicates number of parameters where RPD>25% but analytical result is <5xMDL
RPD-2 Indicates number of parameters where RPD>25% and analytical result is >5xMDL
na Not applicable

Table 3.2: Sample dates at each study site

Sample date	Sites
2002-12-17	1-6
2003-05-22	1-6
2003-07-21	204
2003-07-23	318
2003-10-23	1-6
2004-06-02	1-6
2004-12-07	1-6
2005-05-19	2-6
2005-11-01	1-6
2007-02-13	1-6

Sample date	Sites
2009-09-15	204
2010-01-27	204
2010-07-21	204
2011-02-03	318
2011-02-10	204
2011-07-20	318
2011-07-21	204
2011-08-03	204, 318
2011-10-06	1-6

Charge Balance Error results are shown in Appendix B, Table B.1. Including data for the observation wells, a total of 5 of 64 samples (8%) had a CBE greater than 5% and less than 10% (Table B.1). A CBE ≤5% is generally considered acceptable. Potential reasons why the CBE could exceed 5% include the presence of an ion in a significant concentration that was not considered in the calculation of the CBE, or laboratory error (Appelo & Postma, 1993). All of the data were considered valid for further analysis because the CBE was less than 10%.

A total of 8 replicate samples (representing 13% of 64 samples) and one field blank were collected. The Relative Percent Difference (RPD) was calculated for all replicates and for these, three parameters on different dates had a RPD > 25% where the analytical result was greater than five times the method detection limit (the stated criteria for an unacceptable result). Potential reasons that the RPD criteria were not met could include variation due to the sampling methods, insufficient purging duration (water quality parameters had not stabilized), or real variation within the aquifer (B.C. Ministry of Water, Land and Air Protection, 2003b). The results for parameters with a high RPD were considered valid for further analysis, but flagged in the summary tables (Appendix C). The Relative Percent Difference calculations for each site where replicate samples were taken are shown with the associated data in Appendix C, Table C1. The results for the field blank sample for observation well 318 are also shown in Table C1. All parameters, apart from pH, were less than the detection limit for the field blank.

3.3 Major Ion Chemistry

Major ions are the soluble elements that comprise the majority of dissolved constituents in groundwater. In most groundwater, the major ions include bicarbonate (HCO_3^-), calcium (Ca^{2+}), chloride (Cl^-), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), and sulphate (SO_4^{2-}). In some cases nitrate (NO_3^-), ammonia (NH_3^-) and/or iron (Fe^{3+}) may also be important ionic constituents (Appelo & Postma, 1993).

The observed chemistry of groundwater can give an indication of groundwater age, mixing of water from different sources, and the extent of mineral dissolution. The major cation and anion results for 62 samples with complete results (all applicable parameters), can be visually analyzed with the Piper plot in Figure 3.1. A Piper plot compares the percentage of milliequivalents of cations and anions in a sample with two separate triangular plots, and combines these two points into one point on a diamond plot.

Sites 1 to 5, 204 and 318 show calcium-bicarbonate (Ca^{2+}-HCO_3^-) type groundwater. The observed calcium-bicarbonate water indicates an immature groundwater, i.e. low levels of cation exchange without saltwater intrusion (Appelo & Postma, 1993). Calcium-bicarbonate groundwater is typical in shallow, unconsolidated aquifers that have been recharged fairly recently (Freeze & Cherry, 1979). The sample collected in October 2011 from site 5 had a higher proportion of chloride than the other samples, and plotted separately from the other samples but is still considered representative of fresh groundwater. The groundwater chemistry of site 6 had a higher proportion of both sodium and chloride and greater variability between the different sample events, and plotted in a distinctly different portion of the diamond plot. Possible reasons for the difference include that the well at site 6 is slightly deeper than at the other sample locations therefore could be pumping water from older recharge, the site is found in the Koksilah River drainage (closer spatially to the Koksilah River than the Cowichan River), and the onsite activities include disposal of hatchery wastewater via injection wells, as discussed further in section 3.4.1.

Table 3.3: Summary statistics for major water quality parameters

Parameter	Unit	N	Min	Max	Arithmetic Mean	Median	Standard deviation	Guideline[1]
Ca	mg/l	64	7.6	22	11	10	2.8	-
Cl	mg/l	64	1.6	64	5.5	2.5	9.2	250
HCO_3	mg/l	62	28	49	37	36	5.8	-
K	mg/l	64	0.21	1.0	0.85	1.0	0.29	-
Mg	mg/l	64	0.84	2.6	1.3	1.0	0.47	-
Mn	mg/l	64	0.000008	0.069	0.0032	0.0002	0.011	0.05
Na	mg/l	64	1.5	24	3.8	2.2	4.1	200
NO_3-N	mg/l	62	0.035	2.1	0.31	0.12	0.47	10
pH	pH units	61	6.1	7.8	7.4	7.5	0.33	6.5-8.5
SO_4	mg/l	64	0.5	4.7	2.3	2.1	0.94	500
TDS[2]	mg/l	64	32	150	56	50	23	-

Notes:

[1]Guideline for Canadian Drinking Water Quality

[2]TDS=Total Dissolved Solids (listed in master tables as Residue Filterable 1.0µm)

- Indicates no applicable guideline

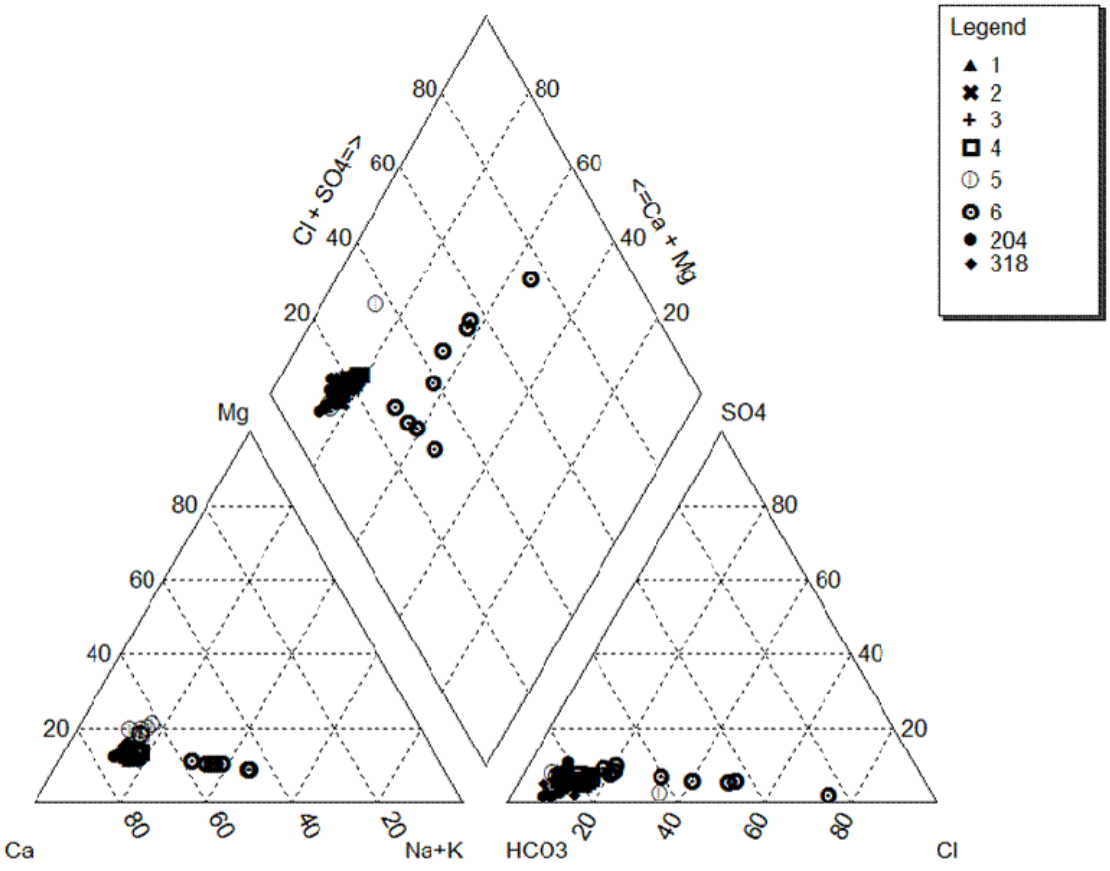

Figure 3.1: Piper Plot showing results of the major ion analyses from all sites in this study and two observation wells.

3.4 Chemical Parameters

The analytical results were compared to the Guidelines for Canadian Drinking Water Quality (GCDWQ) (Health Canada, 2012). The GCDWQ provide health based maximum acceptable concentrations (MAC) and taste, odour, and colour based aesthetic objectives (AO). There are also operating guidelines (OG) that affect the effectiveness of various water treatment methods. The analytical results were also interpreted from a geochemical perspective in order to identify trends (*e.g.* seasonal fluctuations), and to identify the extent of anthropogenic impacts, if any.

From a total of 64 samples that were analyzed for a complete list of parameters (i.e. not including 8 replicate samples which were generally analyzed for a subset of parameters such as anions), the summary statistics were derived for the major parameters, as shown in Table 3.3, above. Analytical results for chloride, sodium, iron, manganese, and nitrate are discussed in the sections below. Most of the other parameters were present at very low concentrations or below the analytical detection limit. The complete laboratory results are included in summary tables in Appendix C, and the water quality guideline for each parameter is also shown in this table.

3.4.1 Chloride

Chloride in groundwater can be naturally occurring due to dissolution from soil and rocks, and can also be attributed to infiltration of surface water containing road salts, pollution from septic systems, industrial pollution, or irrigation drainage. In coastal areas elevated chloride concentrations may be related to saltwater intrusion, old marine water trapped in geological formations, concentration of airborne salts in rainwater, or tides and storm surges. Previous studies found that chloride concentrations in the upper Cowichan aquifer close to the Cowichan Bay estuary were related to tidal inflows of salt water into the Cowichan River channels, in particular during periods of low river flow (Wei, 1985) whereas salt water intrusion was not evident in the lower aquifer based on chloride concentrations in sampled high capacity production wells (Chwojka, 1997).

The results for samples analyzed for chloride are shown in Table 3.4, and plotted in Figure 3.2 and Figure 3.3. None of the samples exceeded the GCDWQ (aesthetic objective) of 250 mg/L for chloride (Health Canada, 2012). The chloride concentration ranged from 1.6 mg/L to 64 mg/L, with the highest concentrations observed at site 6; overall these

chloride concentrations are considered low and do not pose a concern with respect to health, because chloride is an aesthetic parameter related to the taste of the water for drinking. No temporal trend was evident in the chloride concentrations at sites 1 to 4, 204 and 318 (Figure 3.2).

Table 3.4: Chloride (mg/L) in groundwater samples

Date	Site 1	2	3	4	5	6	204	318
2002-Dec-17	2.1	2.3	3.3	4.5	**3.9**	8.4	-	-
2003-May-22	1.9	1.7	2.4	5.7	2.1	26.1	-	-
2003-Jul-21	-	-	-	-	-	-	1.7	-
2003-Jul-23	-	-	-	-	-	-	-	3.8
2003-Oct-23	2.3	2.4	2.9	5.0	3.3	7.3	-	-
2004-Jun-02	2.0	1.9	2.6	5.1	2.1	27.3	-	-
2004-Dec-07	2.0	2.2	3.2	4.9	2.6	13.6	-	-
2005-May-19		1.9	2.4	4.9	3.1	18.7	-	-
2005-Nov-01	1.9	2.7	2.4	4.9	2.3	7.6	-	-
2007-Feb-13	1.8	1.8	1.6	4.0	1.8	6.1	-	-
2009-Sep-15	-	-	-	-	-	-	2.1	-
2010-Jan-27	-	-	-	-	-	-	1.8	-
2010-Jul-21	-	-	-	-	-	-	1.7	-
2011-Feb-03	-	-	-	-	-	-	-	1.3
2011-Feb-10	-	-	-	-	-	-	2.3	-
2011-Jul-20	-	-	-	-	-	-	-	3.5
2011-Jul-21	-	-	-	-	-	-	1.9	-
2011-Aug-03	-	-	-	-	-	-	2.3	4
2011-Oct-06	1.9	2.6	2.5	-	12	64	-	-
2011-Oct-20	-	-	-	4.9	-	-	-	-

Notes:
- indicates no sample was collected.

The chloride concentration in site 5 remained relatively constant until the final sample, which increased from < 4 mg/L to 12 mg/L. The chloride concentration at site 6 followed a rough pattern of seasonal highs and lows, with higher concentrations observed in the dry season, and showed an increasing trend overall during the period of record (Figure 3.2). The final sample in December 2011 showed a chloride concentration more than double that of the previously observed high concentration, and approximately eight times the concentration observed in the December 2002 sample. The plot of chloride over time for all sites has a logarithmic vertical axis, in order to incorporate results for site 6, where chloride concentrations were appreciably higher than at the other sites.

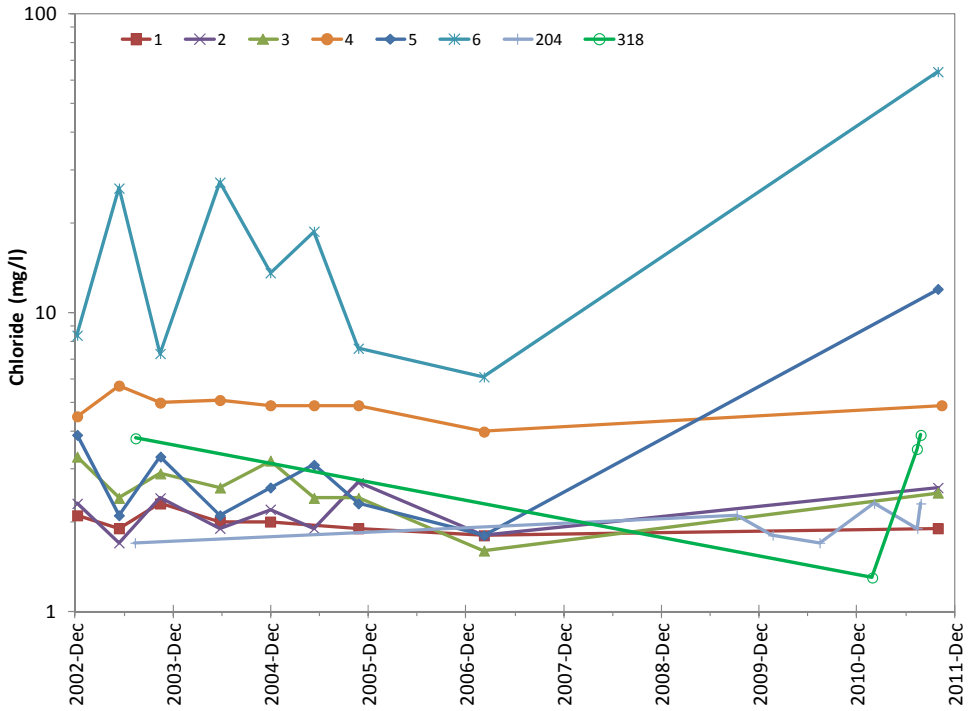

Figure 3.2: Chloride (mg/L) by date

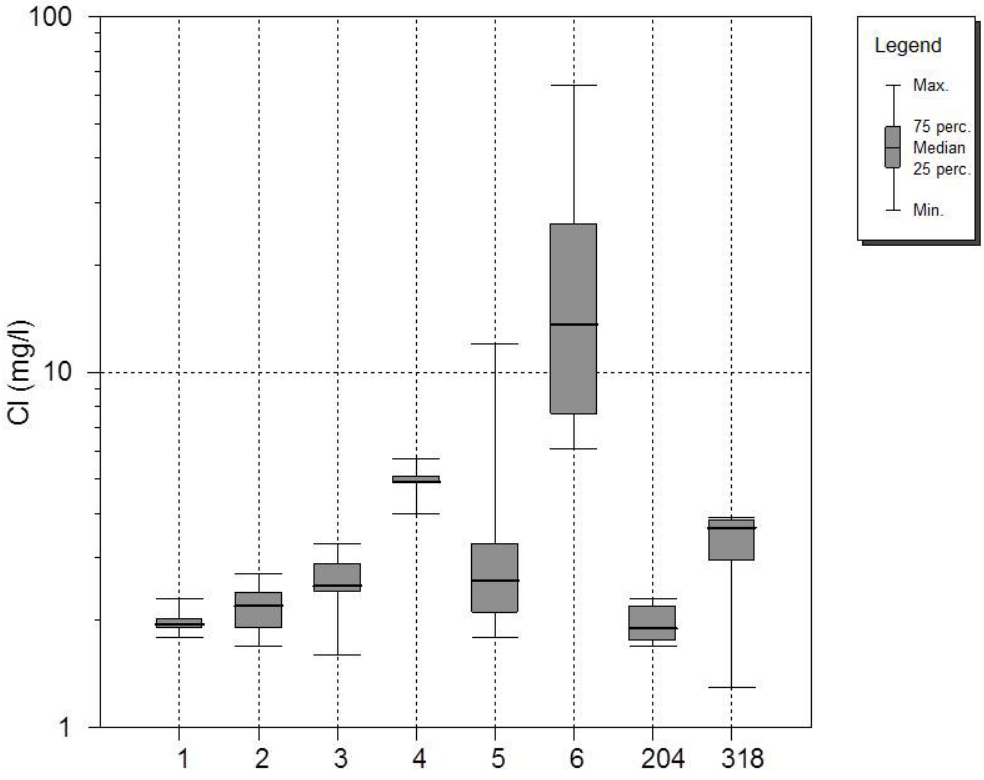

Figure 3.3: Chloride (mg/L) by site

The elevated levels of chloride observed at site 6 could indicate a deeper groundwater source (the screen is deeper than at other sites, and situated in aquifer 187), where concentrations of sulfate and chloride may be higher due to rock-water interaction over time (Freeze & Cherry, 1979). Alternatively, the higher concentrations of chloride could indicate the influence of human activities, including onsite and land-use practices.

For example, one factor is that hatchery wastewater at site 6 is disposed of via 8 injection wells to ground, following preliminary treatment including screening and reduction of solids in settling lagoons. Although the sampled well is constructed in aquifer 187, at this location the middle aquifer is unconfined, and the upper and middle aquifers (186 and 187) are connected, separated by a thin (0.3 m) silt layer according to the well construction log (WTN 85197). Hatchery wastewater may contain elevated chloride due to unconsumed feed (typically marine derived fish pellets), fecal matter and fish tissue from mortalities. Referring to the Piper plot (Figure 3.1) the parameters from site 6 plot on a mixing line directed toward a sea water type water (Na-Cl-SO_4) on the right hand corner of the diamond plot, which provides further support for the idea that groundwater at the site may be influenced by wastewater containing marine derived nutrients. At the other hatcheries sampled for this study, waste effluent is discharged back to the Cowichan River (Lapcevic, Gellein, & Ormond, 2013).

Other factors that vary at this location include that site 6 is located down gradient of industry, including a former landfill (Piteau Associates Engineering Ltd., 2011), is surrounded to the west by agricultural land, and is the only location that borders the Koksilah River (approximately 0.5 km away) compared to the other monitoring sites that are concentrated closer to the Cowichan River. Although site 6 is proximal to the Trans Canada Highway (as are sites 2 and 3), road salt is not thought to be a factor that influences chloride at this location. Sea water intrusion is not considered to be an influential factor due to the greater than 3 km distance of the site from the coast. Residents in the area near site 6 have wastewater service (CVRD, 2012), so septic discharges to ground are also not believed to contribute to chloride levels.

3.4.2 Sodium

Sodium is commonly found in groundwater because most rocks and soil contain sodium compounds that are easily dissolved as water passes through pores and fractures

below ground. Elevated sodium concentrations in groundwater can be attributed to dissolution of salt deposits, industrial pollution, and infiltration of surface water containing road salts. In coastal areas elevated sodium concentrations may indicate saltwater intrusion (Appelo & Postma, 1993).

The GCDWQ (aesthetic objective) for sodium in drinking water is 200 mg/L (Health Canada, 2012). A concentration of sodium exceeding the guideline may produce an objectionable taste but is generally not considered to be a health risk; however it could be a health concern for those on sodium restricted diets (Health Canada, 1992). Water with elevated sodium levels can also be unsuitable for irrigation.

The sodium concentration was low in all of the sample sites, and well below the drinking water guideline, but similar to chloride, the sodium concentration at site 6 was two to three or more times higher than at the other sites (Table 3.5, Figure 3.4 and Figure 3.5). Site 6 also shows an increasing trend over time, whereas sodium concentrations at the other sites remain relatively constant over the period of record, with some minor seasonal variation (winter higher and summer lower) observed at sites 1, 2 and 3.

Table 3.5: Sodium (mg/L) in groundwater samples

Date	Site 1	2	3	4	5	6	204	318
2002-Dec-17	2.09	2.12	2.37	3.28	3.29	10.4	-	-
2003-May-22	1.70	1.55	1.92	3.40	2.01	13.3	-	-
2003-Jul-21	-	-	-	-	-	-	1.88	-
2003-Jul-23	-	-	-	-	-	-	-	2.56
2003-Oct-23	2.14	2.11	2.27	3.38	2.34	11.1	-	-
2004-Jun-02	1.74	1.65	1.82	3.51	2.32	13.4	-	-
2004-Dec-07	2.06	2.16	2.33	3.57	2.50	11.0	-	-
2005-May-19	-	1.72	1.92	3.24	2.54	11.1	-	-
2005-Nov-01	1.75	2.05	2.31	3.24	2.56	9.38	-	-
2007-Feb-13	1.75	1.86	1.85	3.15	2.27	7.7	-	-
2009-Sep-15	-	-	-	-	-	-	2.11	-
2010-Jan-27	-	-	-	-	-	-	1.54	-
2010-Jul-21	-	-	-	-	-	-	1.74	-
2011-Feb-03	-	-	-	-	-	-	-	2.02
2011-Feb-10	-	-	-	-	-	-	1.58	-
2011-Jul-20	-	-	-	-	-	-	-	2.01
2011-Jul-21	-	-	-	-	-	-	1.73	-
2011-Aug-03	-	-	-	-	-	-	1.72	2.00
2011-Oct-06	1.80	2.00	2.07	-	2.60	24.3	-	-
2011-Oct-20	-	-	-	2.70	-	-	-	-

Notes:
- indicates no sample was collected.

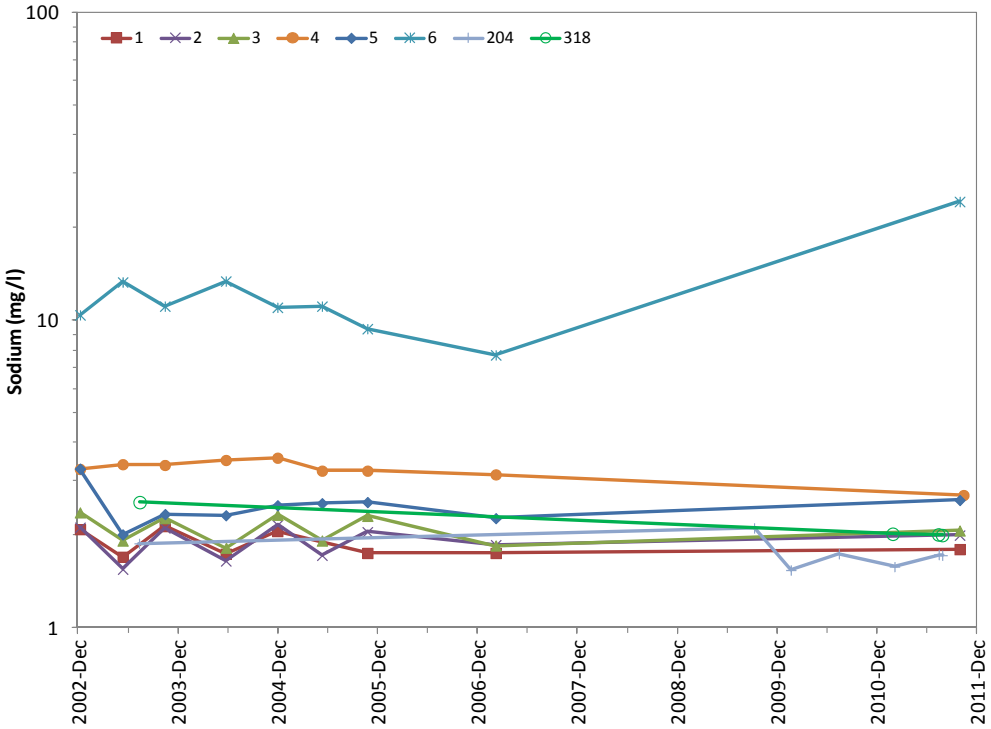

Figure 3.4: Sodium (mg/L) by date

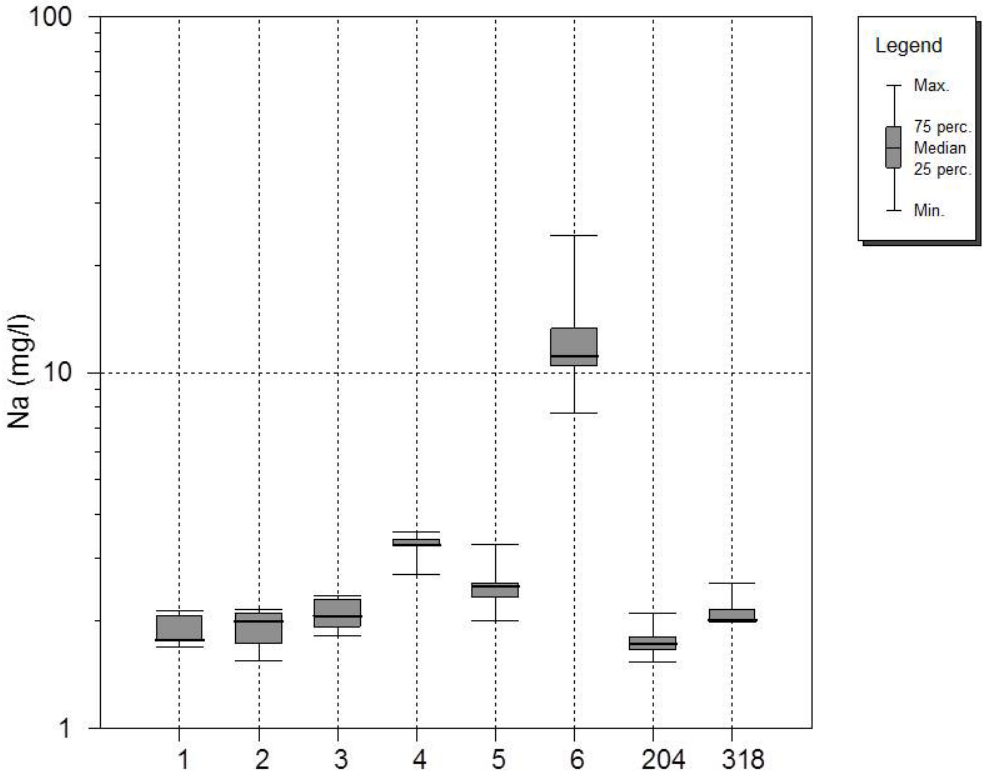

Figure 3.5: Sodium (mg/L) by site

The correlation between sodium and chloride concentrations in milliequivalents per litre is shown in Figure 3.6. The trend line and correlation coefficient (R^2) value for the data, grouped separately into a) all sites (including site 6), b) sites 1-5, 204 and 318 (excluding site 6) and c) site 6, are shown. The correlation/trend line for the site 6 data suggests there is an approximately 2:1 relationship between chloride and sodium concentrations, whereas the other data from the other sites indicate a roughly 1:1 ratio of chloride to sodium. The inference is that there may be additional sources of chloride at site 6, not present in the other wells, or that sodium is reduced (e.g. via cation exchange) at site 6 relative to chloride.

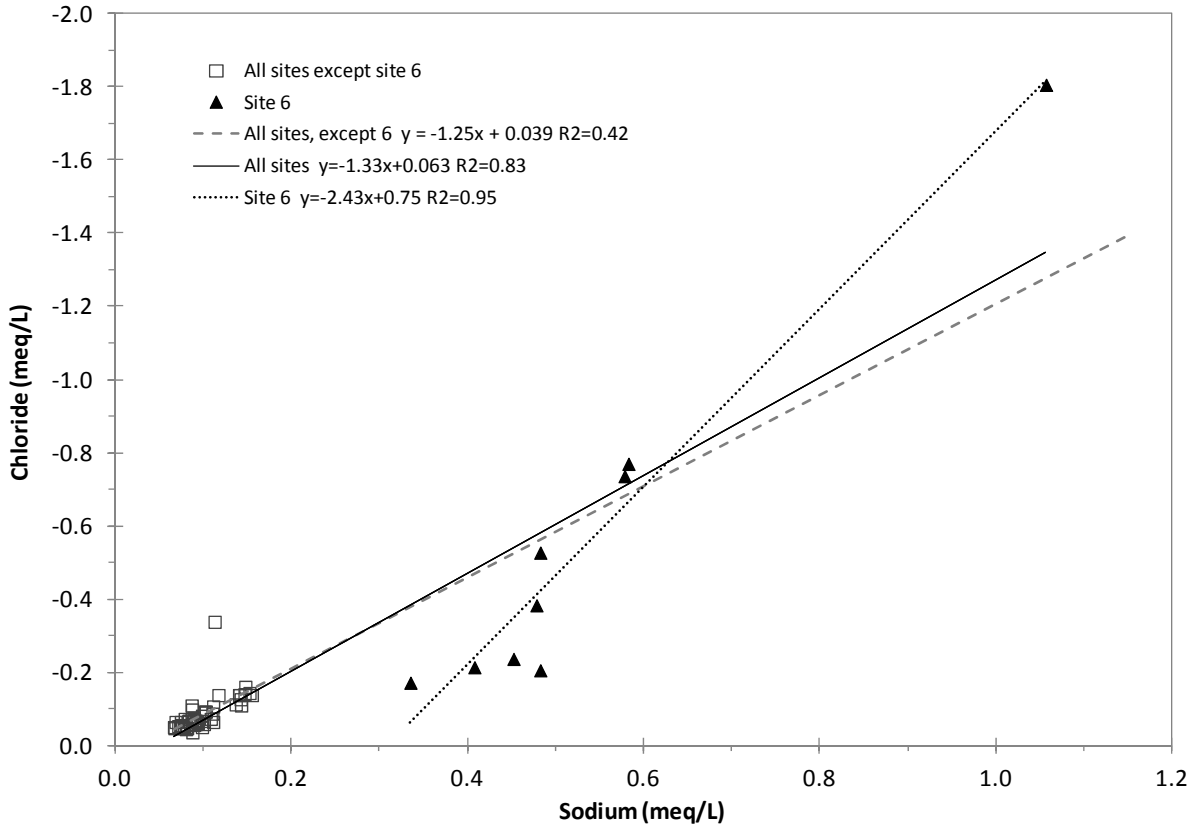

Figure 3.6: Correlation between sodium and chloride concentration (meq/L)

3.4.3 Iron and manganese

The most common sources of iron (Fe) and manganese (Mn) are natural, such as the weathering of minerals and rocks, but other sources may include industrial effluent, landfill leachate, and sewage effluent (Health Canada, 1978; Health Canada, 1987a). The GCDWQ

aesthetic objective is 0.3 mg/L for iron and 0.05 mg/L for manganese (Health Canada, 2012). For the study sites, the iron concentration ranged from 0.001 mg/L to 8.64 mg/L, and the manganese concentration ranged from 0.000008 mg/L to 0.069 mg/L, as shown in Table 3.6 and Table 3.7, and Figure 3.7, Figure 3.8, Figure 3.9, and Figure 3.10.

There were two exceedences of the drinking water guideline for iron, one at site 5 (December 2002) and one at observation well 318 (July 2003). There was one exceedence for manganese at site 5 (also in December 2002). It is believed that the sources of iron and manganese exceedences are natural and related to the geology of the aquifers, and there are no health concerns related to the exceedences. For example, during the July 2003 sampling at observation well 318 the water was noted to have an orange/rusty colour after more than 4 well volumes had been purged, and the sample was taken during the dry season, when natural concentrations of metals in the groundwater are expected to be higher due to less dilution (lower water levels). The iron and manganese concentration observed in the remainder of the samples was very low.

Prior to 2009, the majority of observation well and study site samples were analyzed for the concentration of total iron and total manganese, as opposed to the concentration of dissolved iron and dissolved manganese. Water samples analyzed for dissolved concentrations are passed through a 45 μm filter to remove any particulates in the water, whereas water samples analyzed for total concentrations are not filtered and include the concentrations of metals associated with colloidal particles. Thus, the total concentration of a parameter will be higher than the dissolved concentration.

Some advantages of evaluating the dissolved concentration include that the laboratory can measure metal concentrations more accurately without the interference of suspended particulate matter, and the results on different dates and times are less variable (e.g. if there is a variation in suspended particulates in the sample), facilitating analysis of trends (Nielsen & Nielsen, 2007). Overall, dissolved concentrations are considered a more representative measure of aquifer groundwater chemistry although some colloidal matter up to 10 μm in size may still be present if the sample is filtered to 45 μm (Ibid.). It may be inaccurate to directly compare the total and dissolved values, however the concentrations (both dissolved and total) of these metals are naturally low, and the influence of particulates is considered minimal in most instances.

Table 3.6: Iron (mg/L) in groundwater samples

Date	Site 1	2	3	4	5	6	204	318
2002-Dec-17	0.005	0.042	0.005	0.005	**0.860**	0.225	-	-
2003-May-22	0.005	0.047	0.005	0.007	0.023	0.009	-	-
2003-Jul-21	-	-	-	-	-	-	0.013	-
2003-Jul-23	-	-	-	-	-	-	-	**8.64**
2003-Oct-23	0.011	0.021	0.058	0.005	0.024	0.005	-	-
2004-Jun-02	0.010	0.018	0.021	0.007	0.009	0.005	-	-
2004-Dec-07	0.005	0.009	0.005	0.017	0.025	0.005	-	-
2005-May-19	-	0.030	0.013	0.045	0.050	0.006	-	-
2005-Nov-01	0.005	0.018	0.008	0.045	0.035	0.007	-	-
2007-Feb-13	0.005	0.013	0.005	0.075	0.013	0.005	-	-
2009-Sep-15	-	-	-	-	-	-	0.001	-
2010-Jan-27	-	-	-	-	-	-	< 0.001	-
2010-Jul-21	-	-	-	-	-	-	0.003	-
2011-Feb-03	-	-	-	-	-	-	-	0.160
2011-Feb-10	-	-	-	-	-	-	0.002	-
2011-Jul-20	-	-	-	-	-	-	-	0.069
2011-Jul-21	-	-	-	-	-	-	0.001	-
2011-Aug-03	-	-	-	-	-	-	0.001	2.00
2011-Oct-06	1.000	0.004	0.005	-	0.035	0.002	-	-
2011-Oct-20	-	-	-	0.003	-	-	-	-

Notes:

Bold indicates value above the guideline of 0.3 mg/l; - indicates no sample was collected; shaded data indicates total iron and unshaded data indicates dissolved iron.

Table 3.7: Manganese (mg/L) in groundwater samples

Date	Site 1	2	3	4	5	6	204	318
2002-Dec-17	0.000064	0.000717	<0.000008	<0.000008	**0.0686**	0.00135	-	-
2003-May-22	0.000032	0.00117	0.000075	0.000117	0.00273	0.000236	-	-
2003-07-21	-	-	-	-	-	-	0.000163	-
2003-Jul-23	-	-	-	-	-	-	-	0.0453
2003-Oct-23	0.000194	0.000629	0.000238	0.00012	0.0046	0.000088	-	-
2004-Jun-02	0.000124	0.000308	0.00012	0.000319	0.000752	0.000141	-	-
2004-Dec-07	0.000205	0.00057	0.000048	0.000454	0.0104	0.00014	-	-
2005-May-19	-	0.000997	0.00003	0.000044	0.00813	0.000059	-	-
2005-Nov-01	0.000008	0.000544	0.000018	0.000175	0.0124	0.000163	-	-
2007-Feb-13	0.000066	0.000557	0.000037	0.00022	0.00559	0.000081	-	-
2009-09-15	-	-	-	-	-	-	0.00014	-
2010-01-27	-	-	-	-	-	-	0.00011	-
2010-07-21	-	-	-	-	-	-	0.00179	-
2011-02-03	-	-	-	-	-	-	-	0.0192
2011-02-10	-	-	-	-	-	-	0.00022	-
2011-07-20	-	-	-	-	-	-	-	0.0476
2011-07-21	-	-	-	-	-	-	0.00044	-
2011-08-03	-	-	-	-	-	-	0.00042	0.047
2011-Oct-06	0.00013	0.00046	0.00016	0.00007	0.0189	0.00016	-	-

Notes:

Bold indicates value above the guideline of 0.05 mg/l; - indicates no sample was collected; shaded data indicates total iron and unshaded data indicates dissolved iron.

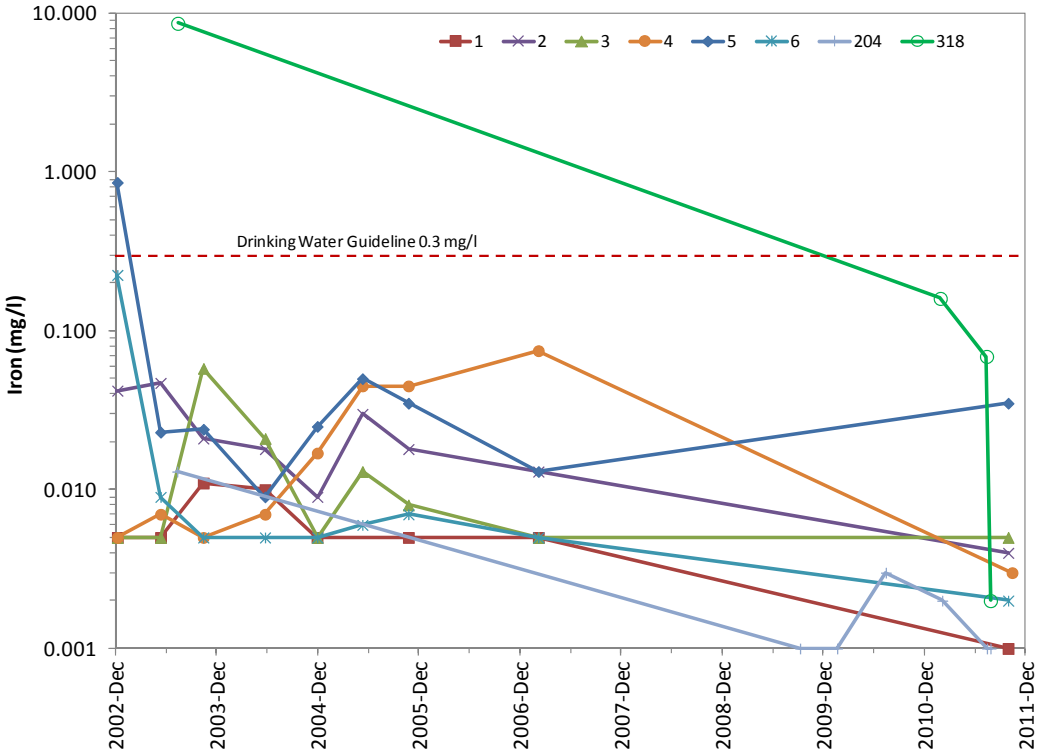

Figure 3.7: Iron (mg/L) by date

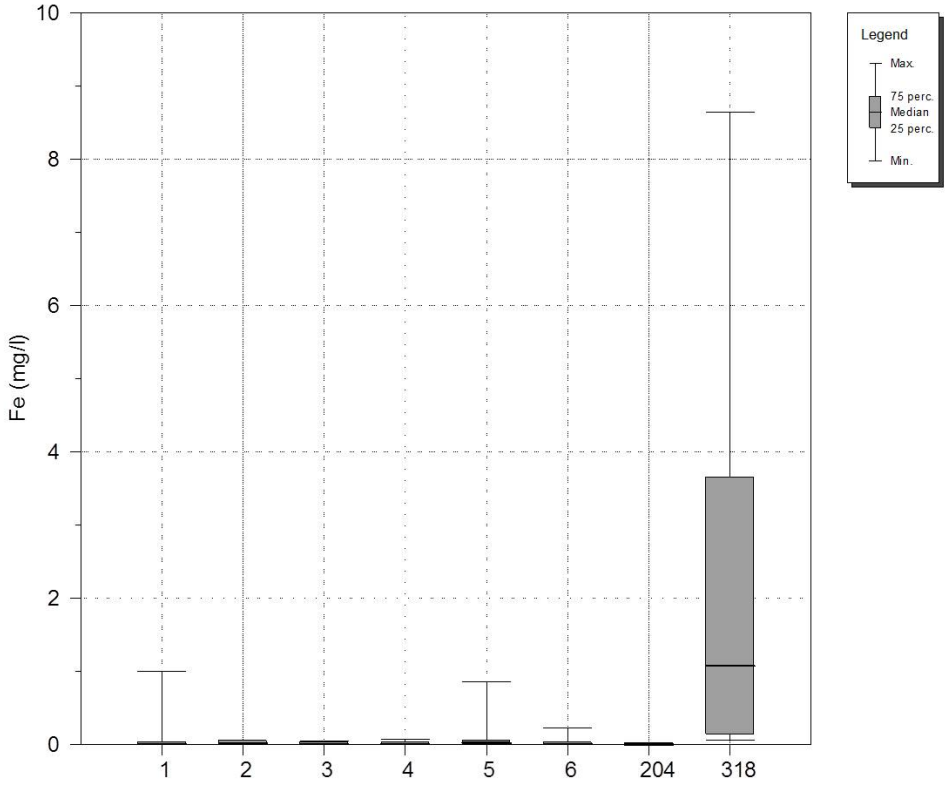

Figure 3.8: Iron (mg/L) by site

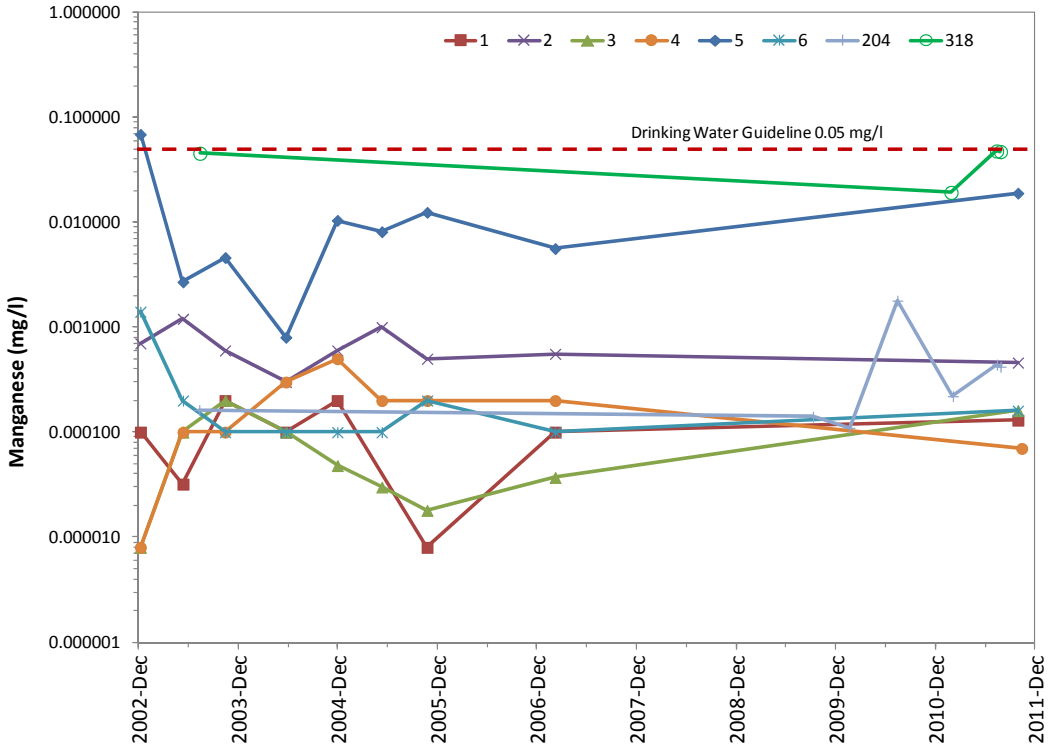

Figure 3.9: Manganese (mg/L) by date

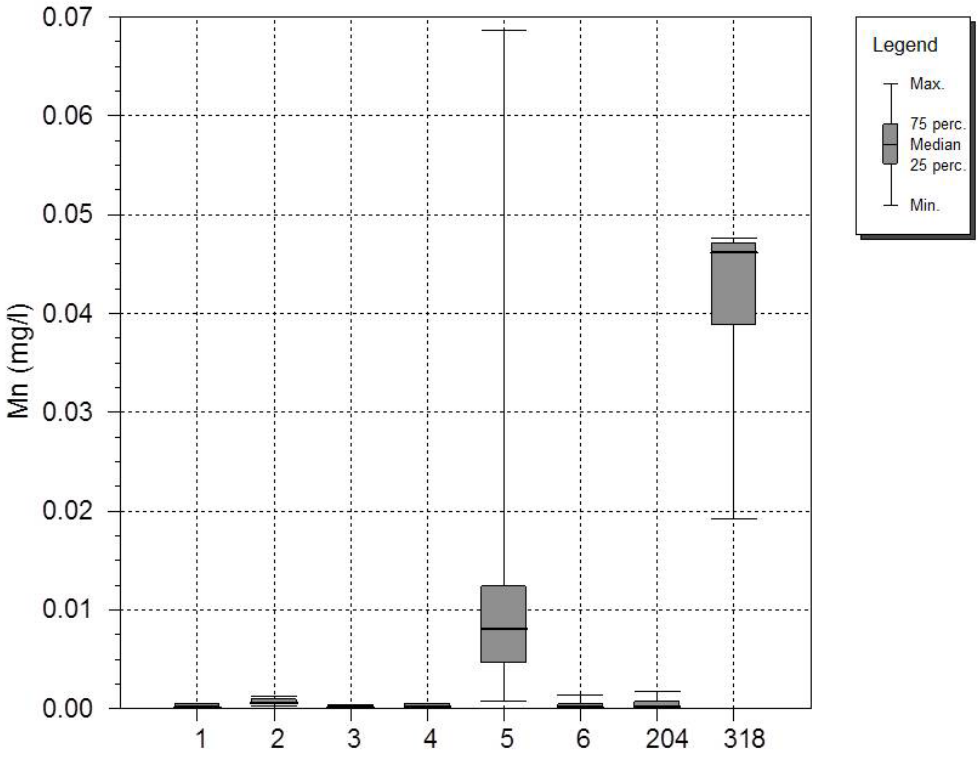

Figure 3.10: Manganese (mg/L) by site

3.4.4 Nitrate

Nitrate (NO_3^-) is the most common form of nitrogen found in water (Health Canada, 1987b). Sources of nitrate in water include decomposing animal and plant materials, such as manure and compost, artificial fertilizers used in agriculture, and domestic sewage. Although there are some forms of nitrate derived from geologic sources which contain soluble nitrogen compounds, these are not widely found in nature and concentrations in groundwater above background are typically considered to be from anthropogenic non-point source contaminants, such as infiltration of surface water run-off containing chemical fertilizers or animal manure, and septic tank or sewage discharges. Other forms of nitrogen that may be present in groundwater include nitrite (NO_2^-), organic nitrogen and ammonia; however the majority of these forms convert to nitrate under aerobic conditions (Health Canada, 1987b). The GCDWQ for nitrate is a Maximum Acceptable Concentration (MAC) of 10 mg/L for results reported as nitrate-nitrogen (NO_3-N), or a MAC of 45 mg/L for results reported as nitrate (NO_3^-) (Health Canada, 2012). The drinking water guideline is an MAC of 1 mg/L nitrite-nitrogen (NO_2-N) or 3.2 mg/l for nitrite (NO_2^-). To provide a comparison to other parts of B.C., a previous study in Grand Forks found that ambient groundwater in that area contained <0.1 mg/L nitrate-nitrogen (Wei, Kohut, Kalyn, & Chwojka, 1993), whereas a concentration in groundwater of nitrate-nitrogen above 3 mg/L is generally considered indicative of anthropogenic impacts (Wei, Allen, Carmichael, & Ronneseth, 2010).

The nitrate-nitrogen concentrations for study sites are shown in Table 3.8 and the summary statistics for all nitrogen compounds are shown in Table 3.9. The nitrate-nitrogen concentration by date and by site is shown in Figure 3.11 and Figure 3.12. Most nitrogen was present as nitrate. The median nitrate-nitrogen was 0.12 mg/L, and the NO_3-N ranged from 0.035 mg/L to 2.08 mg/L, whereas nitrite, ammonia and total organic nitrogen was very low or below the Method Detection Limit (MDL). Nitrate concentrations were ≤0.4 mg/L at all study sites but one, and this may be considered a background concentration for the aquifer. Site 6 had higher nitrate concentrations in the range of 1 to 2 mg/L, which is believed to result from differences in surrounding land-use and onsite practices. As previously discussed, effluent waste at this hatchery site is disposed to ground via infiltration wells. Concentrations of nitrate increased up until the

2007 sample period. In 2009 a recirculation system was introduced at the hatchery to reduce nutrients in the wastewater and improve water use efficiency (Tom Folds, Licence and Compliance Officer, Ewos Canada Ltd., personal communication, September 2011). Subsequently, in 2011 the sample showed a moderate decrease in nitrate compared to the previous high value. Because the hatchery is adjacent to active agricultural land, the nitrate concentration in groundwater at site 6 may also be influenced by non-point source pollutants from agricultural activities such as manure spreading and fertilization, although the nitrate-nitrogen concentrations are still well below the drinking water guideline, and below the concentration typically associated with anthropogenic impacts.

Table 3.8: Nitrate-nitrogen (dissolved) (mg/L) in groundwater samples

Date	Site 1	2	3	4	5	6	204	318
2002-Dec-17	0.13	0.130	0.153	0.21	0.05	0.94	-	-
2003-May-22	0.06	0.07	0.07	0.4	0.04	1.13	-	-
2003-Jul-21	-	-	-	-	-	-	0.097	-
2003-Jul-23	-	-	-	-	-	-	-	0.25
2003-Oct-23	0.16	0.180	0.25	0.27	0.04	1.17	-	-
2004-Jun-02	0.09	0.11	0.089	0.28	0.07	1.03	-	-
2004-Dec-07	0.071	0.106	0.117	0.259	0.058	1.43	-	-
2005-May-19	-	0.15	0.12	0.32	0.05	1.45	-	-
2005-Nov-01	0.072	0.119	0.127	0.224	0.036	2.04	-	-
2007-Feb-13	0.097	0.138	0.129	0.285	0.156	2.08	-	-
2009-Sep-15	-	-	-	-	-	-	0.123	-
2010-Jan-27	-	-	-	-	-	-	0.085	-
2010-Jul-21	-	-	-	-	-	-	0.035	-
2011-Feb-03	-	-	-	-	-	-	-	0.054
2011-Feb-10	-	-	-	-	-	-	0.053	-
2011-Aug-03	-	-	-	-	-	-	0.049	0.098
2011-Oct-06	0.093	0.093	0.099	-	0.043	0.948	-	-
2011-Oct-20	-	-	-	0.168	-	-	-	-

Notes:
- indicates no sample was collected.

Table 3.9: Summary statistics for nitrogen compounds in groundwater

Parameter	N	Min	Max	Median	Mean	Standard deviation
Nitrate (NO_3-N) (mg/L)	62	0.035	2.08	0.12	0.31	0.5
Nitrate + Nitrite (N) (mg/L)	62	0.035	2.08	0.12	0.31	0.5
Nitrite-Nitrogen (NO_2-N) (mg/L)	13	0.002	0.006	0.002	0.003	0.001
Nitrogen (N) Organic Total (mg/L)	16	0.030	0.680	0.05	0.11	0.2
Nitrogen (N) Total (mg/L)	62	0.030	2.230	0.15	0.35	0.5
Ammonia (N) (mg/L)	11	0.005	0.024	0.015	0.014	0.006

N=total number of samples (excluding results that were < MDL)
All parameters based on dissolved concentration, except Total Nitrogen.

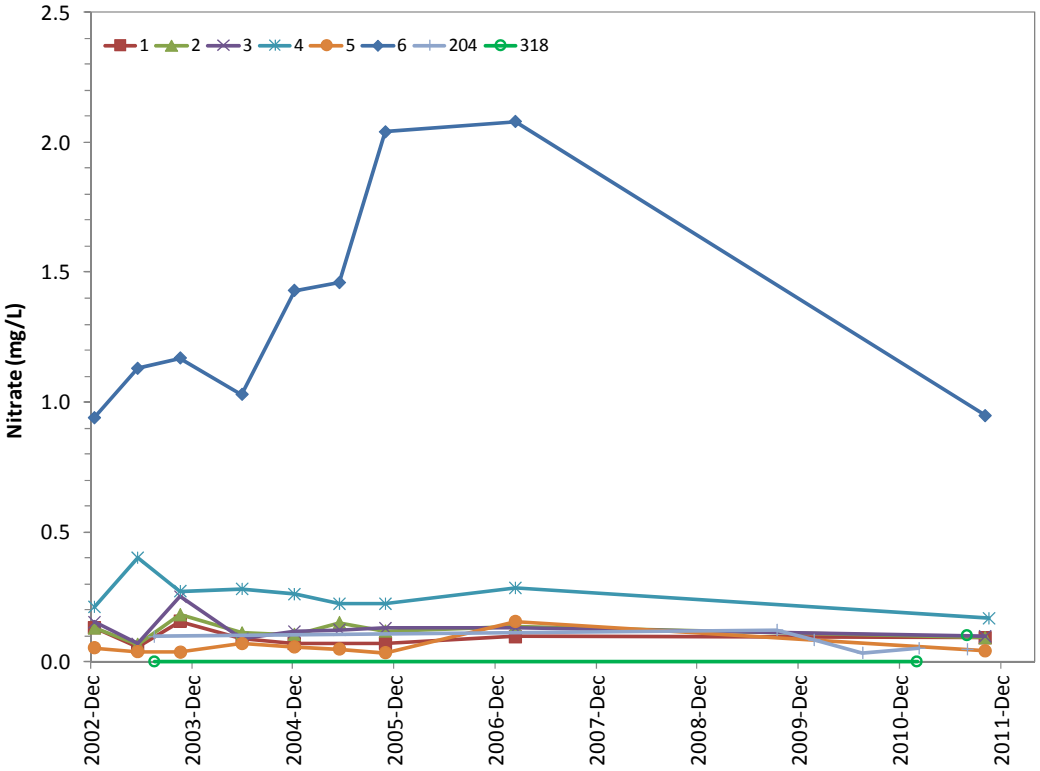

Figure 3.11: Nitrate plus nitrite (dissolved) (mg/L) by date

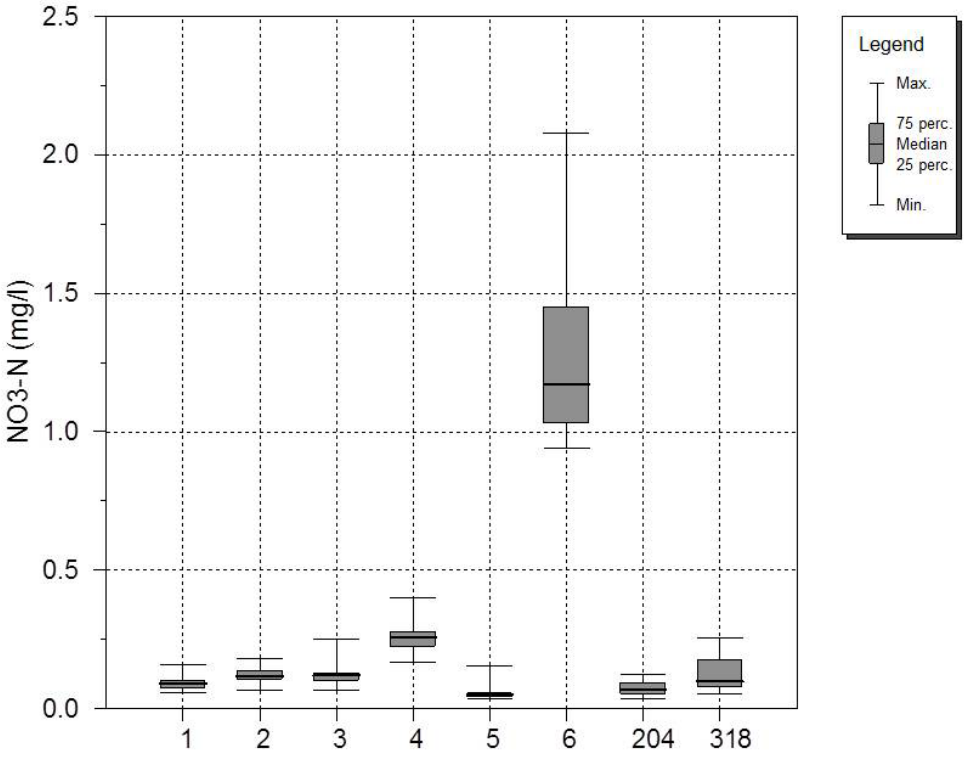

Figure 3.12: Nitrate-nitrogen (dissolved) mg/L by site

3.5 CCME Water Quality Index

The Canadian Council of Ministers of the Environment (CCME) have developed a national Water Quality Index (WQI) that ranks water quality based on three factors: the number of parameters that do not meet the objective; the percentage of tests that do not meet the objective compared to all parameters assessed; and the amount by which failed test values do not meet the objectives (Canadian Council of Ministers of the Environment (CCME), 2001a and 2001b), as described further in Appendix D. The WQI was developed based on the CCME Guidelines for the Protection of Aquatic Life, but for the purposes of this study was calculated based on the parameters with threshold values in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2012).

The WQI was used here as a tool for evaluating water quality in a way that is easy to interpret, compared to the summary of individual parameter exceedences for multiple tests that can be more difficult to synthesize by regulators and the general public. The Water Quality Index has five categories with values ranging from 0 to 100. The highest value, 100, represents "excellent" water quality and the lowest value, 0, represents "poor"

water quality. The WQI was calculated according to the methodology except that parameters without either an aesthetic objective (AO) or a maximum acceptable concentration (MAC) were excluded from the index calculations. pH was also not included due to the variability between field and laboratory measurements. The CCME WQI for the Cowichan 186 aquifer was 100, or "excellent", indicating that water quality is "very close to natural or pristine levels." It is noted, that the WQI only evaluates departures from guidelines, and does not evaluate the presence of anthropogenic impacts, however as discussed in previous sections, the results of this study do not show significant impacts associated with land use or other human activities, based on the set of parameters analyzed.

4.0 Summary

The study was initiated, in part, to determine the baseline chemistry of the Lower Cowichan aquifers 186 and 187, both considered highly developed aquifers with a moderate to high vulnerability to contamination. Samples were collected twice a year between 2002 and 2007 and once in 2011 from six production wells, and at varying frequency from two provincial observation wells also constructed in aquifers 186 and 187.

The lower Cowichan River aquifer complex, situated along the Cowichan River flood plain below and east of the city of Duncan, consist of three highly productive, vertically layered sand and gravel aquifers (aquifers 186, 187 and 188, referring to the upper, middle and lower aquifers, respectively) separated by low permeability sediments such as silt, clay or till. Although the aquifers have been described as separate units (Gallo, 1995a, 1995b, and 1995c), in some areas the confining layers are not present or occur as discontinuous lenses, and there is no geological distinction between the different layers, in particular between the upper and middle aquifers.

This study focussed on the upper two surficial aquifers (186 and 187) which provide water for municipal sources (City of Duncan and Municipality of North Cowichan), and several high capacity production wells servicing hatcheries in the area. The lower aquifer in the aquifer complex (aquifer 188) was not included, as fewer wells are constructed in this source, and it is believed to have a lower productivity in

comparison to the shallower sources (Gallo, 1995c), although there are some highly productive wells in the deep aquifer, closer to the Cowichan River estuary at Cowichan Bay (Wei, 1985). Previous and ongoing studies have shown that the upper and middle aquifers have are hydraulically connected to the Cowichan River (Thurber Engineering, 2001). For example, a time lag from one to three months has been observed between peak water temperatures in the river, and peak groundwater temperatures in observation wells at varying distance from the river (Lapcevic, Gellein, & Ormond, 2013).

The parameters chosen for this sampling program include all constituents typically evaluated in a detailed drinking water package for potable water sources. Water samples were analyzed for general chemistry (e.g. alkalinity, pH, total hardness, pH, specific conductivity, turbidity, and filterable residue (1.0 μm) also known as total dissolved solids), major ions (ammonia, nitrate, bicarbonate, chloride, fluoride, sulfate, calcium, iron, magnesium, potassium and sodium) and total or dissolved metals (silver, aluminum, arsenic, boron, barium, beryllium, bismuth, bromide, cadmium, cobalt, chromium, copper, iron, fluoride, mercury, lithium, manganese, molybdenum, nickel, lead, sulfur, antimony, selenium, silicon, tin, strontium, tellurium, titanium, thallium, uranium, vanadium, zinc, and zirconium). From eight sites, a total of 64 samples were collected and analyzed, in addition to 9 quality assurance and quality control samples (8 replicates for selected parameters and 1 field blank).

The balance of major ions showed that most sites had calcium-bicarbonate type groundwater, representative of immature, recently recharged groundwater from a shallow unconsolidated (sand and gravel) aquifer, where the groundwater has undergone only small amounts of cation exchange. The GCDWQ aesthetic objectives for iron and manganese were exceeded at one hatchery location (site 5, in December 2002) and one observation well also had iron above the aesthetic objective (well 318, in July 2003). Elevated chloride and nitrate (above the "background" values observed at the other sites), were observed at one hatchery site and believed to be attributable to onsite practices, specifically disposal of wastewater via injection wells, and potentially other differences in land-use near this location. However, the chloride and nitrate concentrations in all samples were well below drinking water guidelines and below values typically associated with anthropogenic impacts. Considering this small set of samples, no significant

difference was observed in quality between aquifer 186 and 187. There was also minimal seasonal variability between samples collected in the wet compared to the dry season. The CCME water quality index rates the overall groundwater quality as excellent, indicating that water quality is close to natural or pristine levels.

5.0 Recommendations

The following actions are recommended, based on the results of this study:

1. The Lower Cowichan River aquifers (186 and 187) are an important source of drinking water for the City of Duncan and Municipality of North Cowichan, as well as supplying water for agricultural and industrial use (particularly hatchery operations). Because confining sediments such as silt or clay are discontinuous and absent in some areas overlying the upper and middle aquifers, these sources are considered to be moderately to highly vulnerable to contamination, making aquifer protection a priority. Based upon this small set of samples collected from some of the important high capacity wells in the aquifer complex, and selected active observation wells, the groundwater quality is currently considered high; however groundwater quality is also susceptible to anthropogenic impacts, both due to land use in the recharge areas overlying the aquifers, and indirectly due to recharge from the Cowichan River. While continued monitoring of the aquifer quality and quantity is important, future activities should consider measures to improve aquifer protection, such as regulating land use decisions, identifying hazards, and managing risks not just for individual well capture zones, but also for the aquifer as a whole. Because the hydrology of the river and aquifers are so closely linked, protection of water quality in the Cowichan River is also critical. These actions could originate with local and regional government in cooperation with other provincial and federal government partners.

2. The risk associated with disposal of (untreated or treated) wastewater directly to the aquifers via injection wells should be examined and if necessary, measures should be considered to control or further regulate these types of activities. Use of injection or infiltration wells is not limited to hatchery operations, but has been

identified in some parts of B.C. as a method for storm water disposal. The provincial government (Ministry of Environment) should play a role in guiding best-practices in this area, via regulation and/or voluntary measures. At present the Ministry of Environment is revising the storm water management guidebook to include best practices for injection of storm water to ground.

3. Ongoing monitoring of groundwater quality in the lower Cowichan River aquifer complex has included periodic sampling from wells within the Provincial Government's observation well network (maintained by MOE and FLNRO). Municipal water providers (City of Duncan and Municipality of North Cowichan) and fish hatcheries also conduct their own water quality tests as a part of regular operations. As such, this study focussed on evaluating sources that are heavily used and sampled frequently as a part of drinking water protection programs, and onsite practices.

   As a method to improve efficiency, federal, provincial and municipal/regional governments should continue to work together to combine resources and share information, so that water quality data that is being collected on a frequent basis is made available for future studies. This data could include testing of the large capacity wells in addition to monitoring wells within the City of Duncan and outlying areas. The municipalities have already done this informally, but there may be opportunities to formalize this information sharing relationship. The Vancouver Island Health Authority are an additional source of groundwater quality data from small to moderate capacity water supply systems that could be utilized in future aquifer studies. First Nations water supplies should also be included within data sharing agreements via local communities such as Cowichan Tribes and the federal government (Aboriginal Affairs and Northern Development Canada). The province of British Columbia maintains the Environmental Monitoring System database (EMS), which is recommended as a repository for archiving water quality data from multiple agencies (B.C. Ministry of Environment, 2013).

4. Future evaluations of ambient aquifer quality in the Cowichan watershed should include sampling of individual domestic or agricultural wells, that are traditionally sampled with less frequency, and that are spatially distributed over a larger area. Snapshot surveys at a particular time rather than long-term trend studies are also recommended to characterize baseline groundwater quality and to identify potential hotspots of naturally elevated parameters (e.g. iron, manganese, total dissolved solids) or anthropogenic pollutants (e.g. nitrate). An added benefit of sampling private wells is to provide well owner education and outreach, to improve aquifer protection via wellhead protection measures (e.g. adequate well maintenance, operation and closure of unused wells). Areas of future study could include wells situated closer to the Cowichan estuary, where salt water intrusion has been identified as a concern, and in the Koksilah village area, adjacent to the Trans Canada Highway between the Cowichan and Koksilah Rivers, where there is a range of land use including agriculture, and industry (see also 5. below). Compilation of a larger geochemical data set would be useful to determine with greater certainty the baseline concentration of nitrate for the lower Cowichan aquifers.

5. The City of Duncan lies above the Lower Cowichan River aquifers and both current and historical industrial/urban practices may contribute to groundwater quality. This study focussed primarily on inorganic chemical constituents that are found naturally in groundwater (e.g. metals, chloride). Further study looking at water quality parameters associated with human activities, including nitrates, pesticides and petroleum hydrocarbons could be undertaken in combination with risk analysis, focussing on areas where land-use activities present a particular concern (e.g. onsite septic systems, agricultural activities, waste disposal or contaminated sites).

6. This study did not include evaluation of water quantity, related to interactions between the Cowichan River and the pumping of large capacity wells adjacent to the river. Further study, to develop an integrated surface and groundwater balance, to quantify consumptive versus non-consumptive water use at the

hatcheries and municipal sites, and to evaluate the impacts of groundwater use on the river flows in this area is needed to provide further information in this important area of concern. This is the focus of current, ongoing study by the Ministry of Forests, Lands and Natural Resource Operations, in partnership with the municipal and regional governments, and fisheries conservation agencies.

6.0 References

Aller, L., Bennett, T., Lehr, J., Petty, R., & Hackett, G. (1987). *DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings.* Ada, Oklahoma: U.S. Environmental Protection Agency and National Water Well Association.

Appelo, C., & Postma, D. (1993). *Geochemistry, groundwater and pollution.* Rotterdam, Netherlands: A.A. Balkema.

B.C. Integrated Land Management Bureau. (2012). *iMapBC Map layer: Present land use (1992-1997).* Retrieved from Ministry of Environment GIS Applications (GeoBC): http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc

B.C. Ministry of Environment. (2011a). *B.C. Water Resources Atlas.* Retrieved January 2012, from Ministry of Environment GIS Applications: http://webmaps.gov.bc.ca/imf5/imf.jsp?site=wrbc

B.C. Ministry of Environment. (2011b). *iMap B.C.* Retrieved January 2012, from Ministry of Environment GIS applications: http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc

B.C. Ministry of Environment. (2011c). *Water well search options*. Retrieved January 2012, from WELLS - Ground water wells and aquifer database: https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp

B.C. Ministry of Environment. (2013). *Environmental Databases*. Retrieved January 2013, from Environmental Protection, Water and Air Monitoring and Reporting: http://www.env.gov.bc.ca/epd/wamr/ems_internet/index.html

B.C. Ministry of Environment, Lands and Parks, LandData BC and Geographic Data BC. (1998). *Guidelines for interpreting water quality data.* Victoria, BC: Resources Information Standards Committee.

B.C. Ministry of Forests. (1995). *The ecology of the Douglas fir zone.* Retrieved January 2012, from http://www.for.gov.bc.ca/hfd/pubs/docs/bro/bro30.pdf

B.C. Ministry of Water, Land and Air Protection. (2003a). *Ambient groundwater quality sampling manual for ambient groundwater quality monitoring well network, observation well network, and community well drinking water sources.* Water, Air and Climate Change Branch. Victoria, BC: Province of British Columbia.

B.C. Ministry of Water, Land and Air Protection. (2003b). *British Columbia field sampling manual.* Water, Air and Climate Change Branch. Victoria, BC: Province of British Columbia.

Berardinucci, J., & Ronneseth, K. (2002). *Guide to using the B.C. aquifer classification system.* Victoria, BC: Ministry of Environment.

Blyth, H., & Rutter, N. (1992). Quaternary geology of southeastern Vancouver Island and Gulf Islands (92B/5,6,11,12,13 and 14). *Canadian Quaternary Association Biennial Meeting (April 18-21, 1992), Applied Quaternary Research: Program with abstracts and field guides.* Victoria, BC: Canadian Quaternary Association.

Brown, W., & Carr, J. (1967). *Test drilling on Bradshaw property. Report for the Corporation of the District of North Cowichan.* Ministry of Environment, NTS file 092B/13#5: Unpublished.

Canadian Council of Ministers of the Environment (CCME). (2001a). *Canadian water quality guidelines for the protection of aquatic life, Water Quality Index 1.0 Technical Report.* Ottawa, ON: CCME. Retrieved 2012 January, from http://www.ccme.ca/assets/pdf/wqi_techrprtfctsht_e.pdf

Canadian Council of Ministers of the Environment. (2001b). *CCME Water Quality Index v.1.0, User's Manual.* Retrieved January 2012, from Canadian water quality guidelines for the protection of aquatic life: http://www.ccme.ca/ourwork/water.html?category_id=102#290

Chwojka, F. (1997). *Assessment of water quality and identification of water quality concerns and problem areas Cowichan-Koksilah estuary.* Victoria, BC: Ministry of Environment.

Cowichan Valley Regional District (CVRD). (2010). *Statistical tables.* Retrieved January 2012, from Community and regional planning: http://www.cvrd.bc.ca/DocumentView.aspx?DID=1250

Cowichan Valley Regional District. (2012). *Sewer systems*. Retrieved December 2012, from Cowichan Valley Regional District: http://www.cvrd.bc.ca/index.aspx?nid=420

Cullimore, D. (2008). *Practical manual of groundwater microbiology, 2nd Edition.* Boca Raton, FL: CRC Press.

Environment Canada. (2008a). *Daily Climate Data: Duncan Kelvin Creek (ID1012573).* Retrieved January 2012, from National Climate Data and Information Archive: http://www.climate.weatheroffice.gc.ca/climateData/dailydata_e.html?timeframe=2&Prov=BC&StationID=46&dlyRange=1987-04-01|2012-12-30&cmdB1=Go&Month=1&Year=2008&Day=-21

Environment Canada. (2008b). *Canadian Climate Normals, 1971-2000: Duncan Forestry (ID1012570).* Retrieved January 2012, from National Climate Data and Information Archive: http://www.climate.weatheroffice.gc.ca/climate_normals/results_e.html?stnID=45&lang=e&dCode=0&StationName=DUNCAN&SearchType=Contains&province=ALL&provBut=&month1=0&month2=12

Foweraker, J. (1976). *Groundwater research project Cowichan River aquifer near Duncan, British Columbia-Final Report.* B.C. Department of Environment, Water Resources Service., Victoria, BC. Retrieved January 2012, from http://a100.gov.bc.ca/appsdata/acat/documents/r6450/692_1143681803977_8b7182b483ed458aad9da29ff7cef555.pdf

Freeze, R., & Cherry, J. (1979). *Groundwater.* Englewood Cliffs, NJ: Prentice-Hall, Inc.

Gallo, M. (1995a). *Aquifer classification worksheet 0186.* Ministry of Environment, Lands and Parks. Victoria, BC: Unpublished.

Gallo, M. (1995b). *Aquifer classification worksheet 0187.* Ministry of Environment, Lands and Parks. Victoria, BC: Unpublished.

Gallo, M. (1995c). *Aquifer classification worksheet 0188.* Ministry of Environment, Lands and Parks. Victoria, BC: Unpublished.

Halstead, E. (1968). The Cowichan ice tongue, Vancouver Island. *Canadian Journal of Earth Sciences, 5*, 1409-1415.

Halstead, E. (1996). *Map: Surficial geology, Duncan, British Columbia.* Retrieved January 2012, from Natural Resources Canada Map Image Rendering dAtabase for GEoscience: http://apps1.gdr.nrcan.gc.ca/mirage/full_result_e.php?id=108599

Health Canada. (1978). *Iron.* Retrieved January 2012, from Guidelines for Canadian Drinking Water Quality - Technical Documents: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/iron-fer/index-eng.php

Health Canada. (1987a). *Manganese.* Retrieved January 2012, from Guidelines for Canadian Drinking Water Quality - Technical Documents: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/manganese/index-eng.php

Health Canada. (1987b). *Nitrate/nitrite.* Retrieved January 2012, from Guidelines for Canadian Drinking Water Quality - Technical Documents: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/nitrate_nitrite/index-eng.php

Health Canada. (1992). *Sodium.* Retrieved January 2012, from Guidelines for Canadian Drinking Water Quality - Technical Documents: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sodium/index-eng.php

Health Canada. (2012). *Guidelines for Canadian Drinking Water Quality - Summary Table.* Retrieved January 2012, from Health Canada water quality reports and publications: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/2012-sum_guide-res_recom/index-eng.php

Janicki, E. (2011). *Observation well network: Groundwater level graphs, data to April 2010.* Victoria, BC: Ministry of Environment.

Kreye, R., & Wei, M. (1994). *A proposed aquifer classification system for groundwater management in British Columbia.* Victoria, BC: Ministry of Water, Land and Air Protection.

Kreye, R., Ronneseth, K., & Wei, M. (2001). *An aquifer classification system for ground water management in British Columbia.* Victoria, BC: Ministry of Water, Land and Air Protection.

Lapcevic, P., Gellein, C., & Ormond, R. (2013). *Groundwater in the Cowichan Basin.* Nanaimo, BC: Ministry of Forests, Lands and Natural Resource Operations.

Liggett, J., Lapcevic, P., & Miller, K. (2011). *A guide to the use of intrinsic aquifer vulnerability mapping.* Retrieved January 2012, from https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=23346

Mantua, N. J., & Hare, S. R. (2002). The Pacific Decadal Oscillation. *Journal of Oceanography, 58*, 35-42.

Massey, N. (1994). Geological compilation, Vancouver Island, British Columbia (NTS 92 B, C, E, F, G, K, L, 102 I) . *Open File 1994-6, 5 digital files, legend, 1:250,000-scale map*. Victoria, BC: B.C. Ministry of Energy, Mines and Petroleum Resources.

Maxwell, J., & Wei, M. (2003). *Exemplary Groundwater Monitoring Program, Project 11: Cross-referencing community drinking water wells with IA aquifers.* Victoria, BC: Report for B.C. Ministry of Water, Land and Air Protection.

Muller, J. (1977). *Map: Geology of Vancouver Island - Easter Half, Map 0.F.463.* Ottawa, ON: Geological Survey of Canada.

Nielsen, D., & Nielsen, G. (2007). *The essential handbook of ground-water sampling.* Boca Raton, FL: CRC Press.

Piteau Associates Engineering Ltd. (2011). *Cowichan Valley Regional District 2010 Annual Monitoring Report Koksilah Landfill.* North Vancouver, BC: Unpublished.

Richards, R. (1986). *Cowichan River surface/groundwater study.* Victoria, BC: Ministry of Environment, Water Management Branch, Hydrology Section. Retrieved January 2012, from http://a100.gov.bc.ca/appsdata/acat/documents/r5064/676_1143144980541_4798d26280c04e69989ae5eff515e10f.pdf

Ronneseth, K., Hodge, W., & Kohut, A. (1994). Chapter 9: Groundwater resource of the basins, lowlands and plains. In *Groundwater resources of British Columbia.* Victoria, BC: BC Environment and Environment Canada.

Statistics Canada. (2007a). *Annual statistics 2007-2008.* Retrieved January 2012, from Human activity and the Environment: http://www.statcan.gc.ca/pub/16-201-x/16-201-x2007000-eng.htm

Statistics Canada. (2007b). *Duncan.* Retrieved January 2012, from 2006 Community Profiles: http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E

Statistics Canada. (2007c). *North Cowichan.* Retrieved from 2006 Community profiles: http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E

Thurber Engineering. (2001). *Well Protection Plan Lower Cowichan River Aquifer, Chemainus River Aquifer Primary Wells. Report to District of North Cowichan.* Victoria, BC: Unpublished.

Water Survey of Canada. (2012). *Cowichan River near Duncan (08HA011) Daily Discharge (2003-2010).* Retrieved January 2012, from Environment Canada Water Office: http://www.wsc.ec.gc.ca/applications/H2O/graph-eng.cfm?yearb=&yeare=&station=08HA011&report=daily&year=2003

Wei, M. (1985). *Groundwater quality monitoring and assessment program Cowichan-Koksilah estuary: Fall 1985 field survey.* Retrieved February 2012, from http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=5125

Wei, M., Allen, D. M., Carmichael, V., & Ronneseth, K. (2010). *State of understanding of the hydrogeology of the Grand Forks aquifer.* Victoria, BC: Ministry of Environment and Simon Fraser University.

Wei, M., Kohut, A. P., Kalyn, D., & Chwojka, F. (1993). Occurrence of nitrate in groundwater, Grand Forks, British Columbia. *Quaternary International, 20*, 39-49.

Zubel, M. (1978). *Memo: Cowichan Estuary Task Force (1978) Preliminary Groundwater Study.* Victoria, BC: Ministry of Environment, Water Investigations Branch, Groundwater Section. Retrieved January 2012, from http://a100.gov.bc.ca/appsdata/acat/documents/r5092/702_1143145826556_4798d26280c04e69989ae5eff515e10f.pdf

APPENDIX A: WELL CONSTRUCTION RECORDS

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 33436 Owner: Ministry of Environment Address: Area: VICTORIA WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 37 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: 204 Observation Well Status: Active Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 31 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Y Screen Info Flag: Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1975-09-12 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: 989 Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 35 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level: 5 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400120 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # 120 ACTIVE

LITHOLOGY INFORMATION:

From	0 to	4 Ft.	Gravel fill, water at 4'5"
From	4 to	19 Ft.	Brown water-bearing sand and gravel
From	19 to	21.5 Ft.	Layer glacial till
From	21.5 to	22 Ft.	Change in water - brown to silty
From	22 to	23 Ft.	Till layer
From	23 to	26 Ft.	Coarse water-bearing gravel
From	26 to	27.5 Ft.	Layer glacial till
From	27.5 to	31 Ft.	Coarse water-bearing gravel

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 33437	Construction Date: 1975-09-12 00:00:00.0
Owner: Ministry of Environment	Driller: Drillwell Enterprises Well Identification Plate Number: 697
Address:	Plate Attached By: Where Plate Attached:
Area: VICTORIA	PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 35 (Driller's Estimate) Gallons per Minute (U.S./Imperial)
WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 38	Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 5 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400121 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y
Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: 205 Observation Well Status: Abandoned Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 20 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # ACTIVE

LITHOLOGY INFORMATION:

From	0 to	4 Ft.	Gravel fill, water at 4'5"
From	4 to	19 Ft.	Brown water-bearing sand and gravel
From	19 to	20 Ft.	Layer glacial till

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 33460 Owner: Ministry of Environment Address: Area: VICTORIA WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 41 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: 206 Observation Well Status: Abandoned Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 39 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: Y Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1975-09-16 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 3 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400122 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): N Water Utility: N Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # 122 AB.79

LITHOLOGY INFORMATION:

From	0 to	8 Ft.	Silty sand and gravel
From	8 to	12 Ft.	Brown washed sand and gravel
From	12 to	18 Ft.	Silty blue sand and gravel, water shut
From	0 to	0 Ft.	off
From	18 to	19 Ft.	Water-bearing gravel and sand
From	19 to	22 Ft.	Sand and gravel
From	0 to	0 Ft.	At 22, red-brown colour to sample and to
From	0 to	0 Ft.	water
From	22 to	22.5 Ft.	Washed sand and gravel
From	25.5 to	26 Ft.	Fine sand
From	26 to	39 Ft.	Washed sand and gravel

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 33461 Owner: Ministry of Environment Address: Area: VICTORIA WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 42 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: 207 Observation Well Status: Abandoned Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 14.5 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1975-09-16 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 40 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 3 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400123 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): N Water Utility: N Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
30 MIN. 40 GPM AB. 79

LITHOLOGY INFORMATION:

From	0 to	8 Ft.	Silty sand and gravel
From	8 to	12 Ft.	Brown washed sand and gravel
From	12 to	14.5 Ft.	Silty blue sand and gravel, water shut
From	0 to	0 Ft.	off

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 33478 Owner: Ministry of Environment Address: Area: VICTORIA WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 43 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: 208 Observation Well Status: Abandoned Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 35 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1975-09-18 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: 675 Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 40 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 7 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400124 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y Water Utility: N Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # 124 ACTIVE

LITHOLOGY INFORMATION:

From	0 to	3 Ft.	Fill
From	3 to	10 Ft.	Silty till
From	10 to	18 Ft.	Sand and gravel, brown water
From	18 to	19 Ft.	Light till
From	19 to	22 Ft.	Sand and gravel
From	0 to	0 Ft.	At 22, traces of till
From	22 to	30 Ft.	Sand and gravel
From	30 to	31 Ft.	Till
From	31 to	35 Ft.	Sand and gravel

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 35731 Owner: Ministry of Environment Address: Area: VICTORIA WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 44 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: 209 Observation Well Status: Abandoned Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 36 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1976-09-23 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 3 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400125 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): N Water Utility: N Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # 125 AB.79

LITHOLOGY INFORMATION:

From	0 to	9 Ft.	Sand and gravel
From	9 to	21 Ft.	Loose sand and gravel
From	21 to	23 Ft.	Rusty brown, layer of gravel
From	23 to	36 Ft.	Loose sand and gravel, brown at times

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 33623 Owner: Ministry of Environment Address: Area: VICTORIA WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 45 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: 210 Observation Well Status: Abandoned Construction Method: Drilled Diameter: 8.0 inches Casing drive shoe: Well Depth: 152 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: Y File Info Flag: N Sieve Info Flag: N Screen Info Flag: Y Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1975-10-06 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: Y Artesian Flow: Artesian Pressure (ft): Static Level: 4 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400130 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): N Water Utility: N Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size
58	60	Screen	50
60	62	Screen	100
62	69	Screen	150
94	104	Screen	40

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # 130 AB.79

LITHOLOGY INFORMATION:

From	0 to	2 Ft.	Silt
From	2 to	12 Ft.	Sand and gravel
From	12 to	16 Ft.	Gravel - water
From	16 to	20 Ft.	Med. to coarse gravel, some sand
From	20 to	24 Ft.	Sand and gravel
From	24 to	32 Ft.	Coarse sand and very coarse gravel, some
From	0 to	0 Ft.	"fines"
From	32 to	44 Ft.	Silty sand and gravels with lenses of
From	0 to	0 Ft.	brown and blue silt
From	44 to	52 Ft.	Coarse gravel with some sand
From	52 to	54 Ft.	Silt and fine sand, fine till ?
From	54 to	69 Ft.	Coarse gravel and sand with brown
From	0 to	0 Ft.	(silty) water
From	69 to	70 Ft.	Med. - coarse sand, some stones-tight
From	70 to	74 Ft.	Fine - coarse sand with gravel
From	74 to	90 Ft.	Blue silty clay with some pebbles
From	90 to	104 Ft.	Fine - coarse blue sand layers with some
From	0 to	0 Ft.	gravel lenses
From	104 to	105 Ft.	Fine to medium sand
From	105 to	109 Ft.	Very fine to medium sand, some chips of
From	0 to	0 Ft.	wood
From	109 to	113 Ft.	Very fine to fine sand
From	113 to	124 Ft.	Clay with seeds, cones and wood chips
From	124 to	130 Ft.	Till
From	130 to	138 Ft.	Blue silty clay
From	138 to	145 Ft.	Blue clay with stones
From	145 to	152 Ft.	Silty sand
From	0 to	0 Ft.	End of hole

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 33651 Owner: Ministry of Environment Address: Area: VICTORIA WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 46 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Observation Well Observation Well Number: 211 Observation Well Status: Active Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 104 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1975-10-09 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: 211 Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 4 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: 1400131 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # 131 ACTIVE

LITHOLOGY INFORMATION:

From	0 to	3 Ft.	Silt
From	3 to	12 Ft.	Sand and gravel
From	12 to	16 Ft.	Gravel
From	16 to	20 Ft.	Medium to coarse gravel, some sand
From	20 to	24 Ft.	Coarse sand and gravel
From	24 to	32 Ft.	Coarse sand and very coarse gravel
From	32 to	44 Ft.	Silty sand and gravels with lenses of
From	0 to	0 Ft.	brown and blue silt
From	44 to	52 Ft.	Coarse gravel with some sand
From	52 to	54 Ft.	Silt and fine sand. Fine till?
From	54 to	69 Ft.	Coarse gravel and sand with brown
From	0 to	0 Ft.	(silty ?) water
From	69 to	70 Ft.	Med. coarse sand, some stones - tight
From	70 to	74 Ft.	Fine - coarse sand with gravel
From	74 to	90 Ft.	Blue silty clay with pebbles
From	90 to	104 Ft.	Fine coarse blue sand, layers with some
From	0 to	0 Ft.	gravel lenses
From	0 to	0 Ft.	

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 56954 Owner: Ministry of Environment Address: DYKE ROAD Area: COWICHAN BAY WELL LOCATION: COWICHAN Land District District Lot: Plan: 1725 Lot: Township: Section: 10 Range: 2 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072421 Well: 6 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Observation Well Observation Well Number: 297 Observation Well Status: Abandoned Construction Method: Drilled Diameter: 10.0 inches Casing drive shoe: Well Depth: 140 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1987-03-25 00:00:00.0 Driller: Fyfe's Well Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 104 (Driller's Estimate) U.S. Gallons per Minute Development Method: Pump Test Info Flag: Y Artesian Flow: Artesian Pressure (ft): Static Level: WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: E206919 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): N Water Utility: N Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OLD OBS WELL # WR-297-87 EQUIS SITE NO 1401966

LITHOLOGY INFORMATION:

From	0 to	10 Ft.	Loose black till
From	10 to	15 Ft.	Loose grey clay and sand
From	15 to	23 Ft.	Clay sand and gravel
From	23 to	42 Ft.	Sand and gravel - 10 GPM
From	42 to	60 Ft.	Fine sandy grey clay
From	60 to	65 Ft.	Coarse sandy gravel - 25 GPM
From	65 to	70 Ft.	Tight gravel - less water
From	70 to	90 Ft.	Sand and blue clay
From	90 to	113 Ft.	Hard blue clay and sand
From	113 to	135 Ft.	Mixed coarse sand and gravel - 200+ GPM
From	135 to	140 Ft.	Fine silt @ 140 - less water

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 44174 Owner: NOEL DINSDALE Address: COWICHAN BAY RD Area: WELL LOCATION: COWICHAN Land District District Lot: Plan: 1725 Lot: Township: Section: 10 Range: 1 Indian Reserve: Meridian: Block: 1 Quarter: Island: BCGS Number (NAD 27): 092B072412 Well: 13 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Domestic Observation Well Number: 298 Observation Well Status: Abandoned Construction Method: Dug Diameter: 4.5 inches Casing drive shoe: Well Depth: 14 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1980-01-01 00:00:00.0 Driller: Unknown Well Identification Plate Number: 298 Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: E208059 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y Water Utility: N Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:

LITHOLOGY INFORMATION:
From 0 to 0 Ft. Sand and gravel

- Return to Main

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 59654

Owner: DUNCAN FISH HATCHERY

Address: WHARNCLIFFE RD.,

Area: DUNCAN

WELL LOCATION:
QUAMICHAN Land District
District Lot: Plan: 511 Lot: 11
Township: Section: 16 Range: 7
Indian Reserve: Meridian: Block:
Quarter:
Island:
BCGS Number (NAD 27): 092B072413 Well: 53

Class of Well:
Subclass of Well:
Orientation of Well:
Status of Well: New
Well Use: Observation Well
Observation Well Number: 318
Observation Well Status: Active
Construction Method: Drilled
Diameter: 6.0 inches
Casing drive shoe:
Well Depth: 100 feet
Elevation: 0 feet (ASL)
Final Casing Stick Up: inches
Well Cap Type:
Bedrock Depth: feet
Lithology Info Flag:
File Info Flag:
Sieve Info Flag:
Screen Info Flag:

Site Info Details:
Other Info Flag:
Other Info Details:

Construction Date: 1991-05-01 00:00:00.0

Driller: Drillwell Enterprises
Well Identification Plate Number: 148
Plate Attached By:
Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:
Well Yield: 100 (Driller's Estimate) U.S. Gallons per Minute
Development Method:
Pump Test Info Flag:
Artesian Flow:
Artesian Pressure (ft):
Static Level: 8 feet

WATER QUALITY:
Character:
Colour:
Odour:
Well Disinfected: N
EMS ID: E218238
Water Chemistry Info Flag:
Field Chemistry Info Flag:
Site Info (SEAM):

Water Utility:
Water Supply System Name:
Water Supply System Well Name:

SURFACE SEAL:
Flag:
Material:
Method:
Depth (ft): 0 feet
Thickness (in):
Liner from To: feet

WELL CLOSURE INFORMATION:
Reason For Closure:
Method of Closure:
Closure Sealant Material:
Closure Backfill Material:
Details of Closure:

Screen from	to feet	Type	Slot Size
0	0		0
0	0		0
0	0		0
0	0		0

Casing from	to feet	Diameter	Material	Drive Shoe
0	0	0	null	null

GENERAL REMARKS:
 OBS WELL & 318 WELL BACKFILLED TO 54'

LITHOLOGY INFORMATION:
From 0 to 12 Ft. brown silty sand & gravel
From 12 to 45 Ft. brown coarse stratified sand & gravel
From 45 to 69 Ft. brown coarse to fine stratidied sand
From 0 to 0 Ft. & gravel, some minor silt layers
From 69 to 74 Ft. gray, sandy silt occasional stone
From 74 to 99 Ft. brown coarse, stratified sand & gravel
From 99 to 100 Ft. grey silt

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 36870 Owner: NORTH COWICHAN DISTRICT Address: BETWEEN BOYS ROAD & COWICHAN RIVER Area: DUNCAN WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 50 Class of Well: Water supply Subclass of Well: Domestic Orientation of Well: Vertical Status of Well: New Well Use: Drinking Water Supply System Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 16 inches Casing drive shoe: Y Well Depth: 75 feet Elevation: feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: Y File Info Flag: Y Sieve Info Flag: Y Screen Info Flag: Y Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1977-03-24 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: 13247 Plate Attached By: PUBLIC HEALTH INSPECTOR Where Plate Attached: ENCLOSURE RAILING PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 2118 (Driller's Estimate) U.S. Gallons per Minute Development Method: Pump Test Info Flag: Y Artesian Flow: Artesian Pressure (ft): Static Level: 8 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: E249100 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y Water Utility: N Water Supply System Name: NORTH COWICHAN DISTRICT WATER SYSTEM Water Supply System Well Name: WELL 3 SURFACE SEAL: Flag: Y Material: Bentonite clay Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size
54	75		21

Casing from	to feet	Diameter	Material	Drive Shoe
0	75	16	Steel	Y

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From	0 to	3 Ft.	Silty sand
From	3 to	33 Ft.	Stratified coarse sandy gravel with minor silt lenses
From	33 to	45 Ft.	Silty sandy gravel with lenses of blue and brown silt
From	45 to	52 Ft.	Coarse gravel with some sand
From	52 to	53 Ft.	Sandy silt
From	53 to	63 Ft.	Medium to coarse gravel and boulders with fine to medium silty sand
From	63 to	74 Ft.	Medium to coarse gravel and boulders with medium to coarse sand
From	74 to	75 Ft.	Blue silty clay

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 34362 Owner: CITY OF DUNCAN Address: Area: DUNCAN WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 15 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 47 Class of Well: Water supply Subclass of Well: Domestic Orientation of Well: Vertical Status of Well: New Well Use: Drinking Water Supply System Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 16 inches Casing drive shoe: Well Depth: 65 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: Y File Info Flag: Y Sieve Info Flag: N Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1976-02-27 00:00:00.0 Driller: Drillwell Enterprises Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 2260 (Driller's Estimate) U.S. Gallons per Minute Development Method: Pump Test Info Flag: Y Artesian Flow: Artesian Pressure (ft): Static Level: 11 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: E249106 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y Water Utility: N Water Supply System Name: CITY OF DUNCAN WATER SYSTEM Water Supply System Well Name: PRODUCTION WELL 4: BOYS ROAD WELL SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From	0 to	7 Ft.	Medium to fine brown sand
From	7 to	62 Ft.	Stratified coarse gravel with boulders and coarse sand
From	62 to	65 Ft.	Clay - till

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 18123 Owner: CITY OF DUNCAN Address: Area: DUNCAN WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 16 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072413 Well: 18 Class of Well: Water supply Subclass of Well: Domestic Orientation of Well: Vertical Status of Well: New Well Use: Drinking Water Supply System Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 16 inches Casing drive shoe: Y Well Depth: 49.5 feet Elevation: feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: Y File Info Flag: N Sieve Info Flag: N Screen Info Flag: Y Site Info Details: Other Info Flag: Other Info Details:	Construction Date: 1963-07-01 00:00:00.0 Driller: G. & G. Well Drilling Well Identification Plate Number: 13204 Plate Attached By: PUBLIC HEALTH INSPECTOR Where Plate Attached: DISCHARGE PIPE FROM WELLHEAD PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 2000 (Driller's Estimate) U.S. Gallons per Minute Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 6 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: E249103 Water Chemistry Info Flag: Y Field Chemistry Info Flag: Site Info (SEAM): Y Water Utility: N Water Supply System Name: CITY OF DUNCAN WATER SYSTEM Water Supply System Well Name: MCKINSTRY STREET WELL (WELL 2) SURFACE SEAL: Flag: Y Material: Grouted steel casing Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size
34	49.5		250

Casing from	to feet	Diameter	Material	Drive Shoe
0	49.5	16	Steel	Y

GENERAL REMARKS:
YIELD: 2,000 US GPM.

LITHOLOGY INFORMATION:

From	0 to	4 Ft.	Coarse gravel up to 6" and fine to coarse sand S.L. 3.43'
From	4 to	9 Ft.	Very coarse gravel with little sand
From	9 to	26 Ft.	Med. to coarse gravel and sand
From	26 to	32 Ft.	Very coarse gravel - little sand
From	32 to	36 Ft.	Med. coarse gravel and sand - uniform size
From	36 to	45 Ft.	Coarse clean gravel - little sand
From	45 to	49.5 Ft.	Med. coarse gravel and sand
From	0 to	0 Ft.	Bottom of hole is considered bedrock

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 85198 Owner: VANCOUVER ISLAND TROUT HATCHERY Address: WHARNCLIFFE RD Area: DUNCAN WELL LOCATION: QUAMICHAN Land District District Lot: Plan: Lot: Township: Section: 16 Range: 7 Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 092B072431 Well: 13 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Drinking Water Supply System Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 20 inches Casing drive shoe: Well Depth: 88 feet Elevation: feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: Y Site Info Details: Other Info Flag: Other Info Details:	Construction Date: Driller: Well Identification Plate Number: 1187 Plate Attached By: RUSS LIBOISON Where Plate Attached: INSIDE WELL #101 PUMP ROOM LOCATED INSIDE HATCHERY BUILDING PRODUCTION DATA AT TIME OF DRILLING: Well Yield: (Driller's Estimate) UNKNOWN YIELD Development Method: Pump Test Info Flag: N Artesian Flow: UNKNOWN YIELD Artesian Pressure (ft): Static Level: WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: N Field Chemistry Info Flag: Site Info (SEAM): N Water Utility: N Water Supply System Name: VANCOUVER ISLAND TROUT HATCHERY Water Supply System Well Name: VANCOUVER ISLAND TROUT HATCHERY WS - WELL #101 SURFACE SEAL: Flag: Y Material: Method: Poured Depth (ft): 17 feet Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size
63	69		250
69	73		150
73	88		200

Casing from	to feet	Diameter	Material	Drive Shoe
0	58	20	Other	null
0	17	24	Other	null

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From	to	Ft.	LITHOLOGY DEPTH MEASUREMENTS APPROXIMATE. 0 nothing entered 0 nothing entered 0 nothing entered
From	0 to 3	Ft.	SANDY FILL 0 nothing entered 0 nothing entered 0 nothing entered
From	3 to 16	Ft.	SANDY SILT 0 nothing entered 0 nothing entered 0 nothing entered
From	16 to 36	Ft.	COARSE SANDY GRAVEL 0 nothing entered 0 nothing entered 0 nothing entered
From	36 to 57.5	Ft.	FINE SILTY SAND & GRAVEL WITH SILT LAYERS 0 nothing entered 0 nothing entered 0 nothing entered
From	57.5 to 69	Ft.	COARSE SANDY GRAVEL 0 nothing entered 0 nothing entered 0 nothing entered
From	69 to 73	Ft.	SILTY FINE SAND & GRAVEL 0 nothing entered 0 nothing entered 0 nothing entered
From	73 to 88	Ft.	COARSE SAND & GRAVEL 0 nothing entered 0 nothing entered 0 nothing entered
From	88 to 90	Ft.	SILT (TILL) 0 nothing entered 0 nothing entered 0 nothing entered
From	to	Ft.	BOTTOM OF DRILL HOLE AT 90 FT. 0 nothing entered 0 nothing entered 0 nothing entered
From	to	Ft.	BACKFILLED WITH PEA GRAVEL TO 88 FT. 0 nothing entered 0 nothing entered 0 nothing entered

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 65039

Owner: COWICHAN RIVER SALMO

Address: END OF BOYS RD

Area: DUNCAN

WELL LOCATION:
COWICHAN Land District
District Lot: Plan: Lot:
Township: Section: 15 Range: 1
Indian Reserve: 1 COWICHAN Meridian: Block:
Quarter:
Island:
BCGS Number (NAD 27): 092B072414 Well: 3

Class of Well:
Subclass of Well:
Orientation of Well:
Status of Well: New
Well Use: Other
Observation Well Number:
Observation Well Status:
Construction Method: Drilled
Diameter: 20.0 inches
Casing drive shoe:
Well Depth: 53 feet
Elevation: 0 feet (ASL)
Final Casing Stick Up: inches
Well Cap Type:
Bedrock Depth: feet
Lithology Info Flag: N
File Info Flag: N
Sieve Info Flag: N
Screen Info Flag: N

Site Info Details:
Other Info Flag:
Other Info Details:

Construction Date: 1980-09-13 00:00:00.0

Driller: Drillwell Enterprises
Well Identification Plate Number:
Plate Attached By:
Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:
Well Yield: 1200 (Driller's Estimate) U.S. Gallons per Minute
Development Method:
Pump Test Info Flag: N
Artesian Flow:
Artesian Pressure (ft):
Static Level: 5 feet

WATER QUALITY:
Character:
Colour:
Odour:
Well Disinfected: N
EMS ID:
Water Chemistry Info Flag: N
Field Chemistry Info Flag:
Site Info (SEAM):

Water Utility:
Water Supply System Name:
Water Supply System Well Name:

SURFACE SEAL:
Flag: N
Material:
Method:
Depth (ft):
Thickness (in):

WELL CLOSURE INFORMATION:
Reason For Closure:
Method of Closure:
Closure Sealant Material:
Closure Backfill Material:
Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
 STEEL CASING,0.0 TO 20.0,0.0 TO 334.0, CO,STAINLESS STEEL,

LITHOLOGY INFORMATION:

From	28	to	32 Ft.	MED GRAVEL SOME FINES-BROWN WATER
From	32	to	41 Ft.	COARSE CLEAN GRAVEL-SOME SILT LENSES-WAT
From	0	to	0 Ft.	BROWN
From	41	to	55 Ft.	MED TO COARSE BROWN SAND & GRAVEL
From	55	to	59 Ft.	LENSES OF BLUE SILT IN MED TO COARSE GRA
From	0	to	0 Ft.	WATER BLUE
From	12	to	15 Ft.	BLUE SILTY CLAY
From	15	to	19 Ft.	MED TO COARSE SANDY GRAVEL
From	20	to	26 Ft.	MED TO COARSE GRAVEL SOME BROWN SILT LEN
From	26	to	28 Ft.	LENSES OF BLUE SILT & SAND IN COARSE GRA
From	0	to	12 Ft.	BROWN SILTY SOFT SOME BROW SAND LENSES

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 85197

Owner: HERITAGE AQUA FARM

Address: 2654 CORFIELD RD

Area: DUNCAN

WELL LOCATION:
QUAMICHAN Land District
District Lot: Plan: 25177 Lot:
Township: Section: 12 Range: 8
Indian Reserve: Meridian: Block:
Quarter:
Island:
BCGS Number (NAD 27): 092B072411 Well: 40

Class of Well:
Subclass of Well:
Orientation of Well:
Status of Well: New
Well Use: Drinking Water Supply System
Observation Well Number:
Observation Well Status:
Construction Method: Drilled
Diameter: 20 inches
Casing drive shoe:
Well Depth: 104 feet
Elevation: feet (ASL)
Final Casing Stick Up: inches
Well Cap Type:
Bedrock Depth: feet
Lithology Info Flag: Y
File Info Flag: N
Sieve Info Flag: N
Screen Info Flag: Y

Site Info Details:
Other Info Flag:
Other Info Details:

Construction Date: 2002-01-25 00:00:00.0

Driller: Drillwell Enterprises
Well Identification Plate Number: 1189
Plate Attached By: RUST LIBOIRON
Where Plate Attached: WOOD SIDING ABOVE PUMPHOUSE DOOR

PRODUCTION DATA AT TIME OF DRILLING:
Well Yield: 1000 (Driller's Estimate) U.S. Gallons per Minute
Development Method:
Pump Test Info Flag: N
Artesian Flow:
Artesian Pressure (ft):
Static Level: 12 feet

WATER QUALITY:
Character:
Colour:
Odour:
Well Disinfected: N
EMS ID:
Water Chemistry Info Flag: N
Field Chemistry Info Flag:
Site Info (SEAM): N

Water Utility: N
Water Supply System Name: OCEAN FARMS HATCHERY
Water Supply System Well Name: OCEAN FARMS HATCHERY WS - WELL #4

SURFACE SEAL:
Flag: N
Material:
Method:
Depth (ft):
Thickness (in):

WELL CLOSURE INFORMATION:
Reason For Closure:
Method of Closure:
Closure Sealant Material:
Closure Backfill Material:
Details of Closure:

Screen from	to feet	Type	Slot Size
84	104		250

Casing from	to feet	Diameter	Material	Drive Shoe
0	104	20	Other	null

GENERAL REMARKS:
 LOCATED INSIDE MAIN GATE ON RIGHT. WELDED LID.

LITHOLOGY INFORMATION:

From	0 to	58 Ft.	COARSE BROWN SAND & GRAVEL	0 nothing entered	0 nothing entered	0 nothing entered
From	58 to	63 Ft.	COARSE BROWN SAND WITH GRAVEL	0 nothing entered	0 nothing entered	0 nothing entered
From	63 to	78 Ft.	COARSE BROWN SAND & GRAVEL	0 nothing entered	0 nothing entered	0 nothing entered
From	78 to	82 Ft.	BROWN SAND WITH WOOD	0 nothing entered	0 nothing entered	0 nothing entered
From	82 to	83 Ft.	BROWN SILT	0 nothing entered	0 nothing entered	0 nothing entered
From	83 to	104 Ft.	BROWN COARSE SAND & GRAVEL	0 nothing entered	0 nothing entered	0 nothing entered
From	104 to	Ft.	TILL	0 nothing entered	0 nothing entered	0 nothing entered

- Return to Main
- Return to Search Options
- Return to Search Criteria

APPENDIX B: SAMPLING PROGRAM AND QA/QC METHODS AND RESULTS

SAMPLING PROGRAM AND QA/QC METHODS AND RESULTS

B.1 Sample collection, laboratory analysis and Quality Assurance/Quality Control

The sampling program follows protocols outlined in (B.C. Ministry of Water, Land and Air Protection, 2003a) and (Nielsen & Nielsen, 2007). For the municipal and hatchery wells water samples were collected from wellheads or taps prior to any holding tanks, cisterns, or water treatment. Water was allowed to run for fifteen minutes to clear pipes and fixtures of standing water. Additional purging of the wells was not necessary because all of wells sampled are frequently pumped for operational use. For the observation wells, samples were collected using a Grundfos Redi-Flo2 submersible pump, after purging for sufficient duration that stabilization of field parameters (pH, specific conductivity, and temperature measured using a handheld YSI meter) had stabilized or after discharging two or more well volumes.

Sterile disposable gloves were worn during sample collection to reduce the potential for sample contamination. All samples were collected in polyethylene bottles provided by the laboratories. Sample filtration and preservation was completed by the laboratories.

A Quality Assurance/Quality Control (QA/QC) field program consisting of collection of field replicates was conducted for the 2011 sampling event, for the municipal and hatchery sites (one replicate per day of sampling). Replicates were also collected for observation well sample events in 2009, 2010, and 2011. Field replicates are samples that are collected at the same time as the original sample using the same procedures, which are used to evaluate the reproducibility of the sampling method. A total of 8 field replicates were available for evaluation.

Water samples were shipped via a courier to accredited laboratories in Burnaby, BC. Water chemistry parameters were analyzed by PSC Analytical Services for samples taken in 2002 to mid-2005, and by Maxxam Analytics Inc. for samples collected in mid-2005 to 2011. The laboratories performed an internal QA/QC program consisting of spikes, blanks, and duplicates.

After the sample results were received, the Charge Balance Error (CBE) was calculated for all samples, and the relative percent difference (RPD) was calculated for replicate samples, using the formulas provided below.

B.2 Data Archiving and Analysis

The data collected in this study were uploaded by the analytical laboratories into the B.C. MOE Environmental Monitoring Systems (EMS) database (B.C. Ministry of Environment, 2013). Data analysis was completed with Microsoft Excel®, except tri-linear Piper diagrams, which were completed with AquaChem®.

B.3 Quality Assurance and Quality Control Results

Ideally, all solutions are electrically neutral meaning that the sum of the positively charged ions (cations) should equal the sum of the negatively charged ions (anions). A completely neutral solution will have a charge balance error (CBE) of zero reflecting the electroneutrality of a solution. The integrity of a water sample analysis can be assessed by calculating the CBE as shown in equations (1) and (2) from (Freeze & Cherry, 1979) and (Appelo & Postma, 1993):

$$CBE = \frac{\sum zm_c - \sum zm_a}{\sum zm_c + \sum zm_a} x\,100 \quad (1)$$

Also stated as:

$$\text{Charge Balance Error} = \frac{(\sum CZ_i)_{cations} + (\sum CZ_i)_{anions}}{(\sum CZ_i)_{cations} - (\sum CZ_i)_{anions}} \quad (2)$$

where,

$$CZ_i = \frac{\text{Concentration}}{\text{Molecular Weight}} \times \text{ionic charge} \quad (3)$$

where z and m represent the absolute ionic charge and molality (mmol/L), respectively, of each cation (c) or anion (a).

The CBE was calculated from the concentration of anions bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), and nitrate-nitrogen (NO_3^-N), and cations calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+). Excluding nitrate, these seven major ions comprise the majority of ion concentrations in most groundwater. When an

ion was less than the method detection limit (MDL), the concentration was assumed to be equal to the MDL. A CBE within a range of ± 5% is generally considered acceptable (Appelo and Postma, 1993).

A total of sixty-four samples were analyzed, and of these five samples (8%) had a CBE error greater than 5% but less than 10% (Table B.1) Sources of the high CBE could include the presence of an ion in a significant concentration that was not considered in the calculation of the CBE, or laboratory error. The data were considered valid for further analysis because the CBE was less than 10%.

Table B.1: Summary of Unacceptable Charge Balance Error Results

Date	Sample	CBE (%)
6-Oct-11	Site 1	-9
6-Oct-11	Site 3	-7
20-Oct-11	Site 4	-9
7-Dec-04	Site 6	7
13-Feb-07	Site 6	8

When replicate samples are taken, the Relative Percent Difference (RPD) evaluates the discrepancy between the replicate samples and gives an idea of the reproducibility of the sampling methods (4). In this case, the replicate samples collected in the field were evaluated by calculating the RPD between the field samples and replicates, based on the formula (4) from (Nielsen & Nielsen, 2007):

Relative Percent Difference

$$\text{RPD} = \frac{Sample_1 - Sample_2}{\frac{Sample_1 + Sample_2}{2}} \times 100 \quad (4)$$

It was not possible to calculate the RPD when the results for one or both parameters were below the Method Detection Limit (MDL). A RPD of ≤ 25% is considered an acceptable level of error, and a RPD > 25% is considered acceptable if the analytical result is less than five times the method detection limit (MDL) (B.C. Ministry of Environment, Lands and Parks, LandData BC and Geographic Data BC, 1998).

A total of eight replicate samples were collected from the monitoring sites and observation wells. From these 8 replicates samples, 14 individual parameters had results

where the RPD was greater than 25%, however the analytical result was less than 5 times the MDL, considered within the acceptable level of error. Three replicates had individual parameters that were not within the acceptable range of difference, because the RPD was greater than 25% and the analytical result was greater than 5 times the MDL (Table B.2). Potential reasons that the RPD was not met could include variation due to the sampling methods (e.g. the samples were taken at successive times rather than concurrently as with a split sample), incomplete purging, laboratory error, or real variation within the aquifer. All data were considered valid for further analysis, and none of the results were discarded, however the parameters with high RPD's (i.e. >25% and result > 5% MDL) are flagged in the tabulated data shown below (Table B.3) and in Appendix C (complete results for all sites). One field blank was analyzed for observation well 318 (for the August 2011 sample session), comprised of deionized water collected into a standard sample bottle in the field and therefore exposed to the same environmental conditions as the sample. All parameters analyzed for the field blank indicated concentrations below the MDL.

Table B.2: Summary of Unacceptable Relative Percent Difference Results

Parameter	Sample Concentration (µg/L)	Replicate Concentration (µg/L)	MDL	RPD
Site 4, 20-Oct-11				
Copper	0.59	1.93	0.05	106%
Tin	0.37	0.62	0.01	51%
Site 2, 6-Oct-11				
Manganese	0.46	0.95	0.05	70%

Notes: MDL=method detection limit, RPD=relative percent difference

Table B3: Charge Balance Error Calculations

Parameter (units)	Site 1 DISTRICT OF NORTH COWICHAN WELL PW3, BOYS RD., DUNCAN							
	2002-12-17	**2003-05-22**	**2003-10-23**	**2004-06-02**	**2004-12-07**	**2005-11-01**	**2007-02-13**	**2011-10-06**
Bicarbonate (HCO3) (mg/L)	34.1	30.7	33.2	29.4	34.4	30.8	29.6	36
Ca (mg/L)	9.22	8.83	10.1	8.62	9.52	8.91	8.93	8.02
Chloride Dissolved (mg/L)	2.1	1.9	2.3	2	2	1.9	1.8	1.9
K (mg/L)	1	1	1	1	1	1	1	0.25
Mg (mg/L)	0.98	0.95	1	0.91	0.95	0.84	0.88	0.96
Na (mg/L)	2.09	1.7	2.14	1.74	2.06	1.75	1.75	1.80
Sulfate Dissolved (mg/L)	2.5	2.2	2	2.2	2	1.6	2.1	1.0
Nitrate (NO3) Dissolved	0.13	0.057	0.16	0.089	0.069	0.07	0.095	0.4
Charge Balance Calculations								
Ca	0.460	0.441	0.504	0.430	0.475	0.445	0.446	0.400
Mg	0.081	0.078	0.082	0.075	0.078	0.069	0.072	0.079
Na	0.091	0.074	0.093	0.076	0.090	0.076	0.076	0.078
K	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.006
Sum of Cations	0.657	0.618	0.705	0.606	0.668	0.615	0.620	0.564
Cl	-0.059	-0.054	-0.065	-0.056	-0.056	-0.054	-0.051	-0.054
SO4	-0.052	-0.046	-0.042	-0.046	-0.042	-0.033	-0.044	-0.021
HCO3	-0.559	-0.503	-0.544	-0.482	-0.564	-0.505	-0.485	-0.590
NO3	-0.002	-0.001	-0.003	-0.001	-0.001	-0.001	-0.002	-0.006
Sum of Anions	-0.672	-0.603	-0.653	-0.585	-0.663	-0.593	-0.581	-0.670
Electroneutrality	-1	1	4	2	0	2	3	**-9**

Table B3: Charge Balance Error Calculations

Parameter (units)	Site 2 CITY OF DUNCAN WELL #4, BOYS RD., DUNCAN								
	2002-12-17	**2003-05-22**	**2003-10-23**	**2004-06-02**	**2004-12-07**	**2005-05-19**	**2005-11-01**	**2007-02-13**	**2011-10-06**
Bicarbonate (HCO3) (mg/L)	34.1	29.3	33.4	28.4	36.3	30.1	35.6	29.5	35
Ca (mg/L)	9.13	8.09	10.2	8.65	9.88	9.08	10.3	8.71	9.22
Chloride Dissolved (mg/L)	2.3	1.7	2.4	1.9	2.2	1.9	2.7	1.8	2.6
K (mg/L)	1	1	1	1	1	1	1	1	0.23
Mg (mg/L)	0.94	0.85	1.01	0.91	0.96	0.9	1.02	0.84	0.93
Na (mg/L)	2.12	1.55	2.11	1.65	2.16	1.72	2.05	1.86	2.00
Sulfate Dissolved (mg/L)	1.7	2	2.5	2.2	2	1.7	1.8	2.2	1.3
Nitrate (NO3) Dissolved	0.13	0.068	0.18	0.11	0.104	0.15	0.117	0.138	0.093
Charge Balance Calculations									
Ca	0.456	0.404	0.509	0.432	0.493	0.453	0.514	0.435	0.460
Mg	0.077	0.070	0.083	0.075	0.079	0.074	0.084	0.069	0.077
Na	0.092	0.067	0.092	0.072	0.094	0.075	0.089	0.081	0.087
K	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.006
Sum of Cations	0.651	0.567	0.709	0.604	0.692	0.628	0.713	0.610	0.629
Cl	-0.065	-0.048	-0.068	-0.054	-0.062	-0.054	-0.076	-0.051	-0.073
SO4	-0.035	-0.042	-0.052	-0.046	-0.042	-0.035	-0.037	-0.046	-0.027
HCO3	-0.559	-0.480	-0.547	-0.465	-0.595	-0.493	-0.583	-0.483	-0.574
NO3	-0.002	-0.001	-0.003	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
Sum of Anions	-0.661	-0.571	-0.670	-0.567	-0.700	-0.585	-0.699	-0.582	-0.675
Electroneutrality	-1	0	3	3	-1	4	1	2	-4

Table B3: Charge Balance Error Calculations

Parameter (units)	Site 3 CITY OF DUNCAN WELL #2, MCKINSTRY RD., DUNCAN								
	2002-12-17	**2003-05-22**	**2003-10-23**	**2004-06-02**	**2004-12-07**	**2005-05-19**	**2005-11-01**	**2007-02-13**	**2011-10-06**
Bicarbonate (HCO3) (mg/L)	34.1	34.5	33.5	32.3	33.4	29.5	34.3	28.6	36
Ca (mg/L)	9.57	9.04	10.1	9.34	9.39	9.18	10	8.64	8.42
Chloride Dissolved (mg/L)	3.3	2.4	2.9	2.6	3.2	2.4	2.4	1.6	2.5
K (mg/L)	1	1	1	1	1	1	1	1	0.24
Mg (mg/L)	0.99	0.94	0.98	0.91	0.91	0.89	0.98	0.84	0.92
Na (mg/L)	2.37	1.92	2.27	1.82	2.33	1.92	2.31	1.85	2.07
Sulfate Dissolved (mg/L)	1.6	2	1.9	2.5	2.1	2.3	2.1	1.8	1.1
Nitrate (NO3) Dissolved	0.153	0.067	0.25	0.087	0.115	0.12	0.127	0.129	0.099
Charge Balance Calculations									
Ca	0.478	0.451	0.504	0.466	0.469	0.458	0.499	0.431	0.420
Mg	0.081	0.077	0.081	0.075	0.075	0.073	0.081	0.069	0.076
Na	0.103	0.084	0.099	0.079	0.101	0.084	0.100	0.080	0.090
K	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.006
Sum of Cations	0.688	0.638	0.709	0.646	0.670	0.640	0.706	0.606	0.592
Cl	-0.093	-0.068	-0.082	-0.073	-0.090	-0.068	-0.068	-0.045	-0.071
SO4	-0.033	-0.042	-0.040	-0.052	-0.044	-0.048	-0.044	-0.037	-0.023
HCO3	-0.559	-0.565	-0.549	-0.529	-0.547	-0.483	-0.562	-0.469	-0.590
NO3	-0.002	-0.001	-0.004	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002
Sum of Anions	-0.688	-0.676	-0.674	-0.656	-0.683	-0.601	-0.676	-0.553	-0.685
Electroneutrality	0	-3	2	-1	-1	3	2	5	**-7**

Table B3: Charge Balance Error Calculations

Parameter (units)	Site 4 VANCOUVER ISLAND TROUT HATCHERY WELL #101, BOYS RD., DUNCAN								
	2002-12-17	**2003-05-22**	**2003-10-23**	**2004-06-02**	**2004-12-07**	**2005-05-19**	**2005-11-01**	**2007-02-13**	**2011-10-20**
Bicarbonate (HCO3) (mg/L)	45.1	46.7	43.4	41.9	46.9	42.4	43.3	43.4	44.9
Ca (mg/L)	13.1	13.6	13.5	13.3	14	13.3	13.3	13.2	10.6
Chloride Dissolved (mg/L)	4.5	5.7	5	5.1	4.9	4.9	4.9	4	4.9
K (mg/L)	1	1	1	1	1	1	1	1	0.23
Mg (mg/L)	1.56	1.61	1.57	1.55	1.61	1.51	1.51	1.48	1.35
Na (mg/L)	3.28	3.4	3.38	3.51	3.57	3.24	3.24	3.15	2.7
Sulfate Dissolved (mg/L)	2.6	3	2.8	3.1	2.9	2.4	2.4	3.2	2.14
Nitrate (NO3) Dissolved	0.212	0.399	0.27	0.279	0.259	0.222	0.222	0.283	0.168
Charge Balance Calculations									
Ca	0.654	0.679	0.674	0.664	0.699	0.664	0.664	0.659	0.529
Mg	0.128	0.132	0.129	0.128	0.132	0.124	0.124	0.122	0.111
Na	0.143	0.148	0.147	0.153	0.155	0.141	0.141	0.137	0.117
K	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.006
Sum of Cations	0.950	0.985	0.975	0.969	1.012	0.954	0.954	0.943	0.763
Cl	-0.127	-0.161	-0.141	-0.144	-0.138	-0.138	-0.138	-0.113	-0.138
SO4	-0.054	-0.062	-0.058	-0.065	-0.060	-0.050	-0.050	-0.067	-0.045
HCO3	-0.739	-0.765	-0.711	-0.687	-0.769	-0.695	-0.710	-0.711	-0.736
NO3	-0.003	-0.006	-0.004	-0.005	-0.004	-0.004	-0.004	-0.005	-0.003
Sum of Anions	-0.924	-0.995	-0.915	-0.900	-0.971	-0.887	-0.901	-0.895	-0.921
Electroneutrality	1	-1	3	4	2	4	3	3	**-9**

Table B3: Charge Balance Error Calculations

Parameter (units)	Site 5 COWICHAN TRIBES HATCHERY; WELL #4, BOYS RD., DUNCAN								
	2002-12-17	**2003-05-22**	**2003-10-23**	**2004-06-02**	**2004-12-07**	**2005-05-19**	**2005-11-01**	**2007-02-13**	**2011-10-06**
Bicarbonate (HCO3) (mg/L)	48.8	38.2	39.9	36.4	44.6	42.7	42.7	38.6	38
Ca (mg/L)	12.4	9.81	10.8	9.68	11.4	11.8	11.2	10.6	13.1
Chloride Dissolved (mg/L)	3.9	2.1	3.3	2.1	2.6	3.1	2.3	1.8	12
K (mg/L)	1	1	1	1	1	1	1	1	0.33
Mg (mg/L)	2.59	1.78	1.86	1.85	1.93	2	1.88	1.78	2.29
Na (mg/L)	3.29	2.01	2.34	2.32	2.5	2.54	2.56	2.27	2.60
Sulfate Dissolved (mg/L)	3.1	2.6	2	2.3	1.7	2	1.6	2.8	1.2
Nitrate (NO3) Dissolved	0.05	0.04	0.04	0.069	0.056	0.05	0.034	0.154	0.043
Charge Balance Calculations									
Ca	0.619	0.490	0.539	0.483	0.569	0.589	0.559	0.529	0.654
Mg	0.213	0.146	0.153	0.152	0.159	0.165	0.155	0.146	0.188
Na	0.143	0.087	0.102	0.101	0.109	0.110	0.111	0.099	0.113
K	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.008
Sum of Cations	1.001	0.749	0.819	0.762	0.862	0.889	0.850	0.800	0.964
Cl	-0.110	-0.059	-0.093	-0.059	-0.073	-0.087	-0.065	-0.051	-0.339
SO4	-0.065	-0.054	-0.042	-0.048	-0.035	-0.042	-0.033	-0.058	-0.025
HCO3	-0.800	-0.626	-0.654	-0.597	-0.731	-0.700	-0.700	-0.633	-0.623
NO3	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001
Sum of Anions	-0.975	-0.740	-0.789	-0.705	-0.841	-0.830	-0.799	-0.744	-0.987
Electroneutrality	1	1	2	4	1	3	3	4	-1

Table B3: Charge Balance Error Calculations

Parameter (units)	Site 6 OCEAN FARMS HATCHERY WELL #4; CORFIELD RD., DUNCAN								
	2002-12-17	**2003-05-22**	**2003-10-23**	**2004-06-02**	**2004-12-07**	**2005-05-19**	**2005-11-01**	**2007-02-13**	**2011-10-06**
Bicarbonate (HCO3) (mg/L)	48.8	41.7	42.2	41.1	43.5	43.1	46	42.1	36
Ca (mg/L)	12.6	17.2	10.1	17.6	14.5	16.1	12.8	13.3	21.9
Chloride Dissolved (mg/L)	8.4	26.1	7.3	27.3	13.6	18.7	7.6	6.1	64
K (mg/L)	1	1	1	1	1	1	1	1	0.99
Mg (mg/L)	1.55	2.03	1.17	2.09	1.68	1.83	1.51	1.55	2.57
Na (mg/L)	10.4	13.3	11.1	13.4	11	11.1	9.38	7.71	24.3
Sulfate Dissolved (mg/L)	4.5	3.8	4.7	4.3	3.8	3.6	3.8	4.2	2.3
Nitrate (NO3) Dissolved	0.939	1.13	1.17	1.028	1.428	1.45	2.038	2.078	0.948
Charge Balance Calculations									
Ca	0.629	0.858	0.504	0.878	0.724	0.803	0.639	0.664	1.093
Mg	0.128	0.167	0.096	0.172	0.138	0.151	0.124	0.128	0.211
Na	0.452	0.579	0.483	0.583	0.478	0.483	0.408	0.335	1.057
K	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.025
Sum of Cations	1.234	1.629	1.109	1.659	1.366	1.462	1.197	1.152	2.387
Cl	-0.237	-0.736	-0.206	-0.770	-0.384	-0.528	-0.214	-0.172	-1.805
SO4	-0.094	-0.079	-0.098	-0.090	-0.079	-0.075	-0.079	-0.087	-0.048
HCO3	-0.800	-0.683	-0.692	-0.674	-0.713	-0.706	-0.754	-0.690	-0.590
NO3	-0.015	-0.018	-0.019	-0.017	-0.023	-0.023	-0.033	-0.034	-0.015
Sum of Anions	-1.146	-1.517	-1.014	-1.550	-1.199	-1.332	-1.080	-0.983	-2.459
Electroneutrality	4	4	4	3	**7**	5	5	**8**	-1

Table B3: Charge Balance Error Calculations

Parameter (units)	204 PROVINCIAL OBSERVATION WELL, BOYS RD., DUNCAN						
	2003-07-21	2009-09-15	2010-01-27	2010-07-21	2011-02-10	2011-07-21	2011-08-03
Bicarbonate (HCO3) (mg/L)		33	31	36	32	31	31
Ca (mg/L)	8.69	8.18	7.86	8.47	9.08	7.91	7.55
Chloride Dissolved (mg/L)	1.7	2.1	1.8	1.7	2.3	1.9	2.3
K (mg/L)	1	0.28	0.21	0.23	0.25	0.22	0.26
Mg (mg/L)	0.91	0.87	0.85	1.04	0.9	0.94	0.98
Na (mg/L)	1.88	2.11	1.54	1.74	1.58	1.73	1.72
Sulfate Dissolved (mg/L)	2	3.5	1.7	0.5	1.8	0.5	0.8
Nitrate (NO3) Dissolved	0.097	0.123	0.085	0.035	0.053		0.049
Charge Balance Calculations							
Ca	0.434	0.408	0.392	0.423	0.453	0.395	0.377
Mg	0.075	0.072	0.070	0.086	0.074	0.077	0.081
Na	0.082	0.092	0.067	0.076	0.069	0.075	0.075
K	0.026	0.007	0.005	0.006	0.006	0.006	0.007
Sum of Cations	0.616	0.579	0.535	0.590	0.602	0.553	0.539
Cl	-0.048	-0.059	-0.051	-0.048	-0.065	-0.054	-0.065
SO4	-0.042	-0.073	-0.035	-0.010	-0.037	-0.010	-0.017
HCO3	0.000	-0.541	-0.508	-0.590	-0.524	-0.508	-0.508
NO3	-0.002	-0.002	-0.001	-0.001	-0.001	0.000	-0.001
Sum of Anions	-0.091	-0.675	-0.596	-0.649	-0.628	-0.572	-0.590
Electroneutrality	1	0	0	0	0	0	0

Table B3: Charge Balance Error Calculations

Parameter (units)	318 PROVINCIAL OBSERVATION WELL, WHARNCLIFFE RD., DUNCAN			
	2003-Jul-23	2011-Feb-03	2011-Jul-20	2011-Aug-03
Bicarbonate (HCO3) (mg/L)		33	38	38
Ca (mg/L)	11.8	9.04	10.9	10.3
Chloride Dissolved (mg/L)	3.8	1.3	3.5	3.9
K (mg/L)			0.5	0.5
Mg (mg/L)	1.43	1.08	1.42	1.46
Na (mg/L)	2.56	2.02	2.01	2.00
Sulfate Dissolved (mg/L)	2	1.5	1.6	0.7
Nitrate (NO3) Dissolved	0.254	0.054		0.098
Charge Balance Calculations				
Ca	0.589	0.451	0.544	0.514
Mg	0.118	0.089	0.117	0.120
Na	0.111	0.088	0.087	0.087
K	0.000	0.000	0.013	0.013
Sum of Cations	0.818	0.628	0.761	0.734
Cl	-0.107	-0.037	-0.099	-0.110
SO4	-0.042	-0.031	-0.033	-0.015
HCO3	0.000	-0.541	-0.623	-0.623
NO3	-0.004	-0.001	0.000	-0.002
Sum of Anions	-0.153	-0.610	-0.755	-0.749
Electroneutrality	1	0	0	0

APPENDIX C: ANALYTICAL RESULTS

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 1							
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-Nov-01	2007-Feb-13	2011-Oct-06
Silver*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005
Aluminum*	0.1	OG	< 0.0003	0.0005	0.002	0.0013	0.0007	0.0012	0.0006	0.0015
Alkalinity Total 4.5	-		28	25.2	27.2	24.1	28.2	25.2	24.2	30
Alkalinity pH 8.3	-		< 1	< 1	< 1	< 1	< 1	< 0.5	< 0.5	< 0.5
Ammonia Dissolved	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.015
Arsenic*	0.01	MAC	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0002	< 0.0001	0.00009
Boron*	5	MAC	0.045	< 0.008	0.011	< 0.008	0.009	0.013	< 0.008	< 0.05
Barium*	1	MAC	0.00331	0.00234	0.00355	0.00223	0.00324	0.00309	0.0026	0.00313
Beryllium*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00001
Bismuth*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005
Bicarbonate (HCO3)	-		34.1	30.7	33.2	29.4	34.4	30.8	29.6	36
Bromide Dissolved	-		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.4
Calcium*	-		9.22	8.83	10.1	8.62	9.52	8.91	8.93	8.02
Carbonate	-		NA	NA	NA	NA	NA	NA	NA	< 0.5
Cadmium*	0.005	MAC	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	0.000006
Chloride Dissolved	250	AO	2.1	1.9	2.3	2	2	1.9	1.8	1.9
Cobalt*	-		< 0.000005	0.000025	< 0.000005	0.000005	< 0.000005	< 0.000005	< 0.000005	< 0.000005
Chromium*	0.05	MAC	< 0.0002	< 0.0002	0.0006	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0001
Copper*	1.0	AO	0.0293	0.0222	0.0524	0.014	0.0486	0.0512	0.0248	0.00667
Iron*	0.3	AO	< 0.005	< 0.005	0.011	0.01	< 0.005	< 0.005	< 0.005	0.001
Fluoride	1.5	MAC	< 0.01	0.03	< 0.01	< 0.01	0.01	0.03	NA	0.02
Hardness Total*	-		27.05798	25.96061	29.3377	25.27152	27.68354	25.70739	25.92205	24
Mercury*	0.001	MAC	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	NA	< 0.00001
Hydroxide Alkalinity	-		NA	NA	NA	NA	NA	NA	NA	< 0.5
Potassium*	-		< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.25
Lithium*	-		0.00016	< 0.00005	0.00016	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.0005
Magnesium*	-		0.98	0.95	1	0.91	0.95	0.84	0.88	0.96
Manganese*	0.05	AO	0.000064	0.000032	0.000194	0.000124	0.000205	< 0.000008	0.000066	0.00013
Molybdenum*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.00009	< 0.00005	0.00006
Sodium*	200	AO	2.09	1.7	2.14	1.74	2.06	1.75	1.75	1.8
Nickel*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.00012
Nitrate-Nitrogen (N) Dissolved	10	MAC	0.13	0.06	0.16	0.09	0.071	0.072	0.097	0.093
Nitrate + Nitrite (N) Dissolved	-		0.132	0.057	0.157	0.091	0.071	0.072	0.097	0.093
Total Kjeldahl Nitrogen Dissolved	-		< 0.02	0.02	< 0.02	< 0.02	< 0.02	0.03	< 0.02	0.11
Nitrite-Nitrogen (N) Dissolved	1.0	MAC	< 0.002	< 0.002	0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 1							
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-Nov-01	2007-Feb-13	2011-Oct-06
Nitrogen Organic (N) Total *	-		< 0.10	< 0.01	< 0.01	< 0.10	< 0.10	0.03	< 0.02	0.10
Nitrogen (N) Total*	-		0.14	0.08	0.16	0.10	0.07	0.10	0.11	0.20
Lead*	0.01	MAC	0.0007	0.00035	0.00104	0.00028	0.00063	0.00065	0.00046	0.000379
Phosphorus Total Dissolved	-		0.003	< 0.002	< 0.002	0.004	0.002	0.008	NA	0.003
Residue Filterable 1.0u	-		40	36	40	34	40	46	52	34
Sulphur*	-		0.8	0.7	0.7	0.6	0.6	0.6	0.6	< 10
Antimony*	0.006	MAC	< 0.000005	0.000018	0.000021	0.000031	0.000012	0.000013	0.000011	0.00003
Selenium*	0.01	MAC	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0003	0.0002	< 0.0002	< 0.00004
Silicon*	-		NA	NA	NA	NA	NA	NA	NA	2.45
Tin*	-		< 0.00001	0.00006	0.00077	0.00004	0.00001	0.00003	0.00001	0.00006
Specific Conductance (µS/cm)	-		62	59	65	58	66	56	61	65
Strontium*	-		0.0326	0.0257	0.0308	0.0242	0.0297	0.0239	0.026	0.0286
Sulphate Dissolved	500	AO	2.5	2.2	2	2.2	2	1.6	2.1	1
Tellurium*	-		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	NA	NA	< 0.00002
Titanium*	-		< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.0005
Thallium*	-		< 0.000002	0.000003	0.000008	< 0.000002	< 0.000002	0.000003	< 0.000002	< 0.000002
Uranium*	0.020	MAC	< 0.000002	< 0.000002	< 0.000002	< 0.000002	0.000006	0.000009	< 0.000002	0.000011
Vanadium*	-		0.00044	0.00047	0.0006	0.00035	0.00049	0.00068	0.00035	0.0008
Zinc*	5	AO	0.0005	0.0028	0.0036	0.0005	0.0018	0.0023	0.002	0.0085
Zirconium*	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	NA	< 0.0001
pH (pH units)	6.5-8.5	OG	7.0	7.5	7.4	7.5	7.7	7.5	7.4	7.69
Turbidity (NTU)	-		NA	NA	NA	NA	NA	NA	NA	< 0.1

Notes:

units are mg/L unless otherwise noted

***** indicates dissolved concentration in 2011 results

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guidance value (OG)(Health Canada, 2012)

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TDS)

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 2										
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06	2011-Oct-06 REP	RPD %
Silver*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005	<0.000005	-
Aluminum*	0.1	OG	0.0008	0.0009	0.0013	0.0013	0.0014	< 0.0003	0.001	0.0009	0.0018	0.0018	0
Alkalinity Total 4.5	-		27.7	24	27.4	23.3	29.8	24.7	29.2	24.2	28	30	-7
Alkalinity pH 8.3	-		< 1	< 1	< 1	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.5	<0.5	-
Ammonia Dissolved	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.005	< 0.005	< 0.005	0.021	0.021	0
Arsenic*	0.01	MAC	< 0.0001	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001	0.00009	0.00008	12
Boron*	5	MAC	0.037	< 0.008	0.012	0.013	0.01	< 0.008	0.013	0.009	< 0.05	<0.050	-
Barium*	1	MAC	0.005	0.00345	0.00495	0.00341	0.00512	0.00284	0.00493	0.00421	0.00495	0.00497	0
Beryllium*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00001	<0.00001	-
Bismuth*	-		< 0.00002	0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005	<0.000005	-
Bicarbonate (HCO3)	-		34.1	29.3	33.4	28.4	36.3	30.1	35.6	29.5	35	37	-6
Bromide Dissolved	-		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.4	<0.4	-
Calcium*	-		9.13	8.09	10.2	8.65	9.88	9.08	10.3	8.71	9.22	8.80	5
Carbonate	-		NA	NA	NA	NA	NA	NA	NA	< 0.5	< 0.5	<0.5	-
Cadmium*	0.005	MAC	< 0.00001	0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.000005	<0.000005	-
Chloride Dissolved	250	AO	2.3	1.7	2.4	1.9	2.2	1.9	2.7	1.8	2.6	3.3	-24
Cobalt*	-		< 0.000005	0.00001	< 0.000005	< 0.000005	< 0.000005	< 0.000005	0.000005	< 0.000005	< 0.000005	<0.000005	-
Chromium*	0.05	MAC	< 0.0002	< 0.0002	0.0007	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0001	<0.0001	-
Copper*	1.0	AO	0.00056	0.00094	0.00094	0.00212	0.00273	0.0021	0.00226	0.0033	0.00202	0.00213	-5
Iron*	0.3	AO	0.042	0.047	0.021	0.018	0.009	0.03	0.018	0.013	0.004	0.005	-22
Fluoride	1.5	MAC	< 0.01	< 0.01	< 0.01	0.03	0.01	< 0.01	0.02	0.04	0.02	0.02	0
Hardness Total*	-		26.66853	23.70103	29.62858	25.34643	28.62364	26.37896	29.91946	25.2	26.9	25.9	4
Mercury*	0.001	MAC	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	NA	< 0.00005	NA	< 0.00001	<0.00001	-
Hydroxide Alkalinity	-		NA	NA	NA	NA	NA	NA	NA	< 0.5	< 0.5	<0.5	-
Potassium*	-		< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.23	0.23	0
Lithium*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.0005	<0.0005	-
Magnesium*	-		0.94	0.85	1.01	0.91	0.96	0.9	1.02	0.84	0.93	0.94	-1
Manganese*	0.05	AO	0.000717	0.00117	0.000629	0.000308	0.00057	0.000997	0.000544	0.000557	0.00046	0.00095	-70
Molybdenum*	-		< 0.00005	< 0.00005	< 0.00005	0.00005	0.00005	< 0.00005	0.00005	0.00005	0.00005	0.00006	-18
Sodium*	200	AO	2.12	1.55	2.11	1.65	2.16	1.72	2.05	1.86	2.00	2.04	-2
Nickel*	-		< 0.00005	< 0.00005	< 0.00005	0.00006	0.00006	< 0.00005	0.00033	< 0.00005	0.00007	0.00007	0
Nitrate-Nitrogen (N) Dissolved	10	MAC	0.13	0.07	0.18	0.11	0.106	0.15	0.119	0.138	0.093	0.105	-12
Nitrate + Nitrite (N) Dissolved	-		0.131	0.068	0.182	0.112	0.106	0.152	0.119	0.138	0.093	0.105	-12
Total Kjeldahl Nitrogen Dissolved	-		< 0.02	0.03	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.07	0.05	33
Nitrite-Nitrogen (N) Dissolved	1.0	MAC	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.004	< 0.002	< 0.002	< 0.002	<0.002	-
Nitrogen Organic (N) Total *	-		< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.02	< 0.02	< 0.02	0.05	0.02	86
Nitrogen (N) Total*	-		0.13	0.10	0.19	0.12	0.11	0.15	0.13	0.14	0.16	0.15	-
Lead*	0.01	MAC	0.00027	0.00012	0.00044	0.00013	0.00016	0.00122	0.00139	0.0004	0.000064	0.000054	17
Phosphorus Total Dissolved	-		0.004	< 0.002	< 0.002	0.003	< 0.002	< 0.002	< 0.002	0.003	0.003	0.003	0
Residue Filterable 1.0u	-		52	32	44	36	46	40	46	40	32	40	-22
Sulphur*	-		0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	< 10	<10	-
Antimony*	0.006	MAC	0.000009	0.000017	0.000023	0.000033	0.000021	0.000019	0.000022	0.00002	0.00002	0.00003	-40

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 2										
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06	2011-Oct-06 REP	RPD %
Selenium*	0.01	MAC	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.00005	0.00005	0
Silicon*	-		NA	NA	NA	NA	NA	NA	NA	NA	2.59	2.42	7
Tin*	-		< 0.00001	< 0.00001	0.00002	0.00003	0.00001	< 0.00001	0.00007	0.000002	0.00005	0.00008	-46
Specific Conductance (µS/cm)	-		60	56	66	57	68	58.7	68	60	67	68	-1
Strontium*	-		0.0313	0.024	0.0304	0.0247	0.029	0.0186	0.0301	0.0251	0.0323	0.0320	1
Sulphate Dissolved	500	AO	1.7	2	2.5	2.2	2	1.7	1.8	2.2	1.3	1.5	-14
Tellurium*	-		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	NA	NA	NA	< 0.00002	<0.00002	-
Titanium*	-		< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.0005	<0.0005	-
Thallium*	-		< 0.000002	< 0.000002	0.000004	< 0.000002	< 0.000002	< 0.000002	0.000002	< 0.000002	< 0.000002	<0.000002	-
Uranium*	0.020	MAC	< 0.000002	< 0.000002	< 0.000002	< 0.000002	< 0.000002	< 0.000002	0.000004	< 0.000002	< 0.000002	<0.000002	-
Vanadium*	-		0.0004	0.00036	0.00053	0.00027	0.00038	0.00025	0.00045	0.00034	0.0008	0.0008	0
Zinc*	5	AO	0.0125	0.0061	0.001	0.002	0.0036	0.002	0.0044	0.0024	0.0013	0.0013	0
Zirconium*	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	NA	< 0.0001	<0.0001	-
pH (pH units)	6.5-8.5	OG	7.0	7.4	7.4	7.5	7.7	6.8	7.0	7.4	7.56	7.69	-2
Turbidity (NTU)	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.1	<0.1	-

units are mg/L unless otherwise noted

***indicates dissolved concentration in 2011 results

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guidance value (OG)(Health Canada, 2012)

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TDS)

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

RPD=Relative Percent Difference

bold indicates parameter is above Guideline for Canadian Drinking Water Quality

QA/QC summary

October 6, 2011 (all parameters) One exceedence of RPD criteria (magnanese RPD>25, and result>5*MDL)

indicates Relative Percent Difference >25%

indicates Relative Percent Difference >25% but analytical result is < 5 x MDL

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 3								
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06
Silver*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005
Aluminum*	0.1	OG	0.0006	0.0008	0.0012	0.0009	0.0011	< 0.0003	0.0005	0.0009	0.0032
Alkalinity Total 4.5	-		27.5	28.3	27.5	26.5	27.4	24.2	28.1	23.4	30
Alkalinity pH 8.3	-		< 1	< 1	< 1	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.5
Ammonia Dissolved	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.009
Arsenic*	0.01	MAC	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001	0.0001
Boron*	5	MAC	0.04	< 0.008	0.01	0.011	0.01	< 0.008	< 0.008	0.012	< 0.05
Barium*	1	MAC	0.0046	0.00396	0.0048	0.00364	0.00468	0.00273	0.00464	0.0036	0.0045
Beryllium*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	0.00002	< 0.00002	< 0.00001
Bismuth*	-		0.00008	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005
Bicarbonate (HCO3)	-		34.1	34.5	33.5	32.3	33.4	29.5	34.3	28.6	36
Bromide Dissolved	-		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.4
Calcium*	-		9.57	9.04	10.1	9.34	9.39	9.18	10	8.64	8.42
Carbonate	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5
Cadmium*	0.005	MAC	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	0.000005
Chloride Dissolved	250	AO	3.3	2.4	2.9	2.6	3.2	2.4	2.4	1.6	2.5
Cobalt*	-		< 0.000005	0.000019	< 0.000005	0.000005	< 0.000005	< 0.000005	< 0.000005	< 0.000005	< 0.000005
Chromium*	0.05	MAC	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0001
Copper*	1.0	AO	0.00218	0.00353	0.00475	0.00223	0.00336	0.00324	0.00323	0.00223	0.00342
Iron*	0.3	AO	< 0.005	< 0.005	0.058	0.021	< 0.005	0.013	0.008	< 0.005	0.005
Fluoride	1.5	MAC	0.01	0.01	< 0.01	0.02	< 0.01	< 0.01	0.02	NA	0.02
Hardness Total*	-		27.97311	26.4438	29.25534	27.06936	27.19421	26.58748	29.00564	25.0332	24.8
Mercury*	0.001	MAC	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	NA	< 0.00005	NA	< 0.00001
Hydroxide Alkalinity	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5
Potassium*	-		1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.24
Lithium*	-		0.0002	0.0001	0.00014	< 0.00005	< 0.00005	< 0.00005	0.00013	< 0.00005	< 0.0005
Magnesium*	-		0.99	0.94	0.98	0.91	0.91	0.89	0.98	0.84	0.92
Manganese*	0.05	AO	< 0.000008	0.000075	0.000238	0.00012	0.000048	0.00003	0.000018	0.000037	0.00016
Molybdenum*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.00006
Sodium*	200	AO	2.37	1.92	2.27	1.82	2.33	1.92	2.31	1.85	2.07
Nickel*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.00004
Nitrate-Nitrogen (N) Dissolved	10	MAC	0.15	0.07	0.25	0.089	0.117	0.12	0.127	0.129	0.099
Nitrate + Nitrite (N) Dissolved	-		0.153	0.069	0.251	0.089	0.117	0.124	0.130	0.131	0.099
Total Kjeldahl Nitrogen Dissolved	-		0.008	0.05	< 0.02	< 0.02	0.02	0.05	< 0.02	< 0.02	0.06
Nitrite-Nitrogen (N) Dissolved	1.0	MAC	< 0.002	0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.003	0.002	< 0.002
Nitrogen Organic (N) Total *	-		< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	0.05	< 0.02	< 0.02	0.05
Nitrogen (N) Total*	-		0.23	0.11	0.26	0.10	0.14	0.18	0.13	0.13	0.16
Lead*	0.01	MAC	0.00033	0.00023	0.00091	0.00019	0.00039	0.00023	0.00032	0.00015	0.00038

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 3								
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06
Phosphorus Total Dissolved	-		0.004	< 0.002	< 0.002	< 0.002	< 0.002	0.002	0.003	NA	0.004
Residue Filterable 1.0u	-		50	42	48	38	50	42	46	48	38
Sulphur*	-		0.8	1.5	0.6	0.6	0.6	0.6	0.6	0.6	< 10
Antimony*	0.006	MAC	0.000031	0.000008	0.000022	0.000024	0.000013	0.000009	0.000014	0.000011	0.00002
Selenium*	0.01	MAC	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0002	< 0.0002	0.0002	< 0.0002	0.00005
Silicon*	-		NA	NA	NA	NA	NA	NA	NA	NA	2.31
Tin*	-		< 0.00001	0.00004	0.00035	0.00003	0.00002	0.00002	0.00003	0.00002	0.00003
Specific Conductance (µS/cm)	-		64	63	67	61	71	61.4	66	56	65
Strontium*	-		0.0334	0.0287	0.0326	0.0284	0.0307	0.02	0.0308	0.0255	0.0311
Sulphate Dissolved	500	AO	1.6	2	1.9	2.5	2.1	2.3	2.1	1.8	1.1
Tellurium*	-		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	NA	NA	NA	< 0.00002
Titanium*	-		< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.0005
Thallium*	-		< 0.000002	< 0.000002	0.000005	< 0.000002	< 0.000002	0.000003	0.000002	< 0.000002	< 0.000002
Uranium*	0.020	MAC	< 0.000002	< 0.000002	< 0.000002	< 0.000002	0.000003	< 0.000002	< 0.000002	< 0.000002	< 0.000002
Vanadium*	-		0.00041	0.00042	0.00053	0.00037	0.00048	0.00031	0.00046	0.00034	0.0008
Zinc*	5	AO	< 0.0001	0.0222	0.0036	0.0005	0.0005	0.0005	0.0004	0.0003	0.0012
Zirconium*	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	NA	< 0.0001
pH (pH units)	6.5-8.5	OG	7.3	7.5	7.5	7.7	7.7	6.8	6.6	7.5	7.55
Turbidity (NTU)	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.1

Notes:

units are mg/L unless otherwise noted

***** indicates dissolved concentration in 2011 results

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guidance value (OG)(Health Canada, 2012)

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TDS)

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 4										
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-20	2011-Oct-20 REP	RPD %
Silver*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005	<0.000005	-
Aluminum*	0.1	OG	< 0.0003	0.0004	0.0044	0.003	0.0012	< 0.0003	< 0.0003	0.0049	0.0128	0.0144	-12
Alkalinity Total 4.5	-		36.9	38.3	35.6	34.4	38.5	34.8	35.5	35.6	36.8	33.3	10
Alkalinity pH 8.3	-		< 1	< 1	< 1	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.5	<0.50	-
Ammonia Dissolved	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.0101	-
Arsenic*	0.01	MAC	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001	0.00008	0.00006	29
Boron*	5	MAC	0.033	< 0.008	0.01	0.014	0.009	< 0.008	0.012	0.011	< 0.05	<0.050	-
Barium*	1	MAC	0.00258	0.00276	0.00255	0.00248	0.0028	0.00182	0.00241	0.00246	0.00218	0.00216	1
Beryllium*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00001	<0.00001	-
Bismuth*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005	<0.000005	-
Bicarbonate (HCO3)	-		45.1	46.7	43.4	41.9	46.9	42.4	43.3	43.4	44.9	40.6	10
Bromide Dissolved	-		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.4	<0.4	-
Calcium*	-		13.1	13.6	13.5	13.3	14	13.4	13.3	13.2	10.6	10.8	-2
Carbonate	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5	<0.5	-
Cadmium*	0.005	MAC	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	0.00001	< 0.00001	0.00003	< 0.000005	<0.000005	-
Chloride Dissolved	250	AO	4.5	5.7	5.0	5.1	4.9	4.9	4.9	4	4.9	4.6	6
Cobalt*	-		< 0.000005	< 0.000005	< 0.000005	0.000007	< 0.000005	< 0.000005	< 0.000005	0.000013	< 0.000005	0.000007	-
Chromium*	0.05	MAC	< 0.0002	< 0.0002	0.0009	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0001	0.0001	-
Copper*	1.0	AO	0.00047	0.00039	0.00112	0.0053	0.00345	0.00226	0.00336	0.0585	0.00059	0.00193	-106
Iron*	0.3	AO	< 0.005	0.007	< 0.005	0.007	0.017	0.018	0.045	0.075	0.003	0.006	-67
Fluoride	1.5	MAC	0.02	0.01	< 0.01	0.04	< 0.01	< 0.01	0.02	NA	0.019	0.018	5
Hardness Total*	-		39.13478	40.58918	40.17476	39.593	41.58798	39.59562	39.42828	39.05504	31.9	32.5	-2
Mercury*	0.001	MAC	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	NA	< 0.00005	NA	< 0.00001	<0.00001	-
Hydroxide Alkalinity	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5	<0.50	-
Potassium*	-		< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.23	0.24	-4
Lithium*	-		< 0.00005	0.00009	0.00008	0.0001	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.0005	<0.0005	-
Magnesium*	-		1.56	1.61	1.57	1.55	1.61	1.49	1.51	1.48	1.35	1.36	-1
Manganese*	0.05	AO	< 0.000008	0.000117	0.00012	0.000319	0.000454	0.000044	0.000175	0.00022	0.00007	0.00009	-25
Molybdenum*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	<0.00005	-
Sodium*	200	AO	3.28	3.4	3.38	3.51	3.57	3.18	3.24	3.15	2.7	2.78	-3
Nickel*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.00006	0.00009	0.0006	-148
Nitrate-Nitrogen (N) Dissolved	10	MAC	0.21	0.40	0.27	0.28	0.259	0.32	0.224	0.285	0.168	0.168	0
Nitrate + Nitrite (N) Dissolved	-		0.212	0.401	0.273	0.281	0.261	0.322	0.224	0.285	0.168	0.168	0
Total Kjeldahl Nitrogen Dissolved	-		< 0.02	0.03	< 0.02	0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.043	<0.020	-
Nitrite-Nitrogen (N) Dissolved	1.0	MAC	< 0.002	0.002	0.006	< 0.002	0.002	0.004	< 0.002	< 0.002	< 0.002	<0.002	-
Nitrogen Organic (N) Total *	-		< 0.10	< 0.01	< 0.01	NA	< 0.01	< 0.02	< 0.02	< 0.02	0.04	<0.02	-
Nitrogen (N) Total*	-		0.21	0.43	0.28	0.3	0.26	0.32	0.23	0.28	0.211	0.187	12
Lead*	0.01	MAC	0.00023	0.0001	0.00015	0.00059	0.00045	0.00011	0.00034	0.00995	0.000054	0.000057	-5
Phosphorus Total Dissolved	-		0.006	0.004	0.004	0.003	0.002	0.006	0.004	NA	0.005	0.005	0
Residue Filterable 1.0u	-		66	58	74	52	62	66	62	68	50	68	-31
Sulphur*	-		0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.8	< 10	<10	-
Antimony*	0.006	MAC	< 0.000005	0.000005	< 0.000005	0.000029	0.000008	0.000008	0.000011	0.000026	< 0.00002	<0.00002	-
Selenium*	0.01	MAC	< 0.0002	< 0.0002	0.0003	< 0.0002	0.0003	< 0.0002	0.0003	< 0.0002	0.00005	0.00004	22

Table C.1 Analytical Results Summary

Parameter	GCDWQ Value	Type	Site 4										
			2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-20	2011-Oct-20 REP	RPD %
Silicon*	-		NA	NA	NA	NA	NA	NA	NA	NA	3.69	3.75	-2
Tin*	-		< 0.00001	0.00006	< 0.00001	0.00005	0.00002	< 0.00001	0.00003	0.00023	0.00037	0.00062	-51
Specific Conductance (µS/cm)	-		89	101	91	90	101	91.9	93	93	83.6	83.0	1
Strontium*	-		0.06	0.0587	0.0552	0.0531	0.0573	0.0408	0.0534	0.051	0.0462	0.0465	-1
Sulphate Dissolved	500	AO	2.6	3	2.8	3.1	2.9	2.2	2.4	3.2	2.14	2.33	-9
Tellurium*	-		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	NA	NA	NA	< 0.00002	<0.00002	-
Titanium*	-		< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.0005	<0.0005	-
Thallium*	-		< 0.000002	< 0.000002	0.000009	0.000003	< 0.000002	0.000004	0.000002	< 0.000002	< 0.000002	<0.000002	-
Uranium*	0.020	MAC	< 0.000002	< 0.000002	< 0.000002	< 0.000002	0.000002	< 0.000002	< 0.000002	< 0.000002	< 0.000002	<0.000002	-
Vanadium*	-		0.00042	0.00048	0.00064	0.00048	0.00048	0.00041	0.00054	0.00047	0.0007	0.0008	-13
Zinc*	5	AO	0.0065	0.0099	0.0036	0.0125	0.0061	0.0199	0.011	0.0891	0.0018	0.0022	-20
Zirconium*	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	NA	< 0.0001	<0.0001	-
pH (pH units)	6.5-8.5	OG	7.2	7.6	7.4	7.6	7.8	6.9	7.1	7.4	7.16	7.14	0
Turbidity (NTU)	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.1	<0.10	-

Notes:

units are mg/L unless otherwise noted

***** indicates dissolved concentration in 2011 results

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guidance value (OG)(Health Canada, 2012)

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TDS)

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

bold indicates parameter is above Guideline for Canadian Drinking Water Quality

QA/QC summary

October 20, 2011 (replicate-general chemistry) Two exceedences of RPD criteria (copper, and tin)

indicates Relative Percent Difference >25%

indicates Relative Percent Difference >25% but analytical result is < 5 x MDL

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 5								
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06
Silver*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	NA	< 0.000005
Aluminum*	0.1	OG	0.0058	0.0004	0.0004	0.0006	0.0004	< 0.0003	0.0005	NA	0.0026
Alkalinity Total 4.5	-		40	31.3	32.7	29.9	36.6	35	35	31.6	31
Alkalinity pH 8.3	-		< 1	< 1	< 1	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.5
Ammonia Dissolved	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.024
Arsenic*	0.01	MAC	0.0004	< 0.0001	< 0.0001	0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001	0.00009
Boron*	5	MAC	0.031	< 0.008	0.01	0.01	0.011	0.01	0.011	0.011	< 0.05
Barium*	1	MAC	0.00569	0.00328	0.00438	0.0031	0.00438	0.00321	0.00426	0.00369	0.00533
Beryllium*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00001
Bismuth*	-		< 0.00002	0.00003	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005
Bicarbonate (HCO3)	-		48.8	38.2	39.9	NA	44.6	42.7	42.7	38.6	38
Bromide Dissolved	-		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.4
Calcium*	-		12.4	9.81	10.8	9.68	11.4	11.8	11.2	10.6	13.1
Carbonate	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5
Cadmium*	0.005	MAC	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.000005
Chloride Dissolved	250	AO	3.9	2.1	3.3	2.1	2.6	3.1	2.3	1.8	12
Cobalt*	-		< 0.000005	0.000025	< 0.000005	< 0.000005	0.000007	< 0.000005	0.000008	< 0.000005	0.000014
Chromium*	0.05	MAC	< 0.0002	< 0.0002	0.0006	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0001
Copper*	1.0	AO	0.00382	0.00172	0.00116	0.00036	0.00276	0.00232	0.00264	0.00124	0.00061
Iron*	0.3	AO	**0.86**	0.023	0.024	0.009	0.025	0.05	0.035	0.013	0.035
Fluoride	1.5	MAC	0.03	0.03	< 0.01	0.04	< 0.01	0.02	0.04	NA	0.02
Hardness Total*	-		41.62842	31.82561	34.62708	31.78926	36.41354	37.7006	35.70824	33.79824	42.2
Mercury*	0.001	MAC	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	NA	< 0.00005	NA	< 0.00001
Hydroxide Alkalinity	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5
Potassium*	-		< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.33
Lithium*	-		0.00028	0.00049	0.00052	0.00026	0.00047	0.00036	0.00058	0.00036	< 0.0005
Magnesium*	-		2.59	1.78	1.86	1.85	1.93	2	1.88	1.78	2.29
Manganese*	0.05	AO	**0.0686**	0.00273	0.0046	0.000752	0.0104	0.00813	0.0124	0.00559	0.0189
Molybdenum*	-		< 0.00005	< 0.00005	< 0.00005	0.00009	< 0.00005	< 0.00005	0.00006	0.00006	0.00009
Sodium*	200	AO	3.29	2.01	2.34	2.32	2.50	2.54	2.56	2.27	2.60
Nickel*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.00011
Nitrate-Nitrogen (N) Dissolved	10	MAC	0.05	0.04	0.04	0.07	0.058	0.05	0.036	0.156	0.043
Nitrate + Nitrite (N) Dissolved	-		0.055	0.040	0.038	0.071	0.058	0.05	0.036	0.156	0.043
Total Kjeldahl Nitrogen Dissolved	-		0.10	0.03	< 0.02	< 0.02	0.03	0.07	0.04	< 0.02	0.07
Nitrite-Nitrogen (N) Dissolved	1.0	MAC	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.004	< 0.002	< 0.002	< 0.002
Nitrogen Organic (N) Total *	-		0.1	< 0.10	< 0.10	< 0.10	< 0.10	0.07	0.04	< 0.02	0.05
Nitrogen (N) Total*	-		0.16	0.07	0.03	0.08	0.09	0.12	0.07	0.15	0.12
Lead*	0.01	MAC	0.0012	0.00032	0.00049	0.00017	0.0009	0.00035	0.00036	0.00065	0.000054

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 5								
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06
Phosphorus Total Dissolved	-		0.013	< 0.002	0.004	0.005	0.003	< 0.002	< 0.002	NA	0.005
Residue Filterable 1.0u	-		66	58	62	40	54	50	58	64	68
Sulphur*	-		1.1	0.9	0.7	0.7	0.6	0.8	0.6	0.8	< 10
Antimony*	0.006	MAC	< 0.000005	0.000025	0.000011	0.000022	0.000013	0.00001	0.000017	0.000013	0.00002
Selenium*	0.01	MAC	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.00004
Silicon*	-		NA	NA	NA	NA	NA	NA	NA	NA	4.18
Tin*	-		< 0.00001	0.00004	0.00002	0.00002	< 0.00001	< 0.00001	0.00001	0.00003	0.00004
Specific Conductance (µS/cm)	-		91	71	77	69	85	83.6	79	76	106
Strontium*	-		0.0385	0.0281	0.0319	0.0275	0.033	0.0247	0.0322	0.0307	0.0431
Sulphate Dissolved	500	AO	3.1	2.6	2.0	2.3	1.7	2.0	1.6	2.8	1.2
Tellurium*	-		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	NA	NA	NA	< 0.00002
Titanium*	-		< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.0005
Thallium*	-		< 0.000002	< 0.000002	0.000005	0.000002	0.000002	0.000005	0.000002	< 0.000002	< 0.000002
Uranium*	0.020	MAC	0.000016	0.000002	< 0.000002	0.000002	0.000004	0.000002	0.000003	< 0.000002	0.000002
Vanadium*	-		0.00166	0.00038	0.0005	0.00047	0.00032	0.00031	0.0004	0.00031	0.0005
Zinc*	5	AO	0.0117	0.0064	0.0018	0.0008	0.0047	0.0024	0.0018	0.0032	0.0034
Zirconium*	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	NA	< 0.0001
pH (pH units)	6.5-8.5	OG	7.2	7.6	7.5	7.7	7.8	6.9	7.1	7.5	7.56
Turbidity (NTU)	-		NA	NA	NA	NA	NA	NA	NA	NA	2.1

Notes:

units are mg/L unless otherwise noted

***** indicates dissolved concentration in 2011 results

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guidance value (OG)(Health Canada, 2012)

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TDS)

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 6								
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06
Silver*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005
Aluminum*	0.1	OG	0.0008	0.0025	0.0008	0.0018	0.0006	< 0.0003	0.0012	0.0011	0.0016
Alkalinity Total 4.5	-		40.3	34.2	34.6	33.7	35.7	35.3	37.7	34.5	29
Alkalinity pH 8.3	-		< 1	< 1	< 1	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.5
Ammonia Dissolved	-		< 0.005	< 0.005	< 0.005	< 0.005	0.005	< 0.005	< 0.005	< 0.005	0.015
Arsenic*	0.01	MAC	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001	0.00009
Boron*	5	MAC	0.031	< 0.008	0.01	0.012	0.01	0.009	0.013	0.016	< 0.05
Barium*	1	MAC	0.00694	0.00905	0.00546	0.00863	0.00705	0.00624	0.00629	0.00595	0.0164
Beryllium*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00001
Bismuth*	-		< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.000005
Bicarbonate (HCO3)	-		48.8	41.7	42.2	41.1	43.5	43.1	46	42.1	36
Bromide Dissolved	-		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.4
Calcium*	-		12.6	17.2	10.1	17.6	14.5	16.1	12.8	13.3	21.9
Carbonate	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5
Cadmium*	0.005	MAC	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.000005
Chloride Dissolved	250	AO	8.4	26.1	7.3	27.3	13.6	18.7	7.6	6.1	64.0
Cobalt*	-		< 0.000005	0.000026	< 0.000005	0.000011	0.000016	< 0.000005	0.000018	0.000011	0.000016
Chromium*	0.05	MAC	< 0.0002	< 0.0002	0.0006	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0001
Copper*	1.0	AO	0.00021	0.00044	0.00046	0.0002	0.00078	0.00019	0.00179	0.00039	0.00053
Iron*	0.3	AO	0.225	0.009	< 0.005	< 0.005	< 0.005	0.006	0.007	< 0.005	0.002
Fluoride	1.5	MAC	0.02	0.03	< 0.01	0.19	0.01	0.02	0.04	NA	0.02
Hardness Total*	-		37.8451	51.30794	30.03776	52.55382	43.12474	47.73764	38.17978	39.593	65.2
Mercury*	0.001	MAC	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	NA	< 0.00005	NA	< 0.00001
Hydroxide Alkalinity	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.5
Potassium*	-		1	< 1	< 1	1	< 1	< 1	1	< 1	0.99
Lithium*	-		0.00022	0.00015	0.00014	< 0.00005	< 0.00005	0.00011	< 0.00005	< 0.00005	< 0.0005
Magnesium*	-		1.55	2.03	1.17	2.09	1.68	1.83	1.51	1.55	2.57
Manganese*	0.05	AO	0.00135	0.000236	0.000088	0.000141	0.00014	0.000059	0.000163	0.000081	0.00016
Molybdenum*	-		< 0.00005	0.00005	0.00009	0.00007	0.00007	0.00007	0.00008	0.00007	0.00007
Sodium*	200	AO	10.4	13.3	11.1	13.4	11	11.1	9.38	7.71	24.3
Nickel*	-		< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.00009	< 0.00005	0.00007
Nitrate-Nitrogen (N) Dissolved	10	MAC	0.94	1.13	1.17	1.03	1.43	1.45	2.04	2.08	0.948
Nitrate + Nitrite (N) Dissolved	-		0.940	1.13	1.17	1.03	1.43	1.46	2.04	2.08	0.948
Total Kjeldahl Nitrogen Dissolved	-		0.04	< 0.02	0.03	0.08	0.04	0.08	0.19	< 0.02	0.15
Nitrite-Nitrogen (N) Dissolved	1.0	MAC	< 0.002	< 0.002	0.002	< 0.002	< 0.002	0.003	< 0.002	< 0.002	< 0.002
Nitrogen Organic (N) Total *	-		< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	0.08	0.19	< 0.02	0.13
Nitrogen (N) Total*	-		0.98	1.12	1.20	1.11	1.47	1.53	2.23	1.95	1.10
Lead*	0.01	MAC	0.00027	0.00008	0.00002	< 0.00001	< 0.00001	0.00002	0.00003	0.00002	0.000044
Phosphorus Total Dissolved	-		0.002	< 0.002	0.004	0.006	0.004	0.006	0.011	NA	0.005
Residue Filterable 1.0u	-		78	126	66	104	92	94	72	76	150
Sulphur*	-		1.7	1.3	1.4	1.1	1.3	1.3	1.4	1.4	< 10
Antimony*	0.006	MAC	< 0.000005	0.000015	0.000009	0.000024	0.000012	0.000013	0.000014	0.000014	0.00002
Selenium*	0.01	MAC	0.0002	< 0.0002	< 0.0002	< 0.0002	0.0002	< 0.0002	< 0.0002	< 0.0002	0.00006
Silicon*	-		NA	NA	NA	NA	NA	NA	NA	NA	4.31
Tin*	-		0.00001	0.00006	0.00002	0.00003	< 0.00001	< 0.00001	0.00003	0.00002	0.00006
Specific Conductance (µS/cm)	-		117	176	108	169	144	155	121	114	291
Strontium*	-		0.0467	0.0584	0.0342	0.0587	0.047	0.041	0.0419	0.0405	0.0825
Sulphate Dissolved	500	AO	4.5	3.8	4.7	4.3	3.8	3.6	3.8	4.2	2.3
Tellurium*	-		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	NA	NA	NA	< 0.00002

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Site 6								
	Value	Type	2002-Dec-17	2003-May-22	2003-Oct-23	2004-Jun-02	2004-Dec-07	2005-May-19	2005-Nov-01	2007-Feb-13	2011-Oct-06
Titanium*	-		< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.0005
Thallium*	-		< 0.000002	< 0.000002	0.000013	0.000007	0.000004	0.000004	0.000003	< 0.000002	< 0.000002
Uranium*	0.020	MAC	0.000002	0.000002	< 0.000002	0.000003	0.000004	0.000003	0.000003	0.000002	< 0.000002
Vanadium*	-		0.00031	0.00048	0.00059	0.00066	0.0006	0.00044	0.0006	0.00041	0.0008
Zinc*	5	AO	< 0.0001	0.0096	0.0005	0.0009	0.0004	0.0001	0.0021	0.0008	0.0006
Zirconium*	-		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	NA	< 0.0001
pH (pH units)	6.5-8.5	OG	7.7	7.5	7.6	7.6	7.8	6.9	7.2	7.5	7.47
Turbidity (NTU)	-		NA	NA	NA	NA	NA	NA	NA	NA	< 0.1

Notes:

units are mg/L unless otherwise noted

*****indicates dissolved concentration in 2011 results

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guidance value (OG)(Health Canada, 2012)

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TDS)

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

bold indicates parameter is above Guideline for Canadian Drinking Water Quality

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Obs well 204							
	Value	Type	21-Jul-03	2009-Sep-15	2009-09-15 (REP)	RPD %	2010-Jan-27	2010-Jul-21	2010-Jul-21 (REP)	RPD %
Silver*	-		<0.00002	NA	NA		<0.000005	<0.000005	NA	
Aluminum*	0.1	OG	0.0024	0.0038	NA		0.001	0.0044	NA	
Alkalinity Total 4.5	-		25.2	27	NA		26	30	NA	
Alkalinity pH 8.3	-		<1	NA	NA		<0.5	<0.5	NA	
Ammonia Dissolved	-		<0.005	<0.005	<0.005		<0.005	0.016	0.016	0
Arsenic*	0.01	MAC	0.0001	0.00006	NA		0.00005	<0.00002	NA	
Boron*	5	MAC	<0.008	<0.050	NA		<0.05	<0.05	NA	
Barium*	1	MAC	0.00502	0.006	NA		0.00468	0.00565	NA	
Beryllium*	-		<0.00002	<0.00001	NA		<0.00001	<0.00001	NA	
Bismuth*	-		<0.00002	<0.000005	NA		<0.000005	<0.000005	NA	
Bicarbonate (HCO3)	-		NA	33	NA		31	36	NA	
Bromide Dissolved	-		<0.1	<0.4	<0.4		<0.4	<0.4	<0.4	
Calcium*	-		8.69	8.18	NA		7.86	8.47	NA	
Carbonate	-		NA	<0.5	NA		<0.5	<0.5	NA	
Cadmium*	0.005	MAC	0.00001	<0.000005	NA		<0.000005	<0.000005	NA	
Chloride Dissolved	250	AO	1.7	2.1	3.3	-44	1.8	1.7	1.5	13
Cobalt*	-		<0.000005	0.00001	NA		0.000043	0.00002	NA	
Chromium*	0.05	MAC	0.0007	<0.0001	NA		<0.0001	<0.0001	NA	
Copper*	1.0	AO	0.00042	0.00256	NA		0.00037	0.00052	NA	
Iron*	0.3	AO	0.013	<0.001	NA		<0.001	0.003	NA	
Fluoride	1.5	MAC	0.01	0.02	NA		<0.01	0.02	0.01	67
Hardness Total*	-		25.4	24	NA		23.1	25.4	NA	
Mercury*	0.001	MAC	<0.00005	NA	NA		NA	NA	NA	
Hydroxide Alkalinity	-		NA	NA	NA		NA	NA	NA	
Potassium*	-		<1	0.28	NA		0.21	0.23	NA	
Lithium*	-		<0.00005	<0.0005	NA		<0.0005	<0.0005	NA	
Magnesium*	-		0.91	0.87	NA		0.85	1.04	NA	
Manganese*	0.05	AO	0.000163	0.00014	NA		0.00011	0.00179	NA	
Molybdenum*	-		<0.00005	<0.00005	NA		0.00006	<0.00005	NA	
Sodium*	200	AO	1.88	2.11	NA		1.54	1.74	NA	
Nickel*	-		<0.00005	0.00002	NA		0.00008	0.00023	NA	
Nitrate (NO3) Dissolved	10	MAC	0.097	0.123	0.125	-2	0.085	0.035	0.033	6
Nitrate + Nitrite Dissolved	-		0.097	0.123	0.125	-2	0.085	0.035	0.033	6
Total Kjeldahl Nitrogen Dissolved	-		0.04	0.04	0.02	67	0.68	0.05	0.03	50
Nitrogen - Nitrite Dissolved	1.0	MAC	<0.002	<0.002	<0.002		<0.002	<0.002	<0.002	
Nitrogen Organic Total *	-		<0.10	0.04	0.02	67	0.68	0.03	<0.02	
Nitrogen Total*	-		0.14	0.16	0.15	6	0.76	0.08	0.06	29
Lead*	0.01	MAC	0.00009	0.000011	NA		<0.000005	<0.000005	NA	
Phosphorus Total Dissolved	-		<0.002	NA	NA		NA	NA	NA	
Residue Filterable 1.0u	-		34	32	NA		56	36	NA	
Sulphur*	-		0.6	<3	NA		<3	<10	NA	
Antimony*	0.006	MAC	0.000015	0.00003	NA		<0.00002	<0.00002	NA	
Selenium*	0.01	MAC	0.0003	<0.00004	NA		<0.00004	<0.00004	NA	
Silicon*	-		NA	1.9	NA		2.17	2.49	NA	

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Obs well 204							
	Value	Type	21-Jul-03	2009-Sep-15	2009-09-15 (REP)	RPD %	2010-Jan-27	2010-Jul-21	2010-Jul-21 (REP)	RPD %
Tin*	-		0.00004	<0.00001	NA		0.00001	<0.00001	NA	
Specific Conductance (µS/cm)	-		61	NA	NA		NA	61	NA	
Strontium*	-		0.0245	0.027	NA		0.0239	0.0267	NA	
Sulphate Dissolved	500	AO	2.0	3.5	3.6	-3	1.7	<0.5	1.2	
Tellurium*	-		<0.05	NA	NA		NA	NA	NA	
Titanium*	-		<0.003	<0.0005	NA		<0.0005	<0.0005	NA	
Thallium*	-		<0.000002	<0.000002	NA		<0.000002	<0.000002	NA	
Uranium*	0.020	MAC	<0.000002	<0.000002	NA		<0.000002	<0.000002	NA	
Vanadium*	-		0.00043	0.0003	NA		<0.0002	<0.0002	NA	
Zinc*	5	AO	0.0011	0.0009	NA		0.0005	0.001	NA	
Zirconium*	-		<0.005	<0.0001	NA		<0.0001	<0.0001	NA	
pH (pH units)	6.5-8.5	OG	7.3	6.47	NA		NA	7.26	NA	
Turbidity (NTU)	-		NA	0.1	NA		0.2	0.6	NA	

Notes:

units are mg/L unless otherwise noted

*****indicates dissolved concentration in 2009-2011 results, total in 2003

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guid

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TDS)

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

bold indicates parameter is above Guideline for Canadian Drinking Water Quality

QA/QC summary

September 15, 2009 (anions)	No exceedences of RPD criteria
July 21, 2010 (anions)	No exceedences of RPD criteria
February 10, 2011 (anions)	No exceedences of RPD criteria
July 21, 2011 (anions)	No exceedences of RPD criteria
	Indicates Relative Percent Difference >25%
	Indicates Relative Percent Difference >25% but analytical result is < 5 x MDL

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Obs well 204						
	Value	Type	2011-Feb-10	2011-Feb-10 (REP)	RPD %	2011-Jul-21	2011-Jul-21 (REP)	RPD %	2011-Aug-03
Silver*	-		<0.000005	NA		<0.000005	NA		<0.000005
Aluminum*	0.1	OG	0.0008	NA		0.0029	NA		0.0021
Alkalinity Total 4.5	-		26	NA		26	NA		26
Alkalinity pH 8.3	-		<0.5	NA		<0.5	NA		<0.5
Ammonia Dissolved	-		0.017	0.02	-16	NA	NA		0.015
Arsenic*	0.01	MAC	0.0001	NA		0.00004	NA		0.00004
Boron*	5	MAC	<0.05	NA		<0.05	NA		<0.05
Barium*	1	MAC	0.00516	NA		0.00536	NA		0.00663
Beryllium*	-		<0.00001	NA		<0.00001	NA		<0.00001
Bismuth*	-		<0.000005	NA		<0.000005	NA		<0.000005
Bicarbonate (HCO3)	-		32	NA		31	NA		31
Bromide Dissolved	-		<0.4	<0.4		<0.4	<0.4		<0.4
Calcium*	-		9.08	NA		7.91	NA		7.55
Carbonate	-		<0.5	NA		<0.5	NA		<0.5
Cadmium*	0.005	MAC	<0.000005	NA		<0.000005	NA		<0.000005
Chloride Dissolved	250	AO	2.3	2.2	4	1.9	1.9	0	2.3
Cobalt*	-		0.000088	NA		0.000019	NA		0.000013
Chromium*	0.05	MAC	0.0002	NA		<0.0001	NA		<0.0001
Copper*	1.0	AO	0.00084	NA		0.00034	NA		0.00044
Iron*	0.3	AO	0.002	NA		0.001	NA		0.001
Fluoride	1.5	MAC	0.02	0.02	0	0.02	0.02	0	0.02
Hardness Total*	-		26.4	NA		23.6	NA		22.9
Mercury*	0.001	MAC	NA	NA		<0.00001	NA		<0.00001
Hydroxide Alkalinity	-		NA	NA		<0.5	NA		<0.5
Potassium*	-		0.25	NA		0.22	NA		0.26
Lithium*	-		<0.0005	NA		<0.0005	NA		<0.0005
Magnesium*	-		0.9	NA		0.94	NA		0.98
Manganese*	0.05	AO	0.00022	NA		0.00044	NA		0.00042
Molybdenum*	-		0.00012	NA		<0.00005	NA		<0.00005
Sodium*	200	AO	1.58	NA		1.73	NA		1.72
Nickel*	-		0.00025	NA		0.00017	NA		0.0001
Nitrate (NO3) Dissolved	10	MAC	0.053	0.053	0	NA	NA		0.049
Nitrate + Nitrite Dissolved	-		0.053	0.053	0	NA	NA		0.049
Total Kjeldahl Nitrogen Dissolved	-		0.02	<0.02		NA	NA		<0.02
Nitrogen - Nitrite Dissolved	1.0	MAC	<0.002	<0.002		NA	NA		<0.002
Nitrogen Organic Total *	-		<0.02	<0.02		NA	NA		<0.02
Nitrogen Total*	-		0.07	0.06	15	NA	NA		0.07
Lead*	0.01	MAC	0.000025	NA		0.000007	NA		0.00017
Phosphorus Total Dissolved	-		NA	NA		NA	NA		<0.002
Residue Filterable 1.0u	-		30	NA		34	NA		36
Sulphur*	-			NA		<10	NA		<10
Antimony*	0.006	MAC	0.00002	NA		0.00002	NA		<0.00002
Selenium*	0.01	MAC	<0.00004	NA		0.00008	NA		0.00007
Silicon*	-		2.41	NA		2.5	NA		2.41

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Obs well 204						
	Value	Type	2011-Feb-10	2011-Feb-10 (REP)	RPD %	2011-Jul-21	2011-Jul-21 (REP)	RPD %	2011-Aug-03
Tin*	-		0.00002	NA		0.00002	NA		0.00019
Specific Conductance (µS/cm)	-		60	NA		59	NA		59
Strontium*	-		0.0257	NA		0.0261	NA		0.0268
Sulphate Dissolved	500	AO	1.6	1.8	-12	0.5	<0.5		0.8
Tellurium*	-		NA	NA		<0.00002	NA		<0.00002
Titanium*	-		0.0007	NA		<0.0005	NA		<0.0005
Thallium*	-		<0.000002	NA		<0.000002	NA		<0.000002
Uranium*	0.020	MAC	<0.000002	NA		<0.000002	NA		<0.000002
Vanadium*	-		0.0009	NA		0.0003	NA		0.0003
Zinc*	5	AO	0.0026	NA		0.0021	NA		0.0012
Zirconium*	-		<0.0001	NA		<0.0001	NA		<0.0001
pH (pH units)	6.5-8.5	OG	7.15	NA		NA	NA		6.88
Turbidity (NTU)	-		0.2	NA		NA	NA		<0.1

Notes:

units are mg/L unless otherwise noted

*****indicates dissolved concentration in 2009-2011 results, total

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical

Type indicates whether the Guideline for Canadian Drinking Wance value (OG)(Health Canada, 201

- no drinking water guideline or analytical result for parameter

Residue Filterable 1.0u equivalent to Total Dissolved Solids (TI

Drinking water guidelines are for dissolved constituent concen

bold indicates parameter is above Guideline for Canadian Drin

QA/QC summary

September 15, 2009 (anions)	No exceedences of RPI
July 21, 2010 (anions)	No exceedences of RPI
February 10, 2011 (anions)	No exceedences of RPI
July 21, 2011 (anions)	No exceedences of RPI
	Indicates Relative Perc
	Indicates Relative Perc

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Observation well 318									
	Value	Type	2003-Jul-23	2011-Feb-03	2011-Feb-03 REP	RPD %	2011-Jul-20	2011-Jul-20 REP	RPD %	RPD COMMENT	2011-Aug-03	2011-Aug-03 BLANK
Silver*	-		<0.00002	0.000009	NA		<0.000005	NA			<0.000005	NA
Aluminum*	0.1	OG	0.0267	0.0049	NA		0.0013	NA			0.0029	NA
Alkalinity Total 4.5	-		32.7	27	27	0	31	31	0	RPD<25	31	<0.5
Alkalinity pH 8.3	-		<1	<0.5	<0.5		<0.5	<0.5			<0.5	<0.5
Ammonia Dissolved	-		<0.005	<0.005	NA		NA	NA			0.013	NA
Arsenic*	0.01	MAC	0.0002	0.00004	NA		0.00003	NA			0.00003	NA
Boron*	5	MAC	0.009	<0.05	NA		<0.05	NA			<0.050	NA
Barium*	1	MAC	0.00463	0.0029	NA		0.00362	NA			0.00397	NA
Beryllium*	-		<0.00002	<0.00001	NA		<0.00001	NA			<0.00001	NA
Bismuth*	-		<0.00002	<0.000005	NA		<0.000005	NA			<0.000005	NA
Bicarbonate (HCO3)	-		NA	33	33	0	38	37	3	RPD<25	38	<0.5
Bromide Dissolved	-		<0.1	<0.01	NA		<0.4	NA			<0.4	NA
Calcium*	-		11.8	9.04	NA		10.9	NA			10.3	NA
Carbonate	-		NA	<0.5	<0.5		<0.5	<0.5			<0.5	<0.5
Cadmium*	0.005	MAC	<0.00001	0.000027	NA		<0.000005	NA			0.000007	NA
Chloride Dissolved	250	AO	3.8	1.3	NA		3.5	NA			3.9	NA
Cobalt*	-		0.000142	0.000705	NA		0.000224	NA			0.000305	NA
Chromium*	0.05	MAC	0.0008	<0.0001	NA		<0.0001	NA			<0.0001	NA
Copper*	1.0	AO	0.00066	0.00059	NA		<0.00005	NA			0.0001	NA
Iron*	0.3	AO	**8.64**	0.16	NA		0.069	NA			0.002	NA
Fluoride	1.5	MAC	<0.01	0.02	NA		0.02	NA			0.02	NA
Hardness Total*	-		35.35334	27	NA		33.1	NA			31.7	NA
Mercury*	0.001	MAC	<0.00005	NA	NA		<0.00001	NA			<0.000002	NA
Hydroxide Alkalinity	-		NA	NA	NA		<0.5	<0.5			<0.5	<0.5
Potassium*	-		<1	0.32	NA		0.22	NA			0.25	NA
Lithium*	-		<0.00005	<0.0005	NA		<0.0005	NA			<0.5	NA
Magnesium*	-		1.43	1.08	NA		1.42	NA			1.46	NA
Manganese*	0.05	AO	0.0453	0.0192	NA		0.0476	NA			0.047	NA
Molybdenum*	-		0.00025	0.00061	NA		0.00013	NA			0.00014	NA
Sodium*	200	AO	2.56	2.02	NA		2.01	NA			2.00	NA
Nickel*	-		0.00033	0.00499	NA		0.00079	NA			0.00132	NA
Nitrate-Nitrogen (N) Dissolved	10	MAC	0.25	0.054	NA		NA	NA			0.098	NA
Nitrate + Nitrite (N) Dissolved	-		0.257	0.054	NA		NA	NA			0.101	NA
Total Kjeldahl Nitrogen Dissolved	-		0.03	0.05	NA		NA	NA			0.03	NA
Nitrite-Nitrogen (N) Dissolved	1.0	MAC	0.003	<0.002	NA		NA	NA			0.002	NA
Nitrogen Organic (N) Total *	-		< 0.01	0.05	NA		NA	NA			<0.02	NA
Nitrogen (N) Total*	-		0.28	0.10	NA		NA	NA			0.13	NA
Lead*	0.01	MAC	0.00039	0.00004	NA		<0.000005	NA			0.000017	NA
Phosphorus Total Dissolved	-		<0.002	NA	NA		NA	NA			<0.002	NA
Residue Filterable 1.0u	-		56	32	42	-27	42	62	-38	RPD<25	56	<10
Sulphur*	-		0.7	NA	NA		<10	NA			<10	NA
Antimony*	0.006	MAC	<0.000005	0.00003	NA		<0.00002	NA			<0.00002	NA
Selenium*	0.01	MAC	<0.0002	<0.00004	NA		<0.00004	NA			0.00005	NA
Silicon*	-		NA	3.91	NA		3.92	NA			3.61	NA

Table C.1 Analytical Results Summary

Parameter	GCDWQ		Observation well 318									
	Value	Type	2003-Jul-23	2011-Feb-03	2011-Feb-03 REP	RPD %	2011-Jul-20	2011-Jul-20 REP	RPD %	RPD COMMENT	2011-Aug-03	2011-Aug-03 BLANK
Tin*	-		0.00001	<0.00001	NA		<0.00001	NA			<0.00001	NA
Specific Conductance (µS/cm)	-		85	58	60	-3	78	76	3	RPD<25	77	1
Strontium*	-		0.042	0.0314	NA		0.0386	NA			0.041	NA
Sulphate Dissolved	500	AO	2	1.5	NA		1.6	NA			0.7	NA
Tellurium*	-		<0.05	NA	NA		<0.00002	NA			<0.00002	NA
Titanium*	-		0.003	<0.0005	NA		<0.0005	NA			<0.0005	NA
Thallium*	-		0.000003	<0.000002	NA		<0.000002	NA			<0.000002	NA
Uranium*	0.020	MAC	<0.000002	<0.000002	NA		<0.000002	NA			<0.000002	NA
Vanadium*	-		0.00137	<0.0002	NA		<0.0002	NA			<0.0002	NA
Zinc*	5	AO	0.0007	0.0063	NA		0.0009	NA			0.0006	NA
Zirconium*	-		<0.005	<0.0001	NA		<0.0001	NA			<0.0001	NA
pH (pH units)	6.5-8.5	OG	7.6	7.1	7.14	-1	NA	NA			6.96	5.79
Turbidity (NTU)	-		NA	29.8	26.6	11	NA	NA			11.2	<0.1

Notes:

units are mg/L unless otherwise noted

***** indicates dissolved concentration in 2011 results, total in 2003

NA indicates parameter was not analyzed

<value indicates the result was below the specified analytical Method Detection Limit (MDL)

Type indicates whether the Guideline for Canadian Drinking Water Quality (GCDWQ) is a Maximum Acceptable Concentration (MAC), Aesthetic Objective (AO) or Operational Guidance value (OG)(Health Canada, 2012)

- no drinking water guideline or analytical result for parameter

Drinking water guidelines are for dissolved constituent concentration unless otherwise specified

bold indicates parameter is above Guideline for Canadian Drinking Water Quality

QA/QC summary

February 3, 2011 (replicate-general chemistry)	No exceedences of RPD criteria
July 20, 2011 (replicate-general chemistry)	No exceedences of RPD criteria
August 3, 2011 (field blank-anions)	All parameters <MDL (where applicable)

indicates Relative Percent Difference >25%

indicates Relative Percent Difference >25% but analytical result is < 5 x MDL

APPENDIX D: CCME WATER QUALITY INDEX CALCULATIONS

D.1: CCME Water Quality Index Sample Calculations

This section summarizes the results of the Water Quality Index calculations for the lower Cowichan River aquifer complex (aquifers 186 & 187), determined using the methodology outlined in Canadian Council of Ministers of the Environment (2001b)[1]. A description of the formulas is provided, followed by the sample calculation for the study aquifers. Three factors are considered in the Index: scope, frequency and amplitude.

Scope: Represents the degree of non-compliance to guidelines for water quality during the period of study; "variable" indicates parameter tested during the study period with an established objective to compare the result to. In this case the objective used were the Guidelines for Canadian Drinking Water Quality (Health Canada, 2012). The scope is calculated as follows:

$$F_1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \times 100$$

$$F_1 = \frac{2}{54} \times 100 = 0.03704$$

Frequency: Represents what percentage of tests fail to meet the specified water quality objectives, as per the formula:

$$F_2 = \frac{Number\ of\ failed\ test}{Total\ number\ of\ tests} \times 100$$

$$F_2 = \frac{2}{2439} \times 100 = 0.00082$$

Amplitude: Represents to what degree the failed test parameters exceed the objective, as determined using three steps:

Excursion i: Within the first step of calculating amplitude, for each time an objective is not met, an excursion is calculated. If the objective is a maximum value, this calculation represents the number of times the concentration is greater than the objective (for a single test).

$$excursion_i = \left(\frac{FailedTestValue_i}{Objective_j}\right) - 1^2$$

[1]Methodology descriptions adapted from (CCME), 2001a).

In this case:

Excursion 1:

$$excursion_1 = \left(\frac{0.86}{0.3}\right) - 1 = 1.87$$

Excursion 2:

$$excursion_2 = \left(\frac{0.686}{0.05}\right) - 1 = 0.372$$

nse: The second step to estimate the amplitude is to determine the normalized sum of excursions (nse), by calculating the sum of excursions divided by the total number of tests (including all parameters i.e. those that met or did not meet the objectives):

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{\#\ of\ tests}$$

$$nse = \frac{1.87 + 0.372}{2439} = 0.000918$$

F_3: The final step is to estimate Fe_3, the asymptotic function, which gives the amplitude on a scale of 0 to 100 based on the normalized sum of excursions:

$$F_3 = \frac{nse}{0.01nse + 0.01}$$

$$= \frac{0.000918}{0.01(0.000918) + 0.01}$$

$$=0.091702$$

Finally, the Water Quality Index is calculated on a scale from 1 to 100 as:

$$WQI = 100 - \frac{\sqrt{{F_1}^2 + {F_2}^2 + {F_3}^2}}{1.732}$$

$$= 100 - \frac{\sqrt{0.03704^2 + 0.00082^2 + 0.091702^2}}{1.732} = 99.9$$

This result is compared to preset ranks, ranging from excellent, to good, fair, marginal and poor at the lower end of the scale. This approach can be used to categorize either surface or groundwater quality, and compare the results to drinking water, aquatic life or other criteria as desired.

[2] Where the objective is a minimum then excursion i = ($objective_j$/$FailedTestValue_i$)-1, and represents the number of times the concentration is less than the objective.).