Aquifers of the Capital Regional District

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Executive summary

This project focussed on the delineation and classification of developed aquifers within the Capital Regional District of British Columbia (CRD). The goal was to identify and map water-bearing unconsolidated and bedrock aquifers in the region, and to classify the mapped aquifers according to the methodology outlined in the *B.C. Aquifer Classification System* (Kreye and Wei, 1994). The project began in summer 2003 with the mapping and classification of aquifers in Sooke, and on the Saanich Peninsula. Aquifers in the remaining portion of the CRD including Victoria, Oak Bay, Esquimalt, View Royal, District of Highlands, the Western Communities, Metchosin and Port Renfrew were mapped and classified in summer 2004.

The presence of unconsolidated deposits within the CRD is attributed to glacial activity within the region over the last 20,000 years. Glacial and glaciofluvial modification of the landscape has resulted in the presence of significant water bearing deposits, formed from the sands and gravels of Capilano Sediments, Quadra and Cowichan Head Formations. Delineated aquifers also included units comprised of sedimentary, intrusive or extrusive igneous, and metamorphic bedrock. A total of sixteen unconsolidated aquifers and eight bedrock aquifers were identified in this study area (24 aquifers in total). These aquifers ranged in size from < 1 km^2 to 538 km^2. The majority of aquifers are small (<5 km^2) to moderate (5-25km^2) in size, with the exception of the bedrock aquifers.

Unconsolidated sand and gravel, and bedrock aquifers are important water sources in local areas of the CRD. The largest unconsolidated aquifer in the CRD (aquifer 685) is found at Port Renfrew near the western margin of the study area and is the main water source for the community of Port Renfrew and residents of Pacheedaht band on the Gordon River Indian Reserve. Sand and gravel aquifers at Bazan Bay, Hagan Creek, Keating, West Saanich Road and Cordova Bay, on the Saanich Peninsula are thought to be used largely for commercial and irrigation supplies, but may provide domestic water supplies in areas where connection to the municipal distribution system is not available. There is thought to be a greater reliance upon wells for domestic water sources in Sooke, Metchosin, and the Western Communities. Significant unconsolidated aquifers in these areas included aquifer 682 and 683 made up of sand and gravel of the Colwood Delta and Parry Bay formations, as well as aquifers comprised of glaciofluvial and glaciolacustrine sediments in the Sooke River, Young Lake and Mackenzie Lake areas. Also in Sooke and Metchosin is found the largest aquifer in the study area (aquifer 606) a volcanic/igneous bedrock aquifer; this volcanic bedrock aquifer typically has a very low yield. Domestic water supplies in the District of Highlands are almost entirely obtained from water wells in aquifer 680, made up of metamorphic bedrock, which extends over much of greater Victoria.

The majority of aquifers were classified as having a low or moderate level of development, largely due to the availability of municipally supplied surface water that is expected to reduce groundwater demand in most locations. Demand for groundwater in the CRD may increase in the future with population growth and continued restrictions on water use in the dry summer months.

Nine aquifers were classified as having a low vulnerability, ten aquifers are considered moderately vulnerable, and five aquifers have a high vulnerability. Surficial deposits of clay and till provide confinement for many of the aquifers in the study area, in particular at elevations below 80 m. The partial erosion of these confining sediments resulted in the classification of many of the identified aquifers as moderately vulnerable to contamination associated with pollutants introduced at the land surface. Bedrock aquifers more often encompass land occurring on high elevation ridges and peaks. Often lacking a surficial layer of clay or till, these bedrock aquifers are generally considered more vulnerable to contamination.

The productivity of aquifers within the CRD generally ranges from low to moderate; only two highly productive aquifers were identified, both associated with sedimentary deposits in major river drainages, such as aquifer 684 at the mouth of the Goldstream River and aquifer 685 along the San Juan River floodplain.

Isolated water quality concerns were identified in six aquifers. Identified concerns related to human health included isolated occurrences of bacterial contamination, localized hydrocarbon contamination from underground storage tanks, and high concentrations of nitrate (the latter parameter within the Guidelines for Canadian Drinking Water Quality). Additionally, elevated concentrations of arsenic exceeding the Guidelines for Canadian Drinking Water Quality were reported for one aquifer. Isolated concerns related to the aesthetic potability of water included elevated concentrations of iron and manganese, and intrusion of saline waters in coastal areas. Isolated concerns related to water quantity were identified in eight aquifers, mainly related to well interference, seasonal low yields or dry wells.

Since the initial phase of the aquifer mapping and classification project in 2003, the locations of wells and aquifers in the Capital Region have been added to the data set included on the CRD Natural Areas Atlas online mapping resource. Following the completion of the inventory of aquifers in the study area, the following steps should be considered by the CRD:

1. Present the project results to representatives of the CRD, municipalities, local stewardship groups and stakeholders;
2. Include display themes for all mapped and classified aquifers in the CRD Natural Areas Atlas online resource;
3. Consider exploring ways to promote local well stewardship and to educate well owners about water conservation practices, regular testing of the quality of their well water, and proper well maintenance, operation and abandonment. This may be done in partnership with MWLAP or the local health unit.

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Staff of municipal government agencies assisted in provided information on the drinking water infrastructure within the study area, needed to gauge areas of groundwater use for drinking water, and the relative dependence on the groundwater resource. These individuals include Doug Leslie of the City of Victoria Engineering Department, Corey Paiement and Jas Paul of the District of Saanich Planning Department, Tim Tanton from the Town of Sidney Engineering Department, Julie Rivet of the District of North Saanich Engineering Department, Mike Van der Linden of the District of Central Saanich Engineering Department, Bruce Woodbury of the District of Highlands, David Reay of the City of Colwood Engineering Department, and Dave Newman from City of Langford Engineering. Gary Hendren from CRD Evironmental Services, Rodney Thur administrator with the Pacheedaht Band and Mike Pichichero of Health Canada conveyed information on wells in the Port Renfrew area. Mary Steele and Misty McDuffy of Peninsula Streams were similarly helpful in providing reference materials on Central Saanich. Stefanie Blouin and Bruce Chambers of the Department of National Defence and Rachael McIlroy of Royal Roads University provided numerous hydrological reports on Royal Roads and Esquimalt Lagoon. Lastly, the author wishes to acknowledge the numerous individual well owners and commercial site managers who provided information on their wells, thereby improving the integrity of the primary data set used to identify, map and characterize ground water in the CRD.

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Cover photos, clockwise from top left: (1) pillow basalt of the Metchosin Igneous Complex, Iron Mine Bay, Sooke, August 2002; (2) Tri-K Drilling Ltd. constructing well in Langford, April, 2004; (3) artesian well in District of Highlands; (4) southern Gulf Islands, April 2004; (5) layers of fine sands and clay in coastal bluff, Mount Douglas Beach, August 2004; Victoria clay, Vashon till and Quadra sand in upper strata of the Cowichan Head formation, Island View Beach, October, 2003 (photos by S.Kenny). At centre: Landsat TM image of southern Vancouver Island.

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1. Introduction

Groundwater is an essential component of the British Columbia water resource. Groundwater represents approximately 10% of total water consumed within the province, but on a national basis, 30% of groundwater consumed annually in Canada. Although major population centres, such as Greater Vancouver and Victoria, utilize surface water from protected watersheds, approximately 22% of the population of B.C. (750,000 people) is dependent upon groundwater for industrial, agricultural, and domestic needs (Berardinuci and Ronneseth, 2002; Ministry of Water, Land and Air Protection, 2001a).

The contribution of groundwater to seasonal base flows within river drainages and wetlands is critical to the maintenance of wildlife and aquatic habitat. Additionally, due to its occurrence below ground, groundwater may be naturally better protected from contamination arising from sewage, industrial or other pollutants, in comparison to surface water sources. In future, the overall reliance upon groundwater resources may increase in the Capital Regional District (CRD), due to an anticipated increased reliance on groundwater for irrigation, continued population growth in rural areas not serviced by the municipal water supply, and potential impacts of climate change on natural hydrologic regimes.

Of major concern to users of groundwater in the province are issues related to both the quantity and quality of the resource. These include:

- conflicts between water users where interference effects have occurred between neighbouring wells;
- limited water yields in areas underlain by unfractured bedrock;
- conflicts between surface water and groundwater users where well water withdrawals have reduced the base flow to nearby creeks and rivers, particularly where surface water has been fully licenced or allocated;
- groundwater quality degradation due coastal sea water intrusion, and agricultural or industrial point source and non-point source pollution;
- contamination of groundwater supplies due to natural weathering of bedrock deposits (e.g. arsenic); and,
- contamination of groundwater due to poorly constructed, unsuitably sited or improperly abandoned wells.

In July 2004, the Phase I of the Ground Water Protection Regulation was enacted (MWLAP, 2004). This Regulation sets legislated standards for well construction, maintenance and closure; establishes provisions for the registration of certified well drillers and pump installers within a Provincial registry; and will require the location and tagging of all community wells (wells with more than one connection) in the Province. A main aim of the Phase I Regulation is to protect the groundwater resource by promoting the sanitary integrity of wells.

Prior to the enactment of the Ground Water Protection Regulation, management of the groundwater resource in the province historically focussed on a non-regulatory approach, reliant upon the voluntary participation of well drillers and well owners. The British Columbia Aquifer Classification System has been a critical aspect of non-regulatory groundwater management in the province. Since its development in 1994, the B.C. Aquifer Classification System has been used to inventory and classify aquifers throughout the province using a set of established criteria that considers, in part, the availability, intrinsic vulnerability and relative demand for water. Aquifer classification represents an important first step to identify developed aquifers within the province and to guide further assessment and management of the groundwater resource.

Within the CRD, although much of the population has ready access to municipally supplied surface water, groundwater remains an important water supply source. Within many parts of the region, such as on the Gulf Islands, the District of the Highlands, and within parts of rural Sooke, Metchosin, View Royal and the Saanich Peninsula, groundwater is the main source of water supply for agricultural, industrial and domestic users. Additionally, within urban areas, in response to seasonal municipal restrictions on water use during drought periods, increasing numbers of wells are being drilled or reactivated for irrigation and other uses. This report summarizes the findings of a study of groundwater aquifers in the southern Vancouver Island portion of the CRD. It is hoped that this work will provide a better understanding of the regional occurrence and abundance of groundwater, with the aim of protecting its viability for sustainable future use.

1.1 Project objectives

The primary objective of this study was to identify, map and classify developed aquifers within the CRD. The methods follow those outlined in: *A Proposed Aquifer Classification System for Groundwater Management in British Columbia* (Kreye and Wei, 1994) described below. Through the project, major water–bearing units in the region will be added to the provincial inventory of aquifers. The knowledge gained will assist in guiding land use planning decisions to better protect the local groundwater resource, increase public awareness about the important use and function of aquifers locally in the CRD, and provide a screening tool for further assessment and monitoring of specific aquifers.

This report presents the results of aquifer classification mapping in the CRD. As the scope of the project was the preliminary identification and classification of aquifers within the CRD, this report does not describe detailed aspects of regional or local hydrology, such as the rate and direction of groundwater flow. Locations of groundwater recharge, rates of recharge, analysis of water chemistry, and identification of site specific vulnerability to contamination or land use were similarly not considered. Where possible, existing information on these aspects of regional hydrology has been summarized briefly in relation to specific aquifers. A desired outcome of the project is to prioritize areas for which future research is needed to characterize these aspects of the regional hydrology.

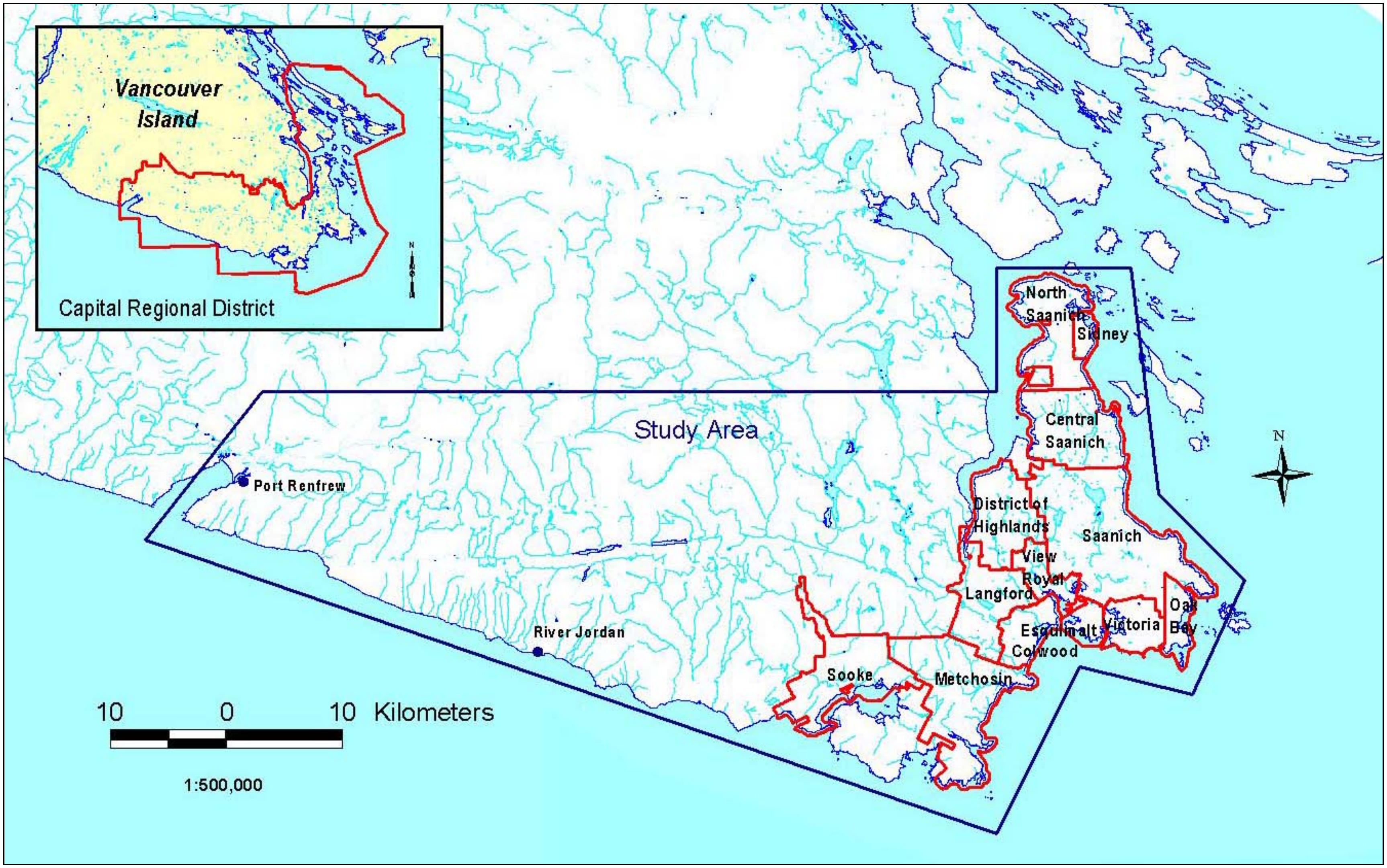
1.2 Description of the study area

The CRD is located on the southern tip of Vancouver Island, and encompasses thirteen municipalities including Central Saanich, Colwood, Esquimalt, the Highlands District, Langford, Metchosin, North Saanich, Oak Bay, Saanich, Sidney, Sooke, Victoria, View Royal, outlying areas in the Juan de Fuca Electoral District including Willis Point, Jordan River and Port Renfrew, and the southernmost Gulf Islands in the Strait of Georgia including Saltspring, Galiano, Pender, Mayne and Saturna Islands (Map 1).

This study focussed on the mapping and classification of aquifers within the Vancouver Island portion of the CRD. Hydrogeologic studies and mapping of aquifers on the southern Gulf Islands, including Salt Spring Island (Hodge, 1995) and Galiano Island (Kohut and Johanson, 1998), has been done previously, and are not discussed herein.

The CRD lies within the Nanaimo Lowlands, Nanaimo Lakes Highland and Victoria Highland physiographic regions (Yorath and Nasmith, 1995) and is characterized by a cool Mediterranean climate influenced by its southerly latitude and proximity to the maritime coast. In this part of southern Vancouver Island the average

Map 1: Capital Regional District aquifer classification study area



annual precipitation ranges from 607.3 mm/y to 883.3 mm/y and the daily mean temperature is from 9.7 °C to 10.3 °C, based on climate averages from 1971 to 2000 at the Victoria Gonzales Heights and Victoria International Airport weather monitoring stations. The greatest precipitation occurs during the months of October to May annually. While the summer months from June to September are characterized by low precipitation and drought conditions (Environment Canada, 2003).

Vancouver Island is found within the Insular Belt of the Canadian Cordillera (Yorath and Nasmith, 1995). The southern Vancouver Island is characterized by a moderate topographic relief of up to 1000 m elevation that has been extensively modified by glacial episodes during the last two million years. Numerous small lakes and permanent to ephemeral streams form an efficient drainage network within the study area. Due to the relatively low relief of the area, the creeks and rivers are generally of low order and small size, with the exception of the Sooke River, Jordan River, Goldstream River and other major drainages that originate within Vancouver Island Range mountains northwest of Victoria. The glacial history, surficial geology and bedrock geology of the study area are described in greater detail in Section 2.0.

1.3 Water supply sources in the CRD

Within the CRD (excluding the Gulf Islands) water for domestic, commercial, and industrial use is predominantly obtained from surface water sources located within the Greater Victoria Water Supply Area. In order to ensure adequate water supplies during annual periods of low precipitation, seasonal water use restrictions have become a fact of life in the CRD since first being implemented in 1993 (CRD, 2000). Although the storage capacity of the Sooke Reservoir was increased by 78% with the completion of a higher dam structure in 2002, due to population growth within the CRD Water District, average annual water demand is projected to rise from 61,700 ML[1] in 1998 to 68,000 ML in 2010 without effective demand-side management programs (CRD, 2003). In response to seasonal restrictions on surface water use, increasing numbers of wells are being drilled or reactivated. Municipalities may use groundwater for irrigation and other purposes. For example, the District of Sidney has reactivated two of its municipal wells for the purposes of irrigation and water main flushing and the City of Langford uses water wells for irrigation of local parks (T. Tanton, Director of Engineering & Public Works, Town of Sidney, pers.comm., June 27, 2003; Dave Newman, District of Langford Engineering, pers.comm., May 18, 2004). Additionally, a number of local golf courses have water wells that may be used for irrigation or to supplement surface water irrigation sources, although the well yields obtained are often too low to provide the significant water quantities required (Paul Robertson, Superintendent, Victoria Golf Club, pers. comm. June 11, 2004; Dave Sullivan, Site Manager, Gorge Vale Golf Club, pers. comm. May 13, 2004; Thurber Engineering Ltd., 2003).

On the Saanich Peninsula, a high density of wells along major transportation corridors reveals the history of early settlement, when groundwater was obtained from natural springs or shallow dug wells. Although the majority of households within Sidney, North Saanich, and Central Saanich have access to municipally supplied surface water, the infrastructure does not extend to all areas, and some rural households are still thought to obtain their domestic water supply from local aquifers. Similarly, within the District of Highlands, and outside of the core areas of Sooke and Metchosin municipalities, the majority of households, commercial and agricultural operations are reliant upon groundwater supplied from private wells, augmented by surface water licenced for extraction from local streams and lakes. Farm operations using the municipal water supply for irrigation are provided with a pricing subsidy for bulk water use that is frozen at the 2001 wholesale water rate (J.Hull, General Manager, CRD Water Department, pers. comm.,

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[1] ML stands for Megalitres or 1,000,000 litres.

November 24, 2003). Agricultural, commercial and industrial water users within the study area may still prefer to use groundwater due to its lower cost, which may be limited to the cost of well construction and maintenance. In this context, the use of, and reliance upon, groundwater in this region may increase in future years.

The density of known wells within the CRD study area is low. In all, based on records in the Province of BC's WELL database, there are 7911 wells within the CRD, representing 14% of the total 57,960 spatially referenced water wells in the province. Given the region's area of approximately 2,400 km^2, this corresponds to a low well density of 3 wells/km^2, yet localized areas of high well density do occur, particularly on the Gulf Islands. Table 1 indicates the number of wells found within the municipalities of the study area. The data shown below may not be represent the actual numbers of water wells in use in some locations, particularly the District of Highlands, Sooke, Metchosin, the Western Communities and Gulf Islands, where there may be significant numbers of unreported wells.

Table 1: Water wells of CRD Municipalities

Municipality	# of water wells in the WELL database
Central Saanich	664
District of Highlands	373
Esquimalt	4
Langford	135
Metchosin	340
North Saanich	1,394
Oak Bay	3
Saanich	757
Sidney	24
Sooke	88
Victoria	5
View Royal	19
Greater Victoria Subtotal	*3806*
Gulf Islands and outlying areas of the CRD	4105
CRD Total	*7911*

2. Mapping and Classifying Aquifers in the CRD

Aquifers within the CRD were mapped and classified according to the BC Aquifer Classification System (Kreye and Wei, 1994). This is the same method used to map and classify developed aquifers in other regions of the province.

2.1 B.C. Aquifer Classification System

The BC Aquifer Classification System is described below, as modified from Kreye and Wei (1994). The system has two separate components:

a) The classification component categorizes aquifers based on their present level of development and vulnerability to contamination.
b) The ranking value component assesses each aquifer according to water use and hydrological criteria.

2.1.1 Classification Component

The classification of an aquifer is achieved by assigning values within two sub-classes:

a) Development Subclass: The Development Sub-class designates a value for the aquifer corresponding to a high (I), moderate (II) or low (III) level of development. This is determined by assessing the level of water demand relative to the aquifer productivity or yield.

b) Vulnerability Subclass: The Vulnerability Subclass is determined for the aquifer, with one of three values selected, corresponding to a high (A), moderate (B) or low (C) level of vulnerability. The Vulnerability Subclass is based upon groundwater levels, geologic characteristics of the aquifer and the characteristics of the overlying geologic layers including their thickness, composition, and extent. The Vulnerability Subclass does not consider land-use or the nature or possible impact of human activities overlying the aquifer.

Aquifer Class: The Development Subclass and Vulnerability Subclass are combined into a single Aquifer Class with nine possible variations, as shown in Table 2.

Table 2: BC Aquifer Classification System – Classification Component

Development Sub-class

I	II	III
Heavy (demand is high relative to productivity)	Moderate (demand is moderate relative to productivity	Low (demand is low relative to productivity

Vulnerability Sub-class

A	B	C
High (highly vulnerable to contamination from surface sources)	Moderate (moderately vulnerable to contamination from surface sources)	Low (not very vulnerable to contamination from surface sources)

Aquifer Class

	I	II	III
A	IA – heavily developed, high vulnerability aquifer	IIA – moderately developed, high vulnerability aquifer	IA – lightly developed, high vulnerability aquifer
B	IB – heavily developed, moderate vulnerability aquifer	IIB – moderately developed, moderate vulnerability aquifer	IIIC – lightly developed, moderate vulnerability aquifer
C	IC – heavily developed, low vulnerability aquifer	IIC – moderately developed, low vulnerability aquifer	IIIC – lightly developed, low vulnerability aquifer

2.1.2 Ranking Value Component

The initial prioritization of aquifers in BC is based upon a relative ranking scale in which point values are determined for the aquifer according to seven key criteria:

- productivity;
- vulnerability to contamination;
- size;
- demand for water;
- type of use (non-drinking, drinking water or multiple use);
- identified water quantity concerns; and
- identified health related water quality concerns.

Each criterion is assigned a point value from 1 to 3, with the exception of quantity and quality criteria which may be assigned a value of 0, if no concerns are noted. The ranking value is the sum of point values for each criterion. The ranking value can range from 5, representing low priority, to 21, representing an aquifer of highest priority. The criteria and possible point values for the ranking system are summarized in Table 3.

Table 3: BC Aquifer Classification System - Ranking Value Component

	Point Value			
Criteria	1	2	3	Rationale
Productivity	Low	Moderate	High	Abundance of the resource
Vulnerability	Low	Moderate	High	Potential for water quality degradation
Size	<5 km^2	5 - 25 km^2	>25 km^2	Regionality of the resource
Demand	Low	Moderate	High	Level of reliance on the resource
Type of Use	Non-drinking water	Drinking water	Multiple use/ drinking water	Variability/ diversity of the resource for supply
Health Related Quality Concerns	Isolated	Local	Regional	Actual concerns
Quantity Concerns	Isolated	Local	Regional	Actual concerns

The aquifer boundaries are determined and the classification described above is usually applied to the aquifer as a whole. In some cases the initial delineation of the aquifer boundary, and classification of the aquifer is limited by data availability and may be altered as data become available. These tools may be effectively used to identify and prioritize the need for further assessments, such as mapping, modelling, delineating aquifer recharge and discharge areas and groundwater monitoring.

Aquifers mapped and classified according to this system are incorporated into a geographic information system (GIS) and are available for public use on the MWLAP internet site *Aquifers and Water Wells of B.C.* (http://maps.gov.bc.ca/apps/wlap_aquifer/). Further details on determination and interpretation of aquifer class and ranking values can be obtained from the *Guide to using BC Aquifer Classification Maps for the Protection and Management of Groundwater* (Berardinucci and Ronneseth, 2002).

2.2 Identifying Aquifers and Delineating Aquifer Boundaries

In this project the focus was on identifying and classifying aquifers which are presently developed, as indicated by well logs provided to the Province by well drillers or well owners and entered into the WELL database. The descriptions of lithological types and the depths at which changes in lithology occur are typically recorded along with well depths, estimated water yields and other data within the logs for individual wells.

Well locations were plotted at a 1:10,000 or 1:20,000 scale along with Terrain Resource Information Mapping (TRIM 1:20,000) water features and topographic data, and the information provided within individual well logs was then spatially correlated with available information on regional surficial and bedrock geology to delineate the areal extent of water bearing units or aquifers. Quaternary and surficial geology maps (Monahan and Levson, 2000; Blyth and Rutter, 1993a, 1993b, and 1993c) provided the basis for identification of the extent of unconsolidated sedimentary deposits, including confining materials such as clay or till. Bedrock geology maps (Massey, 1994; Muller, 1980) were used to identify bedrock types and the locations of major contacts between rocks of different lithology. Field visits were conducted in summer 2003 and 2004 to confirm the locations of major bedrock contacts, and to observe characteristic water-bearing sediments.

In this study, the water well records in the WELL database were checked against the original hard copy well records to verify well locations, confirm well lithology, record the depth and category of confining materials and update address and other information. This was done for the purposes of statistical calculations and to improve the accuracy and completeness of the master computerized database. Contact was also made with municipal representatives, hydrogeologic consultants, local drillers and other individuals in order to collect additional information on present water use and newly constructed wells in the areas of interest.

Limitations upon the accuracy of aquifer boundary determination included the inherent variability in the quality and completeness of available well log information. In some areas where well log information was incomplete or unavailable, aquifer boundaries were inferred from published geologic mapping or by the area of well development. Hydrogeologic cross-sections were also constructed to aid in interpretation and mapping of aquifer boundaries, to illustrate the relative locations of the aquifers at depth.

Although aquifers less than 1 km^2 in size are generally not mapped, exceptions were made in some cases where the presence of or level of development of a water-bearing deposit was considered significant enough to warrant delineation.

2.3 Statistical Methods

As a component of the project, available data from wells in a particular aquifer, were summarized statistically and used to assist with the classification and ranking of each aquifer. These summary statistics are described within the sections for the individual aquifers, and summarized in Appendix A. All statistics were generated using the internal formulas of Microsoft Excel v.10.4302.4219. The arithmetic mean, geometric mean, median, maximum, minimum and standard deviation were calculated for the parameters of well depth, water depth, bedrock depth, estimated yield and depth of confining materials for each aquifer identified. The geometric mean was not determined from the well records for selected aquifers due to limitations of the statistical program; in these cases the median was considered the closest approximation. Zero values were excluded from the calculations of summary statistics for water depth and estimated well yield, as a zero value typically indicates an unknown or unreported value within the WELL database from which the individual well records were obtained. In addition, the numbers of wells within the categories of well water use, and confining materials were summarized for each aquifer and their relative percentage calculated. Where data on transmissivity and specific capacity were available from longer duration pumping tests of individual wells, these were recorded in the summary statistics as a range for the aquifer.

A limitation of the statistical method includes the variable completeness and quality of the well records. A maximum of two significant figures was thought to be reasonable for the summary statistics, based upon the accuracy of available source data. However the level of accuracy may be lower than this, in particular in relation to estimated well yields. For example, the yields reported in the well logs were generally based on a short term air-lift yield test conducted at the time of well construction, and as such may not be representative of sustainable yield from wells under prolonged use. The yields were generally reported in units of gallons per minute, and subsequently converted to litres per second. Similarly, the static water level recorded at the time of construction for individual wells does not capture seasonal variations in water levels. In other cases, data on water depth, estimated yield or lithology were not provided within the original well record. For these reasons the number (N) of wells used to generate the individual statistics was recorded and reported as a percentage of the total number of wells found within the aquifer. For some aquifers where groundwater development is low, the statistics may be based on only a limited number of wells. As the submission of well logs by well drillers is done on a voluntary basis, in some areas there may be additional wells that have not been included within the provincial WELL database, or wells for which the submitted information was insufficient to precisely locate the well. Contacts made with local drillers and consultants during this project provided a small number of additional well logs that were not yet included within the WELL database. These limitations should be kept in mind when considering the significance of the summary statistics for each aquifer.

2.4 Interpretation of Aquifer Classification Maps and Hydrogeologic Cross-Sections

Subsurface detail on parts of the study area is provided in the form of a series of hydrogeologic cross-sections included within Appendix B, with locations shown in Maps 3 and 4. Three cross-sections were prepared using data from well logs and geologic maps: a longitudinal cross-section (A_1-A_6) from Colburne Passage at the northern tip of the Saanich Peninsula to Ten Mile Point east of Victoria intercepts most of the major aquifers of the Saanich Peninsula and Victoria; a latitudinal cross-section (B_1-B_2) from Willis Point to Island View Beach illustrates the location of major bedrock and unconsolidated aquifers in the Central Saanich area; and a latitudinal cross-section (C_1-C_5) from Orveas Bay, east of Sooke, to Ocean Boulevard in Colwood, shows the major unconsolidated and bedrock aquifers in the Sooke, Metchosin and Colwood areas. These cross-sections represent interpretations of regional hydrogeology and the distribution and depths of major surficial deposits and bedrock units relative to one another, but do not show hydrogeologic detail at the local level.

Aquifer Classification Maps showing the locations of the major aquifers identified in this project are found in Appendix C. These maps have been prepared using standardized symbology for the aquifer's lithology, vulnerability and the relative certainty of the established boundary. Bedrock aquifers are represented by a cross-hatch symbol; while unconsolidated aquifers are represented by a stippled symbol. The vulnerability of each aquifer is indicated through a colour coding system where red indicates high vulnerability, yellow indicates moderate vulnerability, and green indicates low vulnerability. The line demarking the aquifer boundary is differentiated according to the surety of its location, where a solid line indicates a boundary of high certainty and a broken line indicates a boundary of lesser certainty. Additional symbology is defined on the legends as shown on the individual map sheets.

3. Geology of Study Area

The geology of Vancouver Island is the complex product of bedrock terrane accretion and glacial modification of the landscape over a period of more than 250 million years. The surficial and bedrock geology of the southern Vancouver Island is summarized below, focusing on the surficial deposits and bedrock units that comprise aquifers delineated within the CRD.

3.1 Surficial geology of the study area

Surficial unconsolidated sediments of the study area are products of a series of glacial and interglacial periods that extensively modified regional topography and stratigraphy during the last 20,000 years. To begin, the glacial history of the region is described briefly. The major surficial deposits comprising aquifers and confining layers in the study area are then discussed in the following sections, from the youngest to the oldest unit.

3.1.1 A Brief Glacial History of Vancouver Island

The processes and products of the glacial history of southern Vancouver Island has been described extensively by Halstead (1968), Clague (1976, 1977, 1981), and Alley and Chatwin (1979). Additional information on type sections and exemplary strata within southwestern B.C. have been compiled by Howes and Nasmith (1983), Blyth and Hebda (1993), Bobrowsky and Clague (1995), and Yorath and Nasmith (1995).

The Quaternary Period, beginning approximately two million years BP[2] and continuing to the present day, has been marked by the advance and retreat of continental glaciers. During the Quaternary Period three major glacial phases occurred, interrupted by three interglacial periods in which fringes of surviving animal and plant life repopulated the exposed landscape in warming areas (Orr and Orr, 1996). The maximum extent of ice advance over western North America occurred approximately 15,000 y BP, during the most recent glaciation period—the Fraser Glaciation—when ice lobes up to 1520 m in thickness extended into Puget Sound, the Okanagan interior of British Columbia and over parts of Northern Washington and Idaho (Bobrowsky and Clague, 1995; Clague, 1977).

Southern Vancouver Island is thought to have been free of ice by roughly 13,000 years ago (Blyth and Rutter, 1993a). Isostatic depression of land masses from the weight of overriding glaciers, and eustatic variations in global oceanic volumes due to glacial growth and retreat caused up to 50 to 100 m variation in sea level within the Victoria area during glacial and interglacial periods. Sea levels reached present levels approximately 11,700 y BP, were lowered by up to 4 m in the period from 9,250 to 5,000 y BP, and have remained relatively constant over the past 5,000 years (Bobrowsky and Clague, 1995; Howes and Nasmith, 1983, Clague, 1977).

On Vancouver Island little exposed evidence remains of glacial events occurring prior to the most recent Fraser Glaciation between 25,000 to 10,000 years BP (Bobrowsky and Clague, 1995). The Fraser glaciation is further divided into three periods of glacial advancement, the Evans Creek Stade, followed by the Vashon Stade and the Sumas Stade (Halstead, 1968). Figure 1 below shows the major periods just prior to and during the Fraser Glaciation, and the primary sedimentary strata produced during each glacial and interglacial phase. These surficial deposits from the Fraser Glaciation to present are the most

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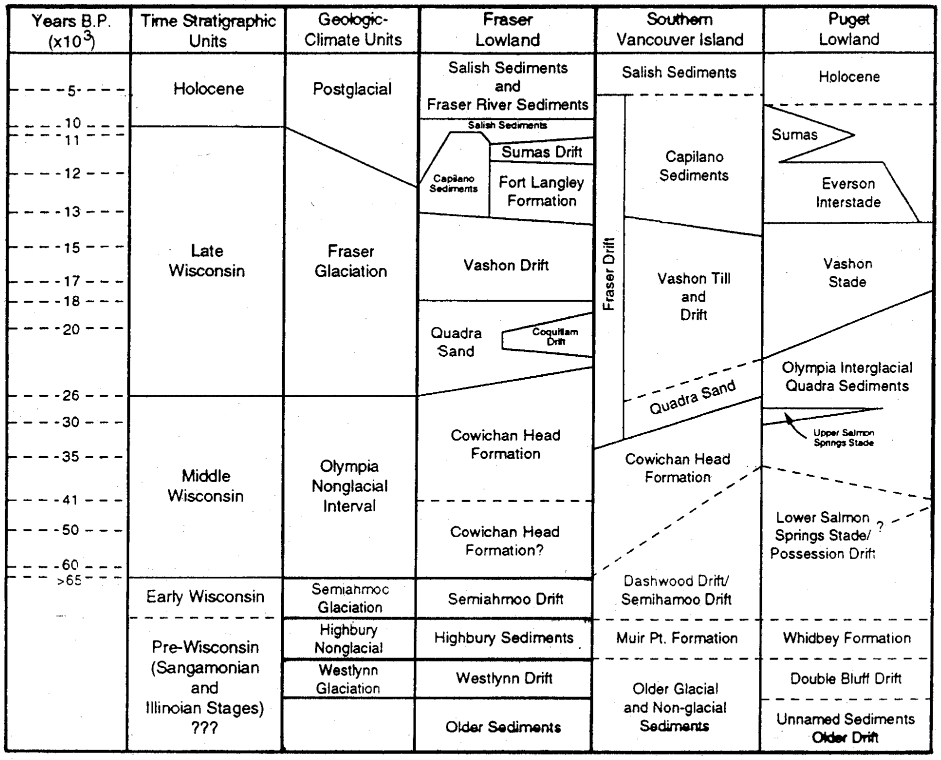
[2] BP means "before present".

important in controlling the occurrence of surficial aquifers in the CRD area and are discussed below, in order from youngest to oldest.

Figure 1: Major glacial and interglacial periods of the late Quaternary in the North American Pacific Northwest and associated sedimentary deposits (Compiled by Bobrowsky and Clague, 1995).



3.1.2 Salish Sediments

Salish Sediments were deposited during the interglacial interval following the conclusion of the Fraser Glaciation up until present day. These include river sediments, organic lake, wetland and estuarine deposits at lower elevations, and colluvial deposits on the peaks and ridges at higher elevation (greater than 90 m). Salish sediments such as clay may form aquitards or confining layers, but are commonly too shallow to comprise significant aquifers. An exception is aquifers 684 and 685 that are comprised of fluvial sands and gravels believed to be partly of Holocene origin (≤10,000 y BP).

3.1.3 Capilano Sediments

Capilano Sediments were formed during a period of gradual warming that began near the conclusion of the Fraser Glaciation. The sediments consist mainly of sand, gravel and silt, deposited by outwashing melt–water from glaciers receding in the coastal lowlands. In the CRD, the Capilano Sediments are represented most distinctively at the Colwood delta, a glaciofluvial sand and gravel deposit, delineated as aquifer 682, that historically covered an area of approximately 29 km^2 within the municipalities of Metchosin, Langford, Colwood and View Royal (Blyth and Levson, 1993). The Colwood Delta was initially formed near the close of Fraser period (c. 14,500 YBP) when glaciers still covered much of mainland B.C. and Vancouver Island and meltwater from glaciers in Saanich Inlet drained southeast through the Goldstream River valley and toward the Juan de Fuca Strait, transporting reworked glacial sediments in the process (Geological Survey of Canada, 2004; Yorath and Nasmith, 1995; Blyth and Levson, 1993). The deposit is made up of hanging melt water channels, terraced glaciofluvial outwash up to 20 m thick, including coarsening upward layers of sand and gravel interrupted by lenses or layers of silt or clay. The strength and direction of paleocurrent flow within the multiple channels of the delta was dictated by topographic boundaries and stagnant ice masses thought to have been present in the Esquimalt Lagoon, Langford Lake and Glen Lake areas at this time (Yorath and Nasmith, 1995). At its maximum extent the delta prograded southeast into the Juan de Fuca Strait extending up to 40 m below present sea level (Bobrowsky and Clague, 1995). With the warming and melting of the ice sheets isostatic rebound caused a rise in relative sea levels which is believed to have resulted in a northward diversion of flow in the rivers forming the Colwood Delta toward the Goldstream River which drained into Finlayson Arm (Bobrowsky and Clague, 1995). The Colwood Delta deposit has been mined as an aggregate source at the Metchosin gravel pit, operated by Construction Aggregates Ltd., on Metchosin Rd, southwest of Esquimalt Lagoon, and at now abandoned gravel pits at Royal Roads, south of Langford Lake (off Leigh Road), and north of Langford Lake (southeast of Lakehurst Drive) (Province of BC, 1987; Blyth and Levson, 1993). Erosion of the Colwood Delta by marine longshore currents has contributed to the formation of coastal sedimentary landforms, such as the Coburg Peninsula, the barrier spit at Esquimalt Lagoon (Yorath and Nasmith, 1995).

Silts of the Capilano sediments comprise the parent material of soils in the most productive farmlands of the Capital Region (Yorath and Nasmith, 1995). Coarse-textured sand and gravel Capilano sediments typically form aquifers. Aquifer 599 is thought to be comprised of Capilano Sediments deposited along the margin of the Sooke River and extending to the lower slopes of Broom Hill, Bluff Mountain and adjacent uplands.

Victoria Clay is a fine-grained clay and silty till facies of the Capilano sediments that is found over much of the study area at elevations generally <60 m, notable for its contribution to the hydrologic confinement of lower sedimentary and bedrock strata. The Victoria clay, classified as brown or grey clay according to the degree of permanent saturation, can reach thicknesses of up to 20 m or greater locally, but is generally < 10 m thick, with varying thicknesses of grey and brown facies (Monahan and Levson, 2000). The presence of Victoria Clay is expected to reduce the rate of infiltration of water from surficial layers, thereby providing a measure of protection of the underlying materials from any pollutants introduced at the surface.

3.1.4 Vashon Till

The Vashon till is a sandy and gravely clay till unit that was deposited by glaciers during the maximum extent of advance during the Fraser Glaciation. The formation of the unit has been dated as later than 17,000 ± 170 years in the Victoria area. The Vashon till is significant to the hydrogeology of the study area as a confining layer of significant thickness and wide distribution over lowlands of the southern Vancouver Island Region. In the CRD area, this till is largely absent from upland areas greater than 90 m in elevation (Blyth and Rutter, 1993a).

3.1.5 Quadra Formation

The Quadra Formation comprises well-sorted, fine to coarse sand and gravel up to 30m in thickness. This deposit was formed 22,600 ± 300 years ago during the onset of the Fraser Glaciation as lobes of the Cordilleran Ice-sheet advanced slowly down the Strait of Georgia (Clague, 1977). The sand was deposited within the channels and marginal flood-plains of braided melt water streams and estuarine deltas along the maritime coast (Bobrowsky and Clague, 1995). The Quadra Formation is generally confined to elevations below 100 m, and overlies the Cowichan Head formation regionally, occurring above bedrock and glaciomarine sediments in areas where the latter unit has been eroded to a greater extent. Silt and clay lenses are also present at intervals within the sand and gravel layers as indicated in well logs and research literature (Clague, 1977).

The Saanichton Gravel, a coarse upper facies of the Quadra Formation, has been an aggregate source extracted commercially on southern Vancouver Island. The Trio gravel pit and Saanich municipal gravel pit in Cordova Bay, and the Central Saanich municipal yard and Butler Brothers gravel pit in the Keating area all extract sand and gravel of the Quadra Formation (Yorath & Nasmith, 1995).

The Quadra Formation represents the most productive water-bearing sediments encountered within the study area, and is found within all of the higher water yielding unconsolidated aquifers on the Saanich Peninsula and in Victoria (e.g. aquifers 609, 610, 611, 612, 613, 616, 617 and 686). The Quadra Formation also comprises aquifers 604 and 605 in the Sooke area.

3.1.6 Cowichan Head Formation

The Cowichan Head Formation is a thick deposit of glaciofluvial sand, gravel, silt and peat produced from outwash of the retreating Cordilleran Ice Sheet and deposited within the coastal shores, channels and floodplains of southern B.C. during the Olympia Interglacial Interval prior to the onset of Fraser Glaciation (Orr and Orr, 1996; Bobrowsky and Clague, 1995; Yorath and Nasmith, 1995). The type section of this unit is found on the east coast of the Saanich Peninsula, at the south end of Island View Beach. Radiocarbon dating of the Cowichan Head Formation indicates a range of sediment ages from 23,800 to 58,800 y BP (Clague, 1977). Aquifer 615 at Cowichan Head was named for this unit, which is encountered at the basal core of the drumlin ridge that comprises the aquifer. Gravel occurring below thicker deposits of sand within aquifers 611, 612, and 613 (Hagan, Keating and Durrance) is also thought to be the coarse upper facies of the Cowichan Head Formation. Thick deposits of sand and oxidized gravel that form aquifer 683 at Parry Bay were likely deposited around the same period as sediments in the Cowichan Head Formation, approximately 40,000 ± 2800 y BP, based on radiocarbon dating of organic wood debris near the centre of Parry Bay section (Blyth and Hebda, 1993).

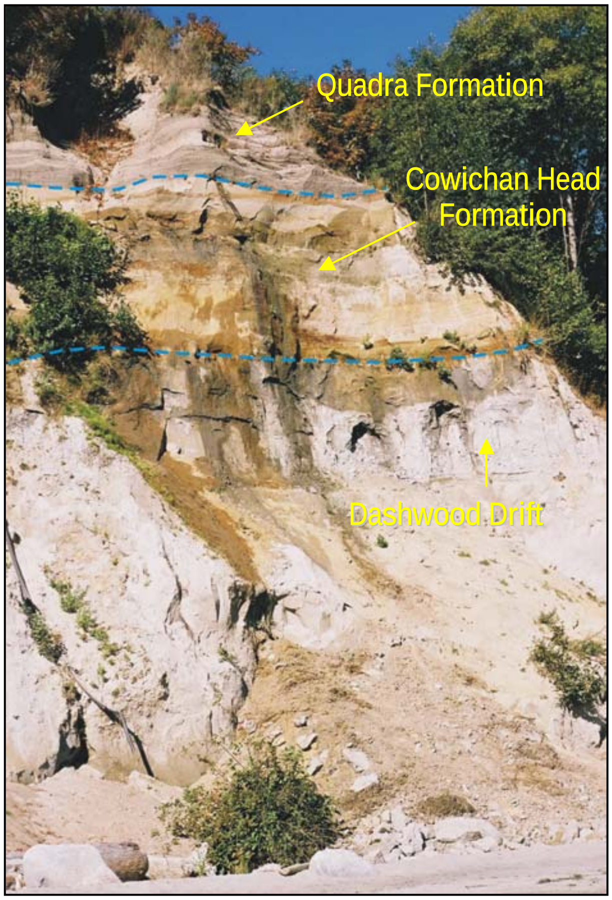


Photo 1: Coastal bluff at Island View Beach, showing (from top of section) the Quadra Formation, the Cowichan Head Formation and Dashwood Drift; dashed line marks the contact between units. Groundwater can be seen seeping from the cliff at the top of the Dashwood Drift, likely due to the low permeability of the unit which is comprised of fine sand, silt and clay.

3.1.7 Earlier Pleistocene Deposits

Below the Cowichan Head Formation are till, silt and silty sands of the Dashwood Drift (southern Vancouver Island) and Semiahmoo Drift (Fraser Lowland). These sediments are poorly represented except in isolated areas, as they were largely removed by subsequent glacial activity. Although the Dashwood and Semiahmoo Drifts are beyond the range of effective radiocarbon dating techniques, their age has been estimated at 65,000 to 80,000 y BP. Below these till deposits are found the Mapleguard Sediments and the Muir Point Formation (Bobrowsky and Clague, 1995).

The Muir Point Formation is a silt, sand, gravel and till unit that underlies the Dashwood Drift in the coastal area west of Sooke Harbour, where its type section is found. The Muir Point Formation is more than 30 m thickness at its maximum and is the result of colluvial and alluvial deposition in the coastal floodplain (Bobrowsky and Clague, 1995). None of the aquifers classified within the Capital Region are believed to be formed from older sediments of the Dashwood Drift and Muir Point Formation. Erosion from subsequent glacial activity are thought to have minimized their thickness and occurrence within the study area. Additionally, as the Muir Point Formation occurs in the stratigraphic profile below at least two significant till bodies, infiltration of water from the surface to the sediments at depth may be minimized, so as to reduce its potential as a water-bearing unit.

3.2 Bedrock geology of study area

The geology of Vancouver Island reflects a diversity of bedrock types and ages juxtaposed through the process terrane accretion along the margin between the North American and Pacific tectonic plates. The bedrock lithology of southern Vancouver Island has been described in detail within the early work of Clapp (1917), Muller (1980), and more recently, Yorath and Nasmith (1995). The known distribution of the major bedrock formations has been modified through subsequent investigations, with the most recent mapped data provided by Massey (1994). The major bedrock types encountered within the study area (in Sooke and Saanich Peninsula) and delineated as aquifers are described below in order of increasing age. The bracketed abbreviations are the symbols used to label the major units on the accompanying Map 2.

3.2.1 Sooke Formation (Tc)

The Sooke Formation is a sedimentary bedrock unit found within the Sooke area (Map 3). The Sooke Formation was formed 23 to 37 My BP[3] and is comprised of cross-bedded sandstone, interbedded with lesser amounts of siltstone, and conglomerate containing cemented pebble to boulder sized clasts (Massey, 1994; Yorath and Nasmith, 1995). Formed as near shore sedimentary deposits eroded from volcanic Metchosin meta-basalts and gabbro (described below), the Sooke Formation also contains fossilized remnants of mollusc shells which have been used to establish the chronology of its formation. The sandstone unit is found in several non-contiguous basins of 0.74 to 33 km^2 in area and strike parallel to the shoreline and dip shallowly to southwest at an average angle of 2 to 3°. The Sooke Formation unconformably overlies volcanic bedrock of the Metchosin Igneous Complex at elevations below 100 m; other isolated deposits occur up to 300 m above sea level on the flanks of mountainous ridges of the Vancouver Island Range (Massey, 1994; Clapp, 1917).

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[3] My BP means “mega-years before present” or 1,000,000 years ago.

Map 2: Bedrock geology of Southern Vancouver Island

The largest deposit of the Sooke Formation is found at Muir Creek and has been delineated as bedrock Aquifer 449. The smaller deposits have not been delineated as aquifers as they are not known to have been developed to date through the construction of water wells. In comparison to igneous and metamorphic bedrock units of the region, the Sooke Formation is expected to have a higher permeability, in part due toits inherent friability and heterogeneous cementation as indicated within well log descriptions. The sandstone and conglomerate is cemented by calcite and limonite, which may contribute to hardness in water obtained from wells in this area. Secondary porosity of the unit may be found in fracturing, observed as normal faults that strike at right angles to the shoreline (Clapp, 1917).

3.2.2 Metchosin Igneous Complex (Em)

The Metchosin Igneous Complex is a volcanic unit that comprises the majority of the bedrock underlying Sooke, Metchosin, and Colwood (Yorath and Nasmith, 1995). The Complex is a grouping of intrusive and extrusive volcanic units formed during the Paleocene to Eocene Epochs (50 – 56 Ma), including coarse crystalline gabbro, diabase, and fine-grained basaltic dykes, pillow and flow formations (Map 2). Also included within the complex are tuff, rare limestone and minor breccia. The northern contact between bedrock of the Metchosin Igneous Complex and adjacent bedrock is the Leech River Fault found 7 to 24 km inland from the coast (Massey, 1994). Structurally the Metchosin Igneous Complex appears as a series of conformably interbedded coarse to fine crystalline green igneous layers with average strike to the northwest and a dip from 15 to 30°, that approaches vertical orientation in some locations (Clapp, 1917).

Though the bedrock map separates the Metchosin Igneous Complex into subcategories reflecting the major constituent (e.g. Em1, Em1a, Em2, Em3, and Em4), it was considered as a single entity for the purposes of aquifer mapping in this area, due in part to the difficulty of discerning between the different rock types using available well logs, and due to the inferred similarity in hydrogeologic properties of the predominantly basaltic to gabbroic unit (Massey, 1994; Muller, 1980). Aquifers 606 is comprised of igneous bedrock from this complex.

3.2.3 Nanaimo Group (uK_N)

The Nanaimo Group is a distinct grouping of sedimentary bedrock that is found on many of the southern Gulf Islands and in the study area, at the northern end of the Saanich Peninsula (Map 2). The Nanaimo Group was formed during 85 My ago as sand, gravel and silt was carried by rivers, and deposited in a broad oceanic basin in the Georgia Strait and along the east coast of Vancouver Island (Yorath and Nasmith, 1995). The unit has been consolidated, uptilted and folded, and today, appears as interbedded layers of conglomerate, sandstone, siltstone, shale, and coal (Massey, 1994).

The Nanaimo Group has been subdivided into nine formations, two of which, the Comox Formation and the Haslam Formation, occur on the Saanich Peninsula. The Comox Formation is the oldest unit in the Nanaimo Group and is comprised of interbedded sandstones and minor shales found in North Saanich, beginning in the area around Deep Cove. Closest to the coast, on the beaches off Colburne Passage, is found the Haslam Formation, a predominantly shale unit. At Armstrong Point the sedimentary bedding has a strike of 150° and a dip from 65 to 70° west, with sets of vertical joints crossing the layers at angles trending 120 and 140° (Yorath & Nasmith, 1995). The weak sedimentary bedrock of the Nanaimo Group has been extensively fractured by tectonic uplift and folding. This may result in greater secondary porosity (i.e., fractures) within the unit, and potentially higher connectivity within the fracture system; consequently wells in the Nanaimo Group may have higher yields, in comparison to those wells completed in more massive, less fractured bedrock. The quality of water from the Nanaimo Group sediments may be affected by concentrations of iron, and other mineral weathering products as indicated within well records. Aquifer 607 at the northern tip of the Saanich Peninsula is made up of sedimentary bedrock of the Nanaimo Group.

3.2.4 Leech River Complex (JKls, JKlv)

The Leech River Complex is a metamorphic bedrock, composed of two principal rock types: a primarily metasedimentary group (JKls) that includes slate, phyllite, quartz-biotite schist, quartz-feldspar-garnet-biotite schist, metagreywacke, meta-arkose sandstone, and interbedded volcanics; and a primarily metavolcanic group (JKlv) that includes metabasalt, metarhyolite, chlorite schist, ribbon chert and cherty argillite (Massey, 1994). The Leech River Complex is part of the Pacific Rim Terrane, formed during the Jurassic to Cretaceous Period (206 – 65 My BP) from terrestrial sediments and volcanic deposits that accumulated in subaqueous continental slope environment (Yorath and Nasmith, 1995). The rock underwent metamorphosis approximately 85 My BP and was accreted upon the margin of the Wrangellia Terrane approximately 50 My BP, becoming further folded and compressed during the accretion of the Crescent Terrane approximately 23 Ma later (Yorath and Nasmith, 1995). In the study area, the Leech River Complex is an arched belt that extends from Port San Juan, on Vancouver Island's west coast, becoming thinner toward the Langford area, with paired 1.5 km wide bands of the unit occurring along the west and east sides of Finlayson Arm, Saanich Inlet. The metamorphic complex is bounded on the north and east by the San Juan-Survey Mountain Fault and to the south by the Leech River Fault, where it is contact with younger Metchosin Igneous Complex (Crescent Terrane - Map 2)(Massey, 1994; Yorath and Nasmith, 1995). Metavolcanic rock of the Leech River Complex (JKlv) has been included as a part of aquifer 680; while the metasedimentary unit makes up aquifer 618 at Port Renfrew.

3.2.5 Island Plutonic Suite (JI)

The Island Plutonic Suite is comprised of granitic bedrock that is the dominant rock type found on the central Saanich Peninsula (Map 2). Formed 170 – 185 Ma ago, this unit contains granodiorite, quartz diorite, quartz monzonite, diorite, amatite, feldspar porphyry with minor gabbro and aplite (Massey, 1994; Yorath & Nasmith, 1995). This unit underlies much of the Saanich Peninsula as the Saanich granodiorite, composed of light coloured quartz and feldspar, speckled with dark inclusions of mica flakes and hornblende phenocrysts. Prominent faults in the unit have a strike between 10 and 35°, with a steep eastward dip (Yorath and Nasmith, 1995). The Island Intrusions comprise aquifer 608, one of the largest and more heavily developed of the aquifers in the study area.

3.2.6 Bonanza Group (lJBv)

The Bonanza group is a volcanic bedrock unit composed of basalt and andesite flows, rhyolite, breccia, green and maroon volcanic tuff, feldspar crystal tuff, and tuffaceous sandstone, argillite, pebble conglomerate and minor limestone (Massey, 1994). The Bonanza group was formed during the Lower Jurassic period (202 – 190 My BP) from subaerially erupted lava, volcanic and shallow marine sediments (Massey, 1994; Yorath and Nasmith, 1995). In the Victoria area, the Bonanza Group is found at Willis Point, along the southwestern and northeastern shores of Tod Inlet, at Cole Hill and the Partridge Hills. The volcanic unit forms a triangular wedge at the east side of Squally Reach, in the Saanich Inlet, that extends inland to the west of Wallace Drive, where it contacts the Karmutsen Formation, and to north of Willis Point Road, where it is in contact with the gneissic Wark-Colquitz Complex (Massey, 1994). Bedrock of the Bonanza group has been delineated as aquifer 681.

3.2.7 Wark-Colquitz Complex (West Coast Crystalline Complex)(PMw)

The Wark-Colquitz Complex is a metamorphic bedrock that includes quartz diorite, tonalite, hornblende-plagioclase gneiss, quartz-feldspar gneiss, amphibolite, diorite, agmatite, gabbro, marble and metasediments (Massey, 1994). Formed approximately 200 My BP during the Paleozoic to Jurassic Periods, the Wark-Colquitz complex is found on the southern Saanich Peninsula, comprising aquifer 680 which extends from Elk Lake south to the coast in the Victoria and Oak Bay area, southeast over much of Colwood, and as far west as Squally Reach, in the Saanich Inlet. On the east side of Saanich/Victoria the Wark-Colquitz Complex is made up mainly of the Colquitz gneiss, a quartz-rich gneiss containing irregular dark Wark gneiss bands. On the mid to west side of the Victoria area, in Colquitz and the District of Highlands the unit is mainly made up of the Wark gneiss, a mafic, more massive, hornblende-rich metamorphic rock formed from an igneous dioritic and volcanic protolith (see Photo 2) (Yorath and Nasmith, 1995; Muller, 1980). The Wark-Colquitz complex is separated from the meta-volcanic rocks of the Leech River Complex to the west by the San Juan-Survey Mountain Fault, in the area of Florence Lake and Mt. Finlayson (Yorath and Nasmith, 1995).

Photo 2: Bedrock fractures, such as these shown in Wark-Colquitz gneiss at Lone Tree Hill, provide a pathway for groundwater movement through rock (outcrop height approximately 2.5 m).

3.2.8 Karmutsen Formation and Quatsino Formation (uTrk, uTrq)

The Karmutsen Formation was formed 221 to 227 Ma ago and is described by Massey (1994) as pillow basalt, breccia, tuff, amygdaloidal flows and interflow sediment with grey lenses of limestone. The Karmutsen is widespread, forming the thick deposits in many parts of Vancouver Island. Within the study area it occurs as an approximately 2 km wide band that trends northwest across the Saanich Peninsula from Cordova Bay to Brentwood Bay (Map 2). The joints and fractures of the Karmutsen have been infilled by mineralized quartz, feldspar, calcite and epidote, with metallic sulphides such as pyrite occurring locally (Clapp, 1918). Also part of the Vancouver Group, and associated with the Karmutsen Formation, is the Quatsino Formation, a limestone and calcareous siltstone sedimentary bedrock formed during the same period, that appears as smaller local deposits, mined historically in the Brentwood and Bamberton areas (Yorath and Nasmith, 1995; Clapp, 1918). The Karmutsen and Quatsino Formations have been grouped and delineated as aquifer 614; the formations were not delineated as separate aquifers as there were only a few wells known to have intercepted limestone, and due to the difficulty of discerning between the bedrock types in this area using available information. To the north of the Karmutsen volcanics is found the granitic bedrock of the Island Plutonic Suite; while metamorphic gneiss of the Wark-Colquitz Complex, is found to the south, and volcanics of the Bonanza Group are found to the west (refer to Map 2).

3.3 General Hydrogeologic Characteristics of Surficial and Bedrock Units in the CRD

The water bearing properties of unconsolidated in comparison to bedrock units is largely a function of differences in way that water is stored within and transmitted through them. *Porosity* is defined as the ratio of the volume of air spaces within a unit in comparison to the total volume of materials present, while *permeability* is the ease with which water can be transmitted through these pore spaces (Freeze and Cherry, 1979).

Unconsolidated sediments store and transmit water within primary porosity or pore spaces between sediment grains; in comparison within bedrock water occurs within secondary porosity, along joints, fractures and fault planes. Coarse-textured surficial deposits such as sand and gravel are typically permeable and may yield large quantities of water to wells. Conversely, fine-textured surficial deposits such as clay and silt are not very permeable and do not yield large quantities of water to wells. Bedrock aquifers are also capable of yielding large quantities in areas where the strata are highly fractured, or where there is a high degree of connectedness between the fractures (Johanson, 1981). The presence of fine particles, such as silt, or dissolved solutes that may precipitate and solidify within fractures can also reduce the permeability of bedrock units.

Recharge to both sand and gravel as well as fractured bedrock aquifers in the CRD is thought to be from infiltration of precipitation falling on the land above the aquifer. Kohut, *et al*. (1984) analyzed ten years of data from observation wells in the granitic bedrock aquifer in central Saanich Peninsula (Aquifer 608) and demonstrated a correlation between the groundwater levels within bedrock wells and seasonal precipitation. Groundwater levels were found to reach a minimum in the months of October to December, while maximum levels were observed during the months of December to April. Seasonal recharge of the aquifer (indicated by a rise in the groundwater levels) occurred in early winter with the arrival of winter rains. Changes in the amount and timing of recharge could even be correlated with specific storm events. The study further demonstrated that available recharge was limited primarily by the hydraulic conductivity of bedrock fractures and the storage capacity of the bedrock fracture system, rather than by absolute amounts of precipitation.

Another prior study of the water balance of a sand and gravel aquifer (aquifer 609) in the Saanich Peninsula also confirmed that precipitation is the main source of recharge, with a two month lag time occurring between peak precipitation and the peak of the monitoring well hydrograph representing the time required for infiltration of surface water through surficial confining sediments (Porter, 1980). Hydrographs from Provincial Observation Wells in other aquifers in the CRD suggest the source of seasonal recharge to those aquifers is the same (i.e., from precipitation).

Groundwater recharge areas typically are located at upland areas; while groundwater discharge areas are located in valleys, and at the toe of slopes. This characteristic is inferred from water level elevations in wells reported in the WELL database.

The major surficial and bedrock units found in the CRD and presented in the previous sections are summarized in Table 4. Also described in Table 4 is whether these units generally form aquifers or aquitards in the CRD.

Table 4: Hydrogeologic properties and lithologies of geological units in the CRD

Geological Unit (from youngest to oldest)	Major lithologies in the CRD	Aquifer or aquitard in the CRD?
Salish Sediments	Sand, gravel, silt and clay (depends on the depositional environment)	Very shallow aquifers such as those made of fluvial deposits, or can form part of aquitards
Capilano Sediments	Sand and gravel; clay and silt	Can be either aquifers or aquitards, depending on lithology
Vashon Till	Till	Generally aquitards
Quadra Formation (including Saanichton Gravel)	Sand; sand and gravel	Generally aquifers
Cowichan Head Formation	Sand and gravel	Generally aquifers
Earlier Pleistocene deposits	Sand, gravel, till, silt	Deep, not well explored in the CRD
Sooke Formation	Sandstone, siltstone, conglomerate	Generally aquifers
Metchosin Igneous Complex	Volcanic rock	Low yielding aquifers
Nanaimo Group	Siltstone and sandstone	Aquifer
Leech River Complex	Sedimentary to metasedimentary rock	Aquifer
Island Plutonic Suite	Granitic rock	Aquifer
Wark-Colquitz Complex	Metamorphic rock	Aquifer
Karmutsen Formation	Volcanic rock	Aquifer
Quatsino Formation	Sedimentary rock	Aquifer

4. Aquifers within the Capital Regional District

A total of twenty-four aquifers were identified within the study area, including sixteen aquifers comprised of unconsolidated sediments and eight bedrock aquifers. The median well depth of aquifers in the CRD is illustrated in Figure 2; the median estimated well yield of aquifers is shown in Figure 3. The geologic unit, classification and ranking value of each are summarized in Table 5. The overall characteristics and properties of each aquifer are subsequently described in greater detail, beginning with the aquifers found within the Sooke, Western Communities and outlying areas and continuing with aquifers on the Saanich Peninsula and in Victoria.

Unless stated otherwise, there was generally insufficient data to confirm the direction of groundwater flow, or quantify aquifer properties such as specific capacity and transmissivity. Additionally, Vulnerability indices such as the Aquifer Vulnerability Index (Van Stempvoort, *et al*., 1993) or DRASTIC (Aller, *et al*., 1987) were not used to evaluate individual well or aquifer vulnerability. A complete summary of statistics for all of the aquifers is included within Appendix A.

Figure 2: Median well depth of aquifers in the CRD

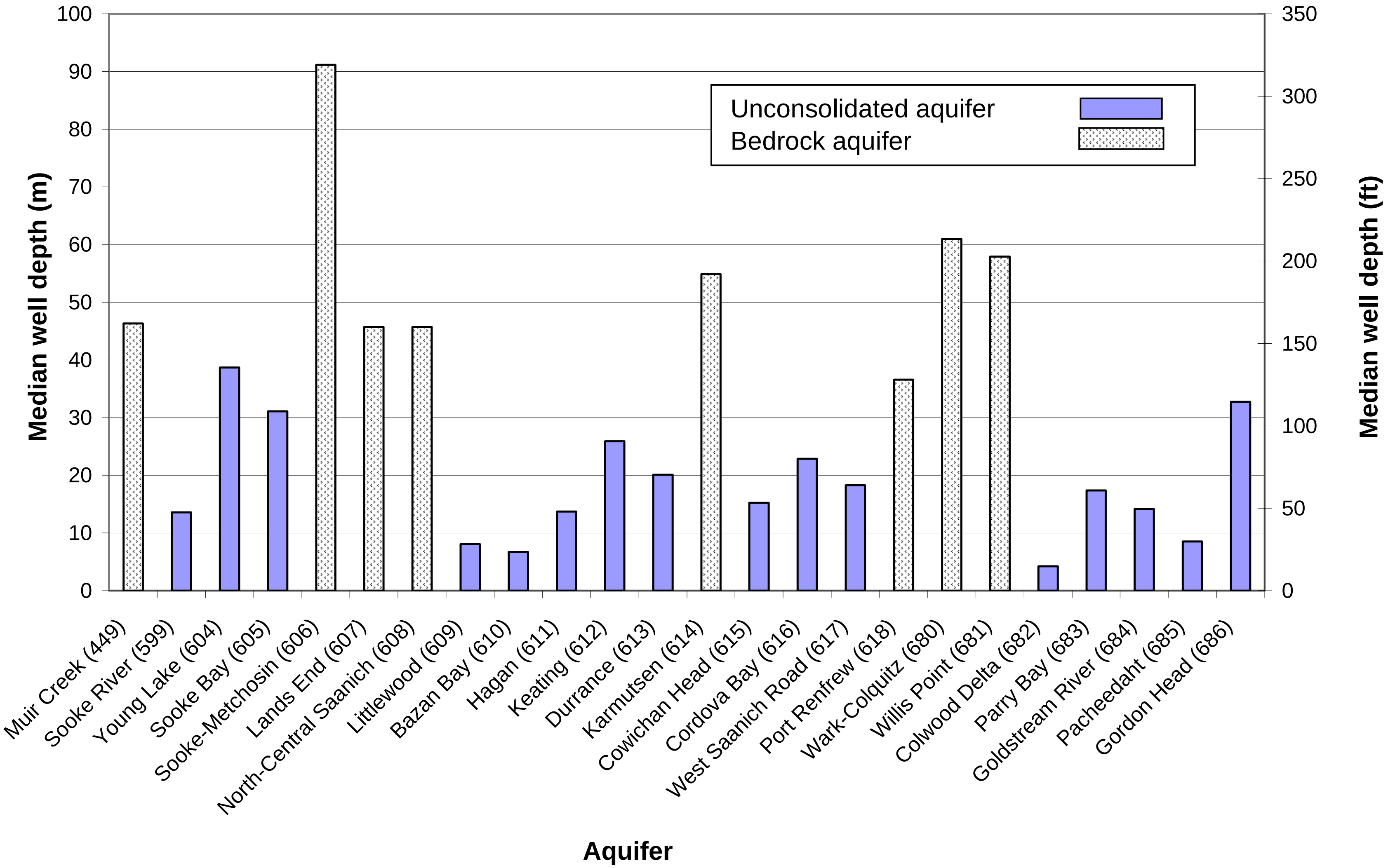


Figure 3: Median estimated well yield of aquifers in the CRD

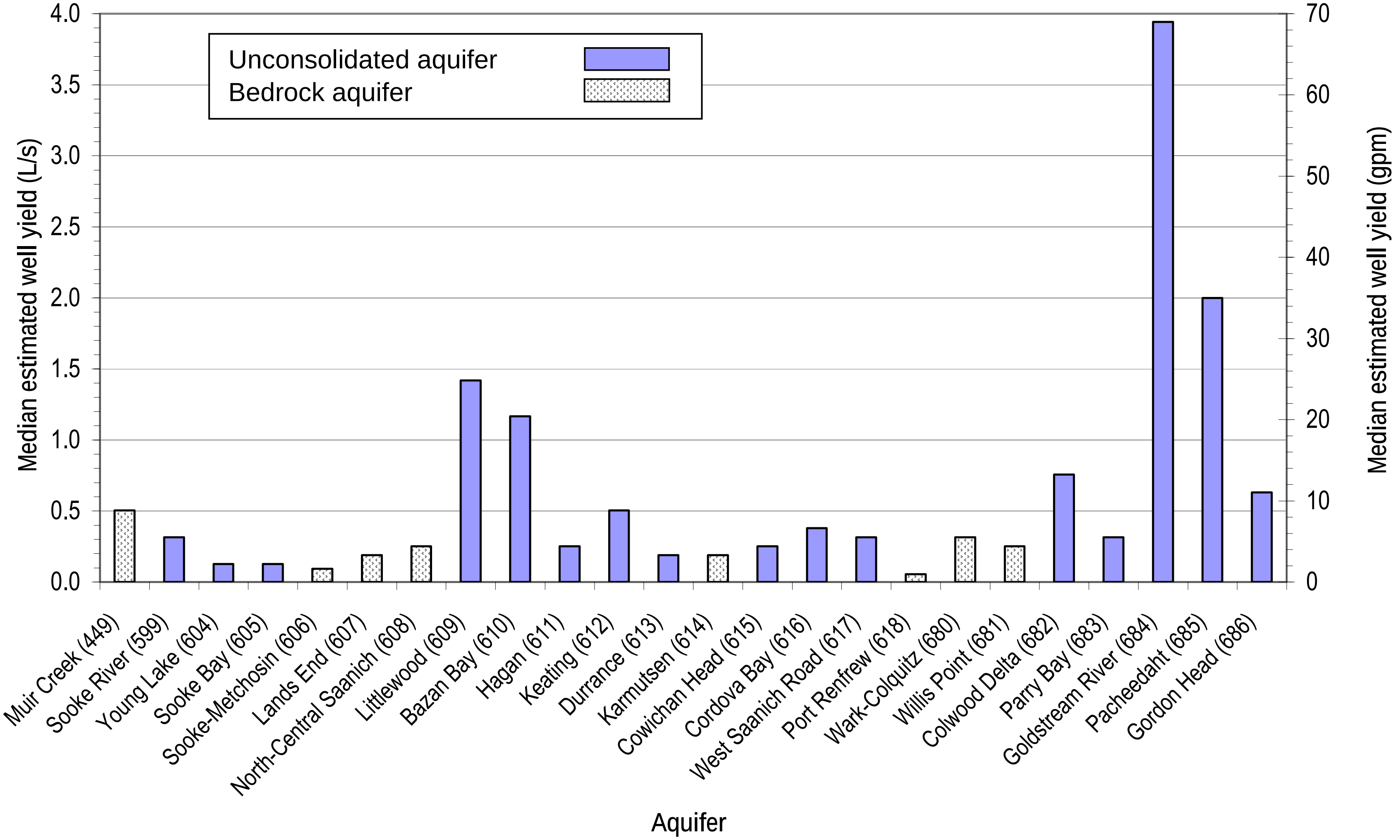


Table 5: CRD aquifer name, lithology, development, vulnerability and ranking value

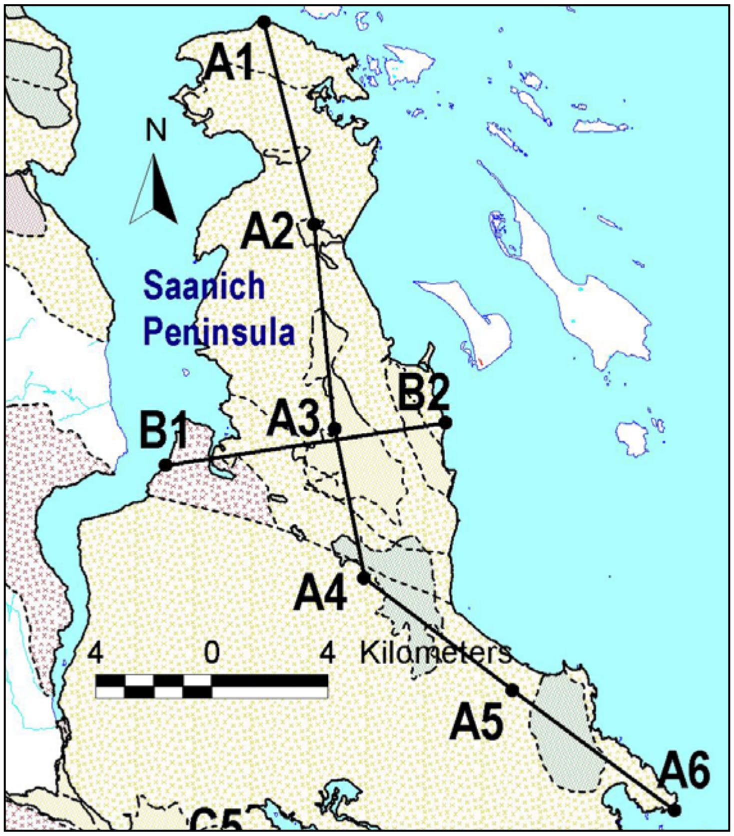
Aquifer Number	Aquifer Name	Inferred Geological Unit	Confined/ Unconfined	Area (km^2)	Number of Wells	Level of Development	Level of Vulnerability	Ranking Value
449	Muir Creek	Sooke Formation	Partially confined	28	18	III	C	10
599	Sooke River	Capilano Sediments	Partially confined	19	20	III	A	11
604	Young Lake	Saanichton Gravel Quadra Formation	Confined	2.0	7	III	C	6
605	Sooke Bay	Saanichton Gravel Quadra Formation	Confined	0.13	3	III	C	6
606	Sooke-Metchosin	Metchosin Igneous Complex	Partially confined	538	632	III	A	12
607	Lands End	Nanaimo Group	Partially confined	9.1	285	III	B	8
608	North-Central Saanich	Island Plutonic Suite	Partially confined	81	1383	II	B	13
609	Littlewood	Quadra Formation	Partially confined	0.55	12	III	B	7
610	Bazan Bay	Quadra Formation	Partially confined	1.0	49	II	B	9
611	Hagan	Quadra Formation, Cowichan Head Formation	Partially confined	2.1	31	II	B	8
612	Keating	Quadra Formation, Cowichan Head Formation	Partially confined	8.5	109	II	B	9
613	Durrance	Quadra Formation, Cowichan Head Formation	Partially confined	0.093	7	II	C	7

Aquifer Number	Aquifer Name	Inferred Geological Unit	Confined/ Unconfined	Area (km^2)	Number of Wells	Level of Development	Level of Vulnerability	Ranking Value
Table 5 (continued)								
614	Karmutsen	Karmutsen Formation	Partially confined	16	216	III	B	7
615	Cowichan Head	Quadra Formation, Cowichan Head Formation	Partially confined	3.4	15	III	B	8
616	Cordova Bay	Quadra Formation	Partially confined	7.8	31	II	C	11
617	West Saanich Rd	Quadra Formation	Confined	0.11	5	II	C	7
618	Port Renfrew	Leech River Formation	Confined	5.8	12	III	C	8
680	Wark-Colquitz	Wark-Colquitz Complex	Partially confined	209	1051	II	B	12
681	Willis Point	Bonanza Group	Partially confined	7.9	165	II	A	10
682	Colwood Delta	Colwood Delta Formation, Cowichan Head Formation	Partially confined	24	34	III	B	11
683	Parry Bay	Cowichan Head Formation, Quadra Formation	Confined	8.9	24	III	C	8
684	Goldstream River	Capilano and Salish sediments	Unconfined	0.25	2	III	A	10
685	Pacheedaht	Capilano and Salish sediments	Unconfined	41	7	III	A	13
686	Gordon Head	Quadra Formation	Partially confined	7.3	8	III	C	7

4.1 Saanich Peninsula and Victoria

Within the Saanich Peninsula and Victoria area a total of fourteen aquifers were identified, five of them consisting of bedrock, and the remaining nine composed of unconsolidated sediments. These aquifers are discussed in greater detail below. Appendix B contains a series of hydrogeologic cross-sections of the Saanich Peninsula. Cross-section A is a longitudinal section (A_1-A_6), 32.6 km in length, in five sub-sections that transverses the Saanich Peninsula from its northern tip at Colburn Passage to Ten Mile Point, east of Victoria, intercepting ten of the fourteen aquifers delineated in the Saanich Peninsula and Victoria area. Cross-section B is a latitudinal section (B_1-B_2), 9.9 km in length. It crosses the Saanich Peninsula west to east in the Keating Cross Road area of Central Saanich, illustrating five of the delineated aquifers in this region and the locations of inferred bedrock contacts between the Island Plutonic Suite, the Karmutsen Formation, and the Bonanza Group. The locations of the hydrogeologic cross sections are shown on Map 3. Appendix C contains the Aquifer Classification Maps 1 and 2 showing the boundaries and spatial extent of aquifers delineated in the Saanich Peninsula and Victoria areas.

Map 3: Location of hydrogeologic cross-sections A and B on the Saanich Peninsula with aquifers shown (red=high vulnerability, yellow=moderate vulnerability, and green=low vulnerability)



4.1.1 Aquifer 607: Lands End IIIB (8)

Aquifer 607 is 9.1 km^2 in area and is found at the northern tip of the Saanich Peninsula along the coastal margin from Deep Cove to Tsehum Harbour (see cross-section A_1-A_2 in Appendix B, and Aquifer Classification Map 1 in Appendix C). The aquifer includes Cloake Hill, Horth Hill, the immediately surrounding lowlands, and the east ends of the peninsulas that extend into Tsehum Harbour including Thumb Point, Armstrong Point, Wales Point and Nymph Point.

The aquifer is composed of sandstone, shale, conglomerate and minor siltstone bedrock of the Upper Cretaceous Nanaimo Group. The majority of the aquifer is comprised of interbedded sandstones and minor shales of the Comox Formation, the lowermost unit of the Nanaimo Group. The extreme northern edge of the aquifer adjacent to Colburne Passage comprises the Haslam Formation, a predominantly shale unit.

The aquifer boundary was delineated based predominantly on the spatial occurrence of wells with sandstone and shale lithology, as indicated within well logs, and upon the mapped extent of the Nanaimo group in this area (Massey, 1994, Muller, 1980). The peninsula that branches to form Wales Point and Nymph Point at Tsehum Harbour was also included within the aquifer boundary, despite a lack of well records for this area. The marine shoreline comprises the aquifer boundary between the land and the ocean.

Over the majority of the aquifer area, well logs indicate sandstones and shales either interbedded or in isolation. In Deep Cove the shale and sandstone is underlain by the Island Plutonic Suite that forms aquifer 608. Additionally, according to driller descriptions of well lithology, sandstone and shale occur in wells further south of the delineated boundary for aquifer 607. These wells were excluded from aquifer 607 due to the limited spatial extent of the sandstone or shale occurrences, lack of quality assurance for identification of the bedrock type, and the fact that granitic bedrock appears to be the predominant water-bearing stratum within the wells in question.

The productivity of aquifer 607 is considered low. The median estimated well yield is 0.19 L/s (3.0 gpm)(see Figure 3), ranging from a minimum of 0.0032 L/s (0.05 gpm) to a maximum of 5.0 L/s (80 gpm). The majority of the wells have a low productivity, while 22% have a moderate productivity (0.3- 3.0 L/s or 5-50 gpm). The wells with the greatest yields are found along the base of the southern slopes of Cloake and Horth Hills at elevations of 60 to 100 m. Water is expected to occur in faults, joints and fractures (secondary porosity). The greatest concentration of fractures is found at depths of 15 to 18, 37, and 43 m below the surface (50 to 60, 120 and 140 ft). Pumping tests were completed for two wells on Cloake Hill (Robinson, Roberts and Brown Ltd., 1979).

The water table is shallow. The median depth to water is 3.7 m (12 ft); the minimum water depth is 0.30 m (1.0 ft), while the maximum water depth is 155 m (510 ft) based on 66, or 23% of available well records. The median well depth is 46 m (150 ft)(see Figure 2).

The aquifer is considered moderately vulnerable to anthropogenic surface contaminants. A total of 56% of the wells are overlain by a layer of clay, till, or combinations of both confining materials, ranging in thickness from 0.30 to 33 m (1 to 58 ft), resulting in a median confining layer thickness of 4.3 m (14 ft). These surficial deposits are interpreted as clay from Capilano sediments and Vashon till. For the remaining wells there is either no confining layer or insufficient information to determine if confining materials are present. The overburden appears to be thinnest within the north-eastern quadrant of the aquifer, and thickest in the northwest; the surficial geology map indicates that the upland areas of Horth Hill and Cloake Hill are unconfined and overlain by colluvial bedrock which may increase the aquifer vulnerability locally (Blyth and Rutter, 1993a).

Groundwater from the aquifer is thought to be used predominantly for irrigation and non-potable purposes, as the majority of residences in this suburban area are connected to a municipal drinking water supply (District of North Saanich, 1994).

Although there is a high well density with a total of 285 wells or 31 wells/km^2, the level of groundwater demand is thought to be low, when considering the proportion of wells on record for this area that may be abandoned or not in use at this time. The low apparent usage suggests that the development of the aquifer is low and there is a low reliance on the aquifer for supply.

Groundwater is expected to flow along the general direction of the topographic gradient from the upland areas of Cloake and Horth Hills.

There are no significant water use conflicts reported for the area in the Water Protection Section files. Adjacent to the wetlands along the middle southern border of the aquifer near the corner of Tatlow Road and Heather Road, there was an isolated historical report of a newly constructed well eliminating flow to a nearby natural spring, suggesting possible interference effects between wells. Additionally, some well records indicate low to trace estimated yields.

There are no documented health-related water quality concerns in the Water Protection Section files. Isolated incidences of saline groundwater at concentrations within the Guidelines for Canadian Drinking Water Quality (1996) have been reported for three coastally situated wells, likely caused by salt water intrusion. High iron or manganese concentrations were noted in two wells. The viability of septic sewage disposal for the Cloake Hill subdivision was evaluated in 1983 (Thurber Consultants Ltd.). The high density of septic fields in the area discharging to a relatively shallow overburden was identified as a potential risk to groundwater quality (Foweraker, 1983). However, none of the available data suggest that contamination has occurred. There are no MWLAP observation wells in the aquifer.

4.1.2 Aquifer 608: North-Central Saanich IIB(13)

The North-Central Saanich aquifer encompasses 81 km^2 on the Saanich Peninsula, from south of Tatlow Road in North Saanich, to the northern slopes of Bear Hill north-east of Elk Lake (see cross-sections A_1-A_2, A^2-A^3, A^3-A^4 and B^1-B^2 in Appendix B, and Aquifer Classification Map 1 in Appendix C). The aquifer is bounded to the west by the Saanich Inlet coastline and to the east by the Sidney and Cordova Channels of the Georgia Strait. To the north of the aquifer is found sedimentary shale and sandstone bedrock of the Nanaimo Group, which forms the Lands End aquifer (607). Beyond the southern boundary of the aquifer the bedrock is comprised of basalt, breccia, minor tuff and limestone of the Karmutsen and Quatsino formations, which comprise the Karmutsen aquifer (614). The aquifer is comprised of granitic bedrock, interpreted to be of the Island Plutonic Suite. The aquifer is partially confined by a combined layer of clay and till, and in some cases either till or clay in isolation.

The aquifer boundary was delineated based upon bedrock geology mapping of the region (Massey, 1994), through the recorded occurrence of granitic bedrock within well logs, and field checks of bedrock outcrops within the Central Saanich area. The interpretation of well logs was hampered by incomplete descriptions of bedrock lithology in some cases, and a lack of discernable difference between the estimated yields recorded for the wells constructed within the granitic and adjacent volcanic rock along the aquifer's southern boundary. Along its southern boundary, although volcanic bedrock is present at the surface, the granodiorite intrudes from beneath the volcanic rock in some locations, resulting in wells which may be drilled through both the volcanic and granitic bedrock units (Riddell, 2000). Additionally, the granodiorite is hypothesised to intrude as smaller dikes or channels within the surrounding country rock (Yorath & Nasmith, 1995; Johanson, 1981). Thus the occurrence of the water-bearing granitic bedrock unit may be more southerly than that determined by considering the exposed surface contact between units.

The North-Central Saanich aquifer is thought to have a low productivity, with a range of estimated yields from 0.0053 L/s (0.083 gpm) to 23 L/s (361 gpm), and a median recorded yield of 0.25 L/s (4.0 gpm) (see Figure 3). As water is transported within the aquifer through joints and fractures, the productivity of individual wells varies, depending upon whether the well intercepts these structures, and upon the hydraulic connectivity of intercepted fractures with other major fault systems. Wells constructed within this aquifer encounter major fractures at a range of depths; analysis of well records shows that 30% of fractures occur at depths between 0 and 30 m (0-100 ft), 29% of fractures occur at depths of 30-60 m (100-200 ft), 23% of fractures occur at depths of 60-90 m (200-300 ft) with the remainder of fractures occurring at depths of 90 m or greater (approximately 300 to 600 ft). Theoretically, the productivity of wells completed into this aquifer is expected to increase with depth as more water-bearing fractures are encountered. Previous studies have found the fracture network within the granodiorite can yield increasing quantities of water with depth, with the greatest yields occurring at depths between 40 and 80 meters, and the second highest yields obtained at depths between 80 and 100 m (Johanson, 1981, Ronneseth, 1986). Despite the generally lower yield expected from bedrock, within this aquifer 699 wells (54% of all wells in the aquifer) have a low yield of < 0.3 L/s (<5 gpm), 566 wells (44%) have moderate yields from 0.3 to 3.0 L/s (5-50 gpm) and 32 wells (2%) have high yields of > 3.0 L/s (>50 gpm). Higher yields may be possible for wells sited along major fault zones or for wells that intercept multiple water-bearing fractures.

Water levels reported for 410 wells (30% of wells) indicate that the water table is relatively shallow with a median depth to water of 4.6 m (15 ft). Water levels range from 0.30 m to 130 m (1.0 to 425 ft). The median well depth is 46 m (150 ft)(see Figure 2), the minimum well depth is 3.7 m (12 ft) and the maximum well depth is 305 m (1001 ft). The median depth of unconsolidated sediments overlying the bedrock is 4.6 m (15 ft).

The aquifer is one of the largest aquifers delineated within the study area and covers a region in which there has been significant residential, agricultural and industrial development both historically and at present. In total 1383 wells are known to be constructed within the aquifer. Consequently, there are pumping tests and data from prior studies that are not available for many other aquifers in this region. A completion report for municipal Sidney Waterworks District wells in 1970 and pumping tests conducted on bedrock wells along Dean Park Road obtained a range of specific capacities from 0.031 L/s/m to 0.72 L/s/m (0.33 to 3.5 USgpm/ft) (Brown, 1970; Brown and Erdman, 1975). Transmissivity of the Dean Park wells ranged from 2.3 x10^{-5} to 5.5 x 10^{-5} m^2/s (160 to 380 USgpd/ft) (Brown and Erdman, 1975). Pumping tests of the Kingswood Estate well near West Saanich and Wain Roads observed transmissivity values from 9.0x10^{-4} m^2/s to 6.1x10^{-4} m^2/s (1,900 to 1,300 USgpd/ft). When the pumping water level in the well dropped below a fracture system at 24 m (80 ft) the transmissivity dropped to 1.8x10^{-4} m^2/s (380 USgpd/ft), suggesting that the greatest proportion of water entering the well was derived from the immediately adjacent, shallow area. In summary, a transmissivity of 1.8×10^{-4} m^2/s (380 USgpd/ft) was considered representative of regional rather than local conditions (Le Breton, 1974).

The vulnerability of the aquifer to contamination from human activities on the land surface is considered moderate. The aquifer is made up of bedrock, which, in most locations, is covered by a layer of unconsolidated sedimentary deposits. A total of 62% of wells are confined; clay is present in 36% of wells, till is present in 9% of wells and a combined clay and till layer is present in 17% of wells. The overburden type is not indicated in 17% of wells and there is no confining layer within 21% of wells. Where present, the median depth of confining materials is 5.2 m (17 ft), with a range from 0.3 to 46 m (1.0 to 150 ft). Surficial deposits are interpreted to be Victoria clay and Vashon till. Within upland areas of the aquifer, including on the slopes of Bear Hill, and Mount Newton, the aquifer has a high local vulnerability due to the absence of confining sediments at these locations (Blyth and Rutter, 1993a).

Well records indicate that 23% of the wells are used for domestic purposes; while 75% of the well records did not report the type of use. Municipal production wells, observation wells, and irrigation wells account for less than 1% of total usage. Additionally a small number of wells are recorded as abandoned. As this information is based upon historical data, it may not accurately represent present well water use. Water from the aquifer is thought to be used predominantly for irrigation and non-potable purposes, as a municipal drinking water supply is accessible over much of the aquifer. A number of small to large scale agricultural operations are thought to use well water from this aquifer for irrigation purposes. Additionally, within some areas such as within parts of Ardmore, on Seacliffe Road near Coles Bay, along West Saanich Road in the area of Patricia Bay, in Deep Cove along John Road and Wayne Road, and along Mount Newton Heights residences are not connected to the municipal water supply and as a consequence rely on well water or surface water purchased and stored on site for domestic needs (District of North Saanich, 1994; J. Rivet, Engineering Department, District of North Saanich, pers.comm., June 26, 2003).

The groundwater demand and reliance upon the aquifer for water are thought to be moderate. There is a moderate well density of 17 wells per km^2. Agricultural operations in the area are thought to utilize well water for a proportion of their total needs, while the majority of households in this rural residential area have access to a municipal water supply (District of North Saanich, 1994; District of Central Saanich, 1999). In addition to municipally supplied water, there are a total of 47 active water licences held for the tributaries of Sandhill Creek, Chalet Creek, Hagan Creek, Reay Creek, and Graham Creek predominantly for irrigation and storage (Land and Water B.C., Inc., 2003). Prior to further development of the aquifer, assessment of the potential effects of additional groundwater withdrawal on local users may be required in locations, such as the Ardmore area, where there is a greater reliance on well water for domestic use and the well density is much higher.

Kohut, *et al*. (1984) analyzed ten years of data from observation wells in this region, and demonstrated a correlation between static water levels within bedrock wells and seasonal precipitation. Groundwater levels were found to reach a minimum in the months of October to December, while maximum levels were observed during the months of December to April. The study further demonstrated that available recharge was limited primarily by the hydraulic conductivity of bedrock fractures and the storage capacity of the bedrock fracture system, rather than by absolute amounts of precipitation. Groundwater recharge occurred at topographic high points, while groundwater discharge areas were found in valleys, and at the toe of slopes. There also appeared to be a wider range between seasonal high and low water level fluctuations within wells in recharge areas (2 to 6 meters) compared to discharge areas (<1 to 2 meters). The corresponding response of well water levels to precipitation inputs in recharge versus discharge areas exhibited a time lag of several weeks. Groundwater flow is assumed to be along the general direction of the topographic gradient from upland areas to adjacent lowlands.

An earlier study by Kohut *et al*. (1980) utilized isotope analysis to determine the relative age of groundwater from bedrock wells on the northern Saanich Peninsula. The study confirmed that brackish waters observed along a northeastern trending linear fracture zone east of Patricia Bay were from 2,500 to 9,100 years in age. In contrast, within the area to the north and south of this brackish zone was found water of 400 to 1,000 years in age, while the youngest water (25 years old) was found within the recharge area to the north of Patricia Bay and was thought to mix with older waters within the bedrock fracture system. The same study estimated that groundwater flow occurred at a rate of 1.7 m/year.

Interference effects have been noted for some wells, such as the Kingswood Well near the junction of Wain Road and West Saanich Road. Drawdown within this high yielding well has been shown to result in decreasing water levels within three neighbouring wells. This interference has been attributed to hydraulic connectivity along a fracture system between spatially separated well locations (Le Breton, 1974; Hodge, 1976). Interference has also been noted between wells in the Ardmore area, and wells near Willingdon Road at Patricia Bay (Johanson, 1981; Tradewell, 1976). There are no additional water use conflicts reported for the aquifer documented in Water Protection Section files. There are no additional documented concerns in relation to water quantity found in the Water Protection Section files.

Levels of chloride exceeding the Canadian Drinking Water Guideline Aesthetic Objective of 250 mg/L have been observed historically in wells within the area of Munro and Wilson Roads (Hodge, 1976; Health Canada, 1996). Water tests for Sidney Waterworks District conducted on test wells along Ardwell Road and Bowerbank Road in 1972 indicated the water quality is hard, with a high concentration of dissolved minerals (Brown, 1972). Intrusion of saline water has also been observed within deep bedrock wells in the area of Willingdon Road and West Saanich Road (Tradewell, 1976). Total dissolved solids, sodium chloride, iron and manganese above the Guidelines for Canadian Guidelines for Canadian Drinking Water Quality Aesthetic Objective, and concentrations of aluminium, lead and zinc above the drinking water Guideline Maximum Acceptable Concentration, have been observed within domestic wells in the Senanus Drive area, possibly attributable to the withdrawal of older, highly mineralized water, or due to sea water intrusion (Giles, 2000; Health Canada, 1996). Iron and manganese above the drinking water guideline have also been observed within wells in the Deep Cove area (Petrie, 1977).

There are ten active and thirty inactive MWLAP observation wells within the aquifer.

4.1.3 Aquifer 609: Littlewood IIIB (7)

The Littlewood Aquifer is in North Saanich, within the gently sloped lowlands north of the Victoria International Airport. The aquifer is bordered to the southwest by Mills Road, and is found east of Patricia Bay and west of MacDonald Park Road (see cross-section A_1-A_2 in Appendix B, and Aquifer Classification Map 1 in Appendix C).

The aquifer is partially confined and comprised of unconsolidated fine to coarse sand and minor gravel sediments, identified in previous studies as belonging to the Quadra Formation (Ronneseth, 1986; Livingston, 1961). Within the aquifer water is expected to travel through primary porosity, or at the boundary between the aquifer and the underlying, less pervious granitic bedrock of aquifer 608.

The aquifer boundary was delineated based mainly on the spatial occurrence of wells constructed in the shallow surficial sediments, as indicated within available well records, and on surficial geology mapping of the area. The aquifer boundary corresponds with, but is generally more conservative than, the area of high groundwater potential determined within prior investigations including Zubel (1980) and Ronneseth (1986). Despite its relatively small size (total area of 0.55 km^2), the aquifer was delineated due to its historical development, and inclusion within prior studies as an area of moderate groundwater potential.

The aquifer is considered moderately productive. The median estimated well yield is 1.4 L/s (23 gpm)(see Figure 3), the minimum estimated yield is 0.076 L/s (1.2 gpm) and the maximum estimated yield is 1.9 L/s (30 gpm), based upon the records from 4 wells (33% of the wells constructed in the aquifer).

The water table is shallow. The median depth to water is 4.9 m (16 ft); the minimum water depth is 0.91 m (3.0 ft), while the maximum water depth is 11 m (37 ft) based on 9 wells, or 75% of all wells in the aquifer. The depth to bedrock, recorded for a single well, is 12 m (40 ft). The median well depth is 8.1 m (27 ft)(see Figure 2), and ranges from 2.4 m (8 ft) to 16 m (54 ft).

The aquifer is considered moderately vulnerable to contamination from human activities on the land surface, largely due to the shallow depth of the aquifer and water table. A confining layer of clay, till or both is present in 58% of the wells, ranging in thickness from 0.61 m (2 ft) to 8.2 m (27 ft) with a median thickness of 1.5 m (5.0 ft). These surficial deposits are interpreted to be Victoria clay and Vashon till. The vulnerability of the aquifer is considered to be higher due to the occurrence of windows or gaps within the clay and till layers.

Groundwater from the aquifer is thought to be used predominantly for irrigation and non-potable purposes, as the majority of residences are expected to be connected to a municipal drinking water supply (District of North Saanich, 1994). There is a moderate well density of 22 wells per km^2. Although not thought to be used extensively for potable domestic use, groundwater extraction for irrigation purposes may be significant due to agricultural activities in this area. More than half of the wells extracting water from the aquifer are dug wells, which may be abandoned or no longer in use at this time. For the above combined reasons the demand is thought to be low.

Groundwater flow is assumed to be from upland areas to adjacent lowland areas. A prior study of the water balance of the aquifer confirmed that precipitation is the main source of aquifer recharge, with a two month lag time occurring between peak precipitation and the peak of the monitoring well hydrograph, representing the time required for infiltration of surface water through surficial confining sediments (Porter, 1980).

There are no concerns in relation to water quantity, no water use conflicts and no health-related water quality concerns in the Water Protection Section files. MWLAP observation well number 60, located near the centre of the aquifer, is one of ten key observation wells included in the Snow Survey Bulletin (Ministry of Water, Land, and Air Protection, 2003).

4.1.4 Aquifer 610: Bazan Bay IIB (9)

Aquifer 610 at Bazan Bay is in North Saanich, within the lowlands southeast of the Victoria International Airport, and extends from Bazan Bay westward, approximately to Cresswell Road, encompassing a total area of 1.0 km^2 (see cross-sections A_1-A_2 and A_2-A_3 in Appendix B, and Aquifer Classification Map 1 in Appendix C). The aquifer is partially confined, and is composed of unconsolidated fine to coarse sand and minor gravel deposits. Previous studies (Ronneseth, 1986; Zubel, 1980; Livingston, 1961) have described the sediments as terraced deposits. Vashon and Capilano sediments overlying the aquifer have been eroded in many places, exposing the underling water bearing sand and gravel, interpreted as Quadra sand. Well logs indicate a range of water bearing strata and confining conditions from thicker sand and gravel deposits, up to 17 m (53 ft) in depth, to thin water-bearing sand lenses in a predominantly clay matrix. Some logs indicate the occurrence of water along the boundary between the unconsolidated overburden and less permeable granitic bedrock of aquifer 608, which underlies the glaciofluvial materials.

The aquifer boundary was delineated based predominantly on the spatial occurrence of wells constructed in water bearing sand and gravel, as indicated within available well records, and confirmed by surficial geology maps of the area (Blyth and Rutter, 1993a). The aquifer boundaries correspond with, but are generally more conservative than, the area of high groundwater potential determined within prior investigations including Zubel (1980) and Ronneseth (1986).

The aquifer is considered moderately productive. The median estimated well yield is 1.2 L/s (19 gpm)(see Figure 3), and ranges from 0.21 to 2.6 L/s (3.3 to 42 gpm), based on data from 8 of a total of 49 wells, or 16% of the wells in the aquifer.

The water table is shallow. The median depth to water is 1.7 m (5.5 ft); the minimum water depth is 0.30 m (1.0 ft), not including an artesian spring, while the maximum water depth is 10 m (32 ft) based on 31 well records, or 63% of wells. The depth of unconsolidated deposits overlying the bedrock is from 11 to 20 meters, based upon the records of wells in this and the underlying bedrock aquifer. The median well depth is 6.7 m (22 ft)(see Figure 2), the maximum well depth is 23 m (75 ft), and the minimum is 2.4 m (8 ft). Water is expected to flow from upland areas to adjacent lowlands.

The aquifer is considered moderately vulnerable to contamination from human activities on the land surface. A confining layer of clay, till or both is present in 51% of the wells, ranging in thickness from 0.91 to 12 m with a median thickness of 5.5 m (3.0, 40 and 18 ft respectively). These surficial deposits are likely Victoria clay and Vashon till. Erosion of the clay and till layers is thought to reduce the degree of confinement and increase the vulnerability of this shallow unconsolidated aquifer.

Well records indicate that 41% of wells are used for domestic purposes, while the type of use is unspecified for the remaining wells. Water from the aquifer is thought to be used mainly for irrigation and non-potable purposes, as the majority of residences utilize the municipal drinking water supply available in this area (District of North Saanich, 1994). The Sidney Water Works District historically constructed a series of wells into this and the underlying bedrock aquifer; these wells are not presently being used by the municipality as a domestic or irrigation water source (T. Tanton, Director of Engineering & Works, Town of Sidney, pers.comm., June 27, 2003).

The level of groundwater demand is considered moderate. Though there is a high well density of 47 wells per km^2, more than three-quarters of the wells extracting water from the aquifer are dug wells, which may be abandoned or no longer in use at this time. Groundwater extraction from drilled wells for irrigation at agricultural operations in this area may be the most significant demand upon the resource.

Well records indicate low to trace yields in a number of wells. There are no other documented concerns in relation to water quantity and no water use conflicts documented within Water Protection Section files.

There are also no documented health-related water quality concerns for the aquifer. Aquifer water levels are actively being monitored within MWLAP observation wells 58 and 59.

4.1.5 Aquifer 611: Hagan IIB(9)

The Hagan aquifer is found in Central Saanich, within the Saanichton area and has an area of 2.1 km^2 (see cross-section A_2-A_3 in Appendix B, and Aquifer Classification Map 1 in Appendix C). Hagan Creek forms the border along its west side, and the east boundary is parallel to and approximately 0.3 km east of Wallace Drive. The southern boundary of the aquifer is found in the vicinity of Hovey Road; while the northern boundary is found approximately 0.35 km north of Haldon Road, near the base of Mount Newton.

The aquifer is partially confined and composed of unconsolidated fine to coarse sand and gravel deposits. The water bearing sediments are interpreted to be sand and gravel of the Quadra Formation and gravel from the upper unit of the Cowichan Head Formation (Ronneseth, 1986; Zubel, 1980; Callan, 1968). Overlying the aquifer are Vashon and Capilano confining sedimentary deposits including till and marine to glaciomarine clays of varying thickness (Blyth and Rutter, 1993). Well logs indicate a range of water bearing strata and confining conditions from thin water-bearing sand and gravel lenses in a predominantly till matrix to deep sand and gravel deposits up to 29 m (94 ft) thick. Artesian conditions exist along the west aquifer boundary where natural springs contribute to the base flow of Hagan Creek (Zubel, 1980). Within or at the margins of the aquifer randomly distributed dug wells are found, constructed within surficial sand and gravel sediments along the Hagan Creek floodplain, or within the till and clay layers overlying aquifer 611. Within the aquifer, water occurs in sediment pores and void spaces (primary porosity). Granitic bedrock comprises the underlying bedrock aquifer 608.

The boundary of the aquifer was delineated based predominantly on the spatial occurrence of wells constructed in unconsolidated sands and gravels that occur beneath a clay or till layer, as indicated within available well records. Surficial and bedrock geology maps reinforced or confirmed boundary inferences made from the well records (Blyth and Rutter, 1993a). In the case of this aquifer there was a discrepancy between the surficial geology map and well log data. The surficial geology map indicates the occurrence of colluvial deposits beneath a blanket of till within the central area of the aquifer (Blyth and Rutter, 1993a). However, the well records suggest that till is absent in that area. The aquifer boundaries correspond with, but are generally more conservative than, the area of high groundwater potential determined within prior investigations including Zubel (1980) and Ronneseth (1986). The aquifer boundary shows a separation of the Hagan aquifer (611) from the Keating aquifer (612) to the south as it is thought that, due to the presence of a bedrock ridge, the gravel and sand strata of the aquifer pinch out or are of minimal thickness along the boundary between the aquifers, effectively reducing the hydraulic connectivity between the units. The Hagan and Keating aquifers have differences in characteristics which suggest that their separation into unique units is appropriate. For example the Hagan aquifer has a lower median reported well yield (Figure 2). A bedrock ridge on the east side of the Saanich Peninsula prevents water flow between the inland sedimentary deposits and more coastally deposited sediments, as shown with the separation of the Keating aquifer and the Cowichan Head aquifer 615 (Zubel, 1980).

Although the aquifer is comprised of unconsolidated sand and gravel generally associated with moderate to high yields, the productivity of the aquifer is considered low. The median estimated well yield is 0.25 L/s (4.0 gpm)(see Figure 3) based on data available from only 15 wells of 31 wells (48% of wells). The minimum estimated yield is 0.032 L/s and the maximum well yield is 6.3 L/s (0.50 to 100 gpm) indicating that the aquifer is capable of yielding higher water volumes than adjacent bedrock formations. Pumping tests conducted by the Department of Lands, Forests and Water Resources (former provincial ministry responsible for water resource management) in 1968 estimated the specific capacity of test wells to range from 0.452 to 0.460 L/s/m (2.19 to 2.22 USgpm/ft) (Callan, 1968). The transmissivity of the aquifer, also determined during historical well pumping tests, was estimated at 4.0 $x10^{-3}$ m^2/s (8.4 $x10^3$ USgpd/ft) (Petrie, 1976). Recent data on the specific capacity and transmissivity of the aquifer are not available at this time.

The water table is moderately shallow. Based on the records for 12 of the total 31 well records (39% of wells) the median depth to water is 7.9 m (26 ft); the minimum water depth is 1.2 m (4.0 ft), while the maximum water depth is 23 m (74 ft). The thickness of unconsolidated sediments ranges from 12 to 30 metres (39 to 97 feet). The median well depth is 14 m (45 ft)(see Figure 2), the maximum well depth is 41 m (134 ft), and the minimum well depth is 4.9 m (16 ft).

The aquifer is considered moderately vulnerable to contamination from human activities on the land surface. A confining layer of clay, till or both is present in 22 wells (76 % of wells), ranging in thickness from 0.91 m (3 ft) to 18 m (60 ft) with a median thickness of 8.1 m (27 ft). These surficial deposits are interpreted to be Victoria clay and Vashon till. The remaining wells are unconfined, or the well records do not indicate whether a confining layer is present. The surficial geology map indicates that the entire aquifer area is covered by greater than 1 m thickness of till (Blyth and Rutter, 1993a). However, this confining layer may be eroded to a greater or lesser extent over parts of the aquifer.

Well records indicate that 19% of wells are used for domestic purposes, while the remaining well usage is unspecified or unknown. Water from the aquifer is thought to be used mainly for irrigation and non-potable purposes, as the majority of residences in this area are connected to a municipal drinking water supply (District of Central Saanich, 1999; M. Van der Linden, Senior Engineering Technologist, District of Central Saanich, personal communication, August 18, 2003).

Groundwater demand and reliance upon the aquifer for supply are thought to be moderate. There is a moderate well density of 15 wells per km^2 and a total of 31 wells constructed within the aquifer. Approximately 29% of the wells are dug wells which may be abandoned or no longer in use at this time. There is a high level of small to large scale agriculture in this area; therefore groundwater for irrigation purposes may be significant. Nine surface water licences exist for Hagan Creek, for the purposes of domestic use, irrigation and storage (Land and Water B.C., Inc., 2003).

The source of recharge to the aquifer is thought to be from infiltration of precipitation within overlying and adjacent areas, particularly along the southeastern slope of Mount Newton. Infiltration from Hagan Creek and Graham Creek could also be a source of aquifer recharge and discharge, as the hydraulic connection between water levels within Hagan Creek and well water extraction has been demonstrated in prior studies (Callan, 1969; Bannister, *et al*., 1995). Within the aquifer, water from the topographic ridge along the southern boundary of the aquifer is expected to drain west toward Brentwood Bay along the Hagan Creek valley and east toward Saanichton Bay (Wei, 2001).

There are documented interference effects; pumping water wells adjacent to Hagan Creek have been shown to cause water level fluctuations in the creek, particularly during low flow periods (Callan, 1969; Bannister *et al*, 1995). There are no groundwater use conflicts and no additional concerns in relation to water quantity or quality documented in the Water Protection Section files. There are no MWLAP observation wells in the aquifer.

4.1.6 Aquifer 612: Keating IIB (9)

This unconsolidated, partially confined aquifer is found in Central Saanich within the Keating area, and has a total area of 8.5 km^2. West Saanich Road demarks the western boundary of the aquifer; while the eastern boundary extends to Lochside Drive. Latitudinally, the aquifer extends southward to the base of Bear Hill and northward to Hovey Road in Saanichton (see cross-sections A_2-A_3, A_3-A_4, and B_1-B_2 in Appendix B, and Aquifer Classification Map 1 in Appendix C).

The aquifer is composed of unconsolidated fine to coarse sand and gravel deposits. As in much of the Central Saanich area, the water bearing sediments are interpreted to be Quadra Sand and gravel from the upper unit of the Cowichan Head formation (Ronneseth, 1986; Zubel, 1980; Callan, 1968). Overlying the aquifer are Vashon and Capilano confining sedimentary deposits including till and marine to glaciomarine clays of varying thickness (Blyth and Rutter, 1993a). Well records describe a range of water bearing strata and confining conditions, from thin water-bearing sand and gravel lenses in a clay or till matrix, to deep sand and gravel deposits up to 62 m (203 ft) in thickness. Artesian conditions exist along the west side of the aquifer where a large number of historical wells are dug in surficial till, clay or shallow surficial sand and gravel sediments. Additionally, throughout the aquifer area, and beyond the aquifer margins, are dug or shallow drilled wells that do not appear to be constructed within the sub-till unconsolidated sands and gravels of the Keating deposit. Granitic bedrock comprises the underlying aquifer (aquifer 608).

The aquifer boundary was delineated based predominantly on the spatial occurrence of wells constructed in unconsolidated sands and gravels that occur beneath a clay or till layer, as indicated within available well records. The surficial geology map of the area reinforced or confirmed boundary inferences made from the well records (Blyth and Rutter, 1993a). In the case of this aquifer there were some discrepancies between the surficial geology map and well log data. The surficial geology map indicates the majority of the aquifer area is covered by a blanket (> 1 m thickness) of sandy till, underlain by sand and gravel of glaciofluvial origin; in contrast on the west side of the aquifer, colluvium is expected to occur beneath the till. Well records indicate that fluvial sand and gravel extends further west beneath the till, as the aquifer boundary indicates (see Aquifer Classification Map 1 in Appendix C). The boundary corresponds approximately with the area of high groundwater potential determined in prior investigations including Callan (1968), Zubel (1980) and Ronneseth (1986). Previously mapped separately, the Keating and East Saanich Aquifers identified in earlier studies were combined into one unit as the water-bearing sediments appear to be contiguous across the aquifer’s extent. The Keating aquifer (612) and Hagan aquifer (611), which are adjacent to one another and possibly contiguous at the north in the area of Hovey Road, were delineated separately due to differences in estimated well yields, and because it is thought that due to the presence of a bedrock ridge, the gravel and sand strata of the aquifer pinch out or are sufficiently diminished in thickness along the boundary between the aquifers to reduce the hydraulic connectivity between the units (see cross-section A_2-A_3 in Appendix B). The Keating Aquifer is separated from the Cowichan Head aquifer (615) to the east by an underground bedrock ridge that is thought to act as a structural barrier, impeding water flow between the two aquifers (see cross-section B_1-B_2 in Appendix B).

The aquifer is considered moderately productive. The median estimated well yield is 0.5 L/s (8 gpm)(see Figure 3), based on data from 55 of 107 wells constructed in the aquifer (50 % of the wells). Estimated well yields from the sand and gravel aquifer range from 0.038 L/s to 6.3 L/s (0.60 to 100 gpm). Transmissivity of the aquifer, determined during historical well pumping tests, was estimated at 4.4 x10^{-2} m^2/s to 4.9 x10^{-2} m^2/s (9.3 x10^4 USgpd/ft to 1.03 x10^5 USgpd/ft) (Petrie, 1976).

The water table is moderately shallow. Based on the records for 49 of the total 109 well records (45% of wells) the median depth to water is 23 m (77 ft); the minimum water depth is 0.61 m (2.0 ft), while the maximum water depth is 51 m (168 ft). The thickness of unconsolidated sediments ranges from 18 to 62 metres (59 to 203 ft). The median well depth is 26 m (85 ft)(see Figure 2), the maximum well depth is 62 m (203 ft), and the minimum is 3.0 m (10 ft).

The aquifer is considered moderately vulnerable to contamination from human activities on the land surface. A confining layer of clay was noted in 27 wells, till was present in 26 wells and a combined layer of till and clay was reported for 18 wells; thus at least 71% of wells are confined, not including 29 wells for which the confinement status is unknown due to a lack of information within the well records. A confining layer is absent in 7 wells (7% of all wells). Where present, the confining layer ranges in thickness from 0.43 m (1.4 ft) to 23 m (76 ft), and has a median thickness of 8.1 m (27 ft). The surficial geology map indicates that the aquifer area is covered by a > 1 m thick layer of till (Blyth & Rutter, 1993a). Over much of the aquifer this till is overlain by clay. The combined surficial confining deposits are interpreted to be Victoria clay and Vashon till. The vulnerability of the aquifer may be increased somewhat by removal of the confining layers and exposure of the underlying sand and gravel deposits in the area of the Central Saanich Municipal Yard and Butler Brothers gravel pit along Keating Cross Road (cross-section B_1-B_2 in Appendix C). The high density of agriculture in the Keating area has also been identified as a potential contamination risk to groundwater (Best, 2000).

Well records indicate that 12% of wells are used for domestic purposes, 1% are used for irrigation, while the type of use for the remaining wells is unspecified or unknown. Water from the aquifer is thought to be used predominantly for irrigation and non-potable purposes, as the majority of residences in this area have access to a municipal drinking water supply (District of Central Saanich, 1999).

There is a moderate well density of 13 wells per km^2. Groundwater extraction from drilled wells for irrigation purposes may be significant due to the high level of small to large scale agriculture in this area. There are forty-six active surface water licences for Sandhill Creek, O'Donnel Creek and Graham Creek for the purposes of irrigation, storage, land improvement and domestic use (Land and Water B.C., Inc, 2003). The degree to which well water from the aquifer is used for household purposes is unknown at this time, but thought to be minor. Due mostly to the concentration of agricultural operations in this area, the overall demand for groundwater and reliance upon the aquifer for supply is considered moderate.

There are no groundwater use conflicts, and no documented concerns in relation to water quantity found in the Water Protection Section files. There are also no documented health-related water quality concerns. No MWLAP observation wells are found within this aquifer.

4.1.7 Aquifer 613: Durrance IIC(7)

Aquifer 613 is located in the Municipality of Saanich, west of West Saanich Road, along Durrance Road near the junction with Wallace Drive (see Aquifer Classification Map 1 in Appendix C). The aquifer is partially confined and composed of unconsolidated fine to coarse sand and gravel deposits. As over much of the Saanich Peninsula, the water bearing sediments are interpreted to be Quadra Sand and gravel from the upper unit of the Cowichan Head formation (Ronneseth, 1986; Zubel, 1980; Callan, 1968). The aquifer is a smaller (0.093 km^2) isolated deposit of these sediments that does not appear to be spatially contiguous with the larger Keating aquifer to the east, according to well logs and field assessments of the area. Despite its small size, the aquifer was considered to warrant delineation on the basis of groundwater use by domestic households in the area without access to the municipal water infrastructure. Overlying the aquifer are Vashon and Capilano confining sedimentary deposits including till and marine to glaciomarine clays of varying thickness (Blyth and Rutter, 1993a).

The aquifer boundary was delineated based predominantly on the spatial occurrence of wells constructed in unconsolidated sands and gravels that occur beneath a clay or till layer, as indicated within available well records, and confirmed by surficial geology maps (Blyth and Rutter, 1993a). A number of shallow surficial and dug wells also occur in the areas between this aquifer and the Keating aquifer (612) that appear to be constructed within the overlying till and clay layers or isolated deposits of sand and gravel from the post-glacial period.

The productivity of the aquifer is considered low. Estimated well yields range from 0.13 L/s (2 gpm) to 0.53 L/s (8.3 gpm), resulting in a median estimated yield of 0.19 L/s (3 gpm)(see Figure 3). The water table is moderately shallow. Reported static water levels range from 2.1 m to 12 m (7 to 40 ft) based on two of seven wells. The well depth ranges from 3.0 to 31 m (10 to 102 ft), and the median well depth is 20 m (66 ft)(see Figure 2).

The vulnerability of the aquifer to contamination from human activities on the land surface is considered low. Clay, till or combined clay and till layers have been noted in 5 wells, or 72% of total wells constructed within the aquifer.

Well records indicate that 14 % of the wells are used for domestic purposes, while the remaining well usage is classified as unspecified or unknown. Water from the aquifer may be used for household use and domestic irrigation. Residences within this area are beyond the boundary of the District of Saanich Water Service Area (C. Paiement, Planning Department, District of Saanich, pers.comm., June 24, 2003; District of Saanich, 2003). There are a total of seven wells constructed in the aquifer, corresponding to a high well density of 75 wells per km^2. The water demand is thought to be moderate, including water used for domestic or irrigation purposes. It is thought that there is presently a moderate reliance upon the aquifer for supply, given the high density of wells known to be constructed within this small aquifer.

There are no documented concerns in relation to water quantity and no water use conflicts reported for the aquifer in Water Protection Section files. Additionally, there are no documented health-related water quality concerns, and no MWLAP observation wells in the aquifer.

4.1.8 Aquifer 614: Karmutsen IIIB(7)

The Karmutsen aquifer is found on the Saanich Peninsula and encompasses a northwest trending band approximately 2 km in width that extends from Cordova Bay, beneath Elk Lake, to Brentwood Bay off the Saanich Inlet. The southern boundary of the aquifer occurs just north of Observatory Hill in Saanich, and the northern boundary of the aquifer is found in the area of West Saanich Road and Stelly's Cross Road in Brentwood Bay (see cross-sections A_3-A_4 and B_1-B_2 in Appendix B, and Aquifer Classification Map 1 in Appendix C). To the north of the aquifer is found granitic bedrock of the North-Central Saanich aquifer (608) and to the south lies metamorphic gneiss interpreted to be part of the Wark-Colquitz Complex (aquifer 680) (Massey, 1994).

The aquifer is partially confined, has a total area of 16 km^2, and is comprised of volcanic bedrock, interpreted to be of the Karmutsen Formation, a mainly basaltic unit with minor breccia, tuff, and limestone lenses. The aquifer also includes limestone observed within the Brentwood Bay area interpreted to be the Quatsino Formation and formed during the same period.

The aquifer boundary was delineated based upon the boundaries indicated on the bedrock geology map of the region, through the recorded occurrence of volcanic bedrock within well logs and field checks of bedrock outcrops within the Central Saanich area. The interpretation of well logs was hampered by incomplete descriptions of bedrock lithology in some cases, and a lack of discernable difference between the yields recorded for the wells constructed within this aquifer and the granitic aquifer to the north. Along the northern aquifer boundary, though volcanic bedrock is present at the surface, the granodiorite intrudes from beneath the volcanic rock, resulting in some wells which may be drilled through both the volcanic and granitic bedrock units (Riddell, 2000). Thus the actual aquifer boundary may be more southerly than that determined by considering the exposed surface contact between units. Additionally the granodiorite is hypothesised to intrude as smaller dikes or channels within the surrounding country rock (Yorath & Nasmith, 1995; Johanson, 1981).

The aquifer has a low productivity, with a range of estimated yields from 0.0074 L/s (0.12 gpm) to 21 L/s (335 gpm), and a median recorded yield of 0.19 L/s (3 gpm)(see Figure 3). As water is transported within the aquifer through joints and fractures, the productivity of individual wells varies depending upon whether these structures are intercepted by the well and upon the hydraulic connectivity of intercepted fractures with major fault systems.

Water levels are reported for 43 wells (20% of wells) indicate that the water table is relatively shallow. The median depth to water is 4.0 m (13 ft), and static water levels range from 0.30 m to 38 m (1.0 to 125 ft). The median well depth is 55 m (180 ft)(see Figure 2), the minimum well depth is 7.9 m (26 ft) and the maximum well depth is 250 m (820 ft). The median depth of unconsolidated sediments overlying the bedrock is 4.6 m (15 ft). There is insufficient information to determine the direction of groundwater flow at this time, although groundwater is expected to flow from upland areas, along a topographic gradient toward adjacent lowlands.

The aquifer is considered moderately vulnerable to contamination from human activities on the land surface, due to the presence of a confining layer over much of the aquifer. The aquifer is comprised of bedrock, which in most locations is overlain by a layer of unconsolidated sedimentary deposits. A total of 53 of the wells are confined; a clay confining layer is present in 31% of wells, till is present in 12% of wells and a combined clay and till layer is present in 10% of wells. Overburden type is not indicated in 16% of wells and there is no confining layer within 31% of wells. Where present, the median depth of confining materials is 4.6 m (15 ft), with a range from 0.61 to 27 m (2.0 to 90 ft). Surficial deposits are interpreted to be Vashon till and Victoria clay. There are local areas of high vulnerability within the uplands such as on Bear Hill, and in lowland areas in the vicinity of Tod Inlet and Butchart Gardens where the surficial layer consists largely of colluvium (Blyth and Rutter, 1993a).

Well records indicate that 30% of the wells are used for domestic purposes; the type of use is unknown for 69% of the wells. Municipal production wells and other categories account for less than 1% of total usage. Water from the aquifer is thought to be used predominantly for irrigation and non-potable purposes, as a municipal drinking water supply is accessible within the majority of the aquifer area (District of Saanich, 2003).

The demand for groundwater from the aquifer and reliance upon the resource is thought to be low. There are 217 wells known to be constructed in the aquifer, and a moderate well density of 14 wells per km^2.

However, the majority of households in this rural residential enclave have access to a municipal water supply. Agricultural operations in the area are thought to utilize well water for a proportion of their total needs; yet, in comparison to aquifer 608 to the north, the total size of the aquifer is smaller, and the number of commercial or industrial water users is expected to be less numerous. There are a total of 9 active water licences for surface water bodies in the area (Land and Water B.C., Inc., 2003).

There are no water use conflicts reported and no documented concerns in relation to water quantity found in the Water Protection Section files. There are also no identified concerns related to water quality. MWLAP observation well number 70 is constructed in the aquifer.

4.1.9 Aquifer 615: Cowichan Head IIIB(8)

The Cowichan Head aquifer is in Central Saanich, on the east side of the Saanich Peninsula west of Island View Beach (see cross-section B_1-B_2 in Appendix B, and Aquifer Classification Map 1 in Appendix C). The northern boundary of the aquifer is found south of Mount Newton Cross Road, and the southern boundary is found in the vicinity of Dooley Road. The west boundary of the aquifer is located 0.8 to 1.5 km from the coast, running approximately parallel to Lochside Drive. The total area of the partially confined unconsolidated water-bearing deposit is 3.4 km^2.

The aquifer is composed of unconsolidated medium to coarse sand and gravel. The water bearing stratum is interpreted to be formed primarily from the Quadra Formation. Gravel, also reported in well logs, is interpreted to be locally coarse deposits of the Quadra sand grading into the upper layers of the Cowichan Head Formation (see Photo 1).

Vashon till and Victoria clay form a natural confining layer over the majority of the aquifer (Blyth and Rutter, 1993a). This confining layer is expected to slow the infiltration of precipitation, possibly resulting in the surface ponding observed in the agricultural fields of this area during the winter period. The slow infiltration and presence of a shallow water-bearing layer is thought to have provided sufficient water for modest historical domestic use, as evidenced by the large number of shallow dug wells in this area. These shallow wells constructed in the uppermost sand, clay or till strata have not been grouped or classified as belonging to an aquifer, due in part to incomplete information within the associated well logs, and because there is insufficient spatial continuity between wells to delineate a contiguous water-bearing layer.

The aquifer boundary was delineated based predominantly on the spatial occurrence of wells constructed in the shallow surficial sediments, as indicated within available well records, combined with data from surficial and bedrock geology maps of the area (Blyth and Rutter, 1993a). The Cowichan Head aquifer is considered separate from the Keating aquifer (612) to the west due to the presence of a shallow bedrock ridge, approximately 1.6 km from the eastern coast of the Saanich Peninsula near the junction of Island View and Puckle Roads, (see hydrogeologic cross-section B_1-B_2 in Appendix B). The present boundaries of the Cowichan Head aquifer were modified somewhat from those determined by Zubel (1980).

Although the aquifer is comprised of sands and gravels typically associated with moderate to high yields, the productivity of the aquifer is considered low. The median estimated well yield is 0.25 L/s (4 gpm)(see Figure 3), based on the records from 5 out of a total 15 wells (33% of wells). The range of estimated yields is from a low of 0.11 L/s to a high of 0.53 L/s (1.8 to 8.3 gpm).

The water table is shallow. The median depth to water is 9.4 m (31 ft), and the water depth ranges from 4.0 m to 28 m (13 to 93 ft) based on 5 of 15 well records (33% of wells). The total depth of wells in the aquifer ranges from 11 m to 52 m (36 to 170 ft), and the median well depth is 15 m (50 ft). The total thickness of the unconsolidated sediments overlying the bedrock in this area ranges from 12 to 59 metres (41 to 194 ft). Groundwater is expected to flow outward and downslope from the ridge of high elevation approximately central to the drumlin deposit, with the majority of water movement to the east and west of this ridge (Gallo, 1992).

The aquifer is considered moderately vulnerable to contamination from human activities on the land surface. The majority of wells are confined by a clay layer, reported in 7 (47%) of the water wells. Combined clay and till was observed in 5 wells (33%), whereas in 3 wells (20%) no confining layer was observed or there was insufficient information to determine the presence of confining materials. Where present the clay and till ranges in thickness from 6.4 m to 49 m (21 to 161 ft), resulting in a median confining layer thickness of 12 m (38 ft).

Well records indicate that 20% of the wells are used for domestic purposes, while 80% of the well records do not report type of use. Water from the aquifer is thought to be used predominantly for irrigation and non-potable purposes, as a municipal drinking water supply is accessible in this area. A number of agricultural operations based here are thought to utilize groundwater for irrigation and livestock watering. There is a low well density of 4 wells per km^2 and the groundwater demand and reliance upon the aquifer for supply is expected to be low. In addition to municipally supplied surface water, there are 19 surface water licences for nearby Sandhill Creek (Land and Water B.C., Inc, 2003).

A well drilled close to Island View Beach yielded saline water and was subsequently abandoned. Water quality tests of water from wells constructed in this aquifer, and springs, bedrock and surficial wells in the area of Lamont Road and Highcrest Terrace showed concentrations of fecal and total coliforms above the Guidelines for Canadian Drinking Water Quality (Gallo, 1992; Health Canada, 1996). High concentrations of nitrate below the drinking water guideline were also found at this time. The source of the contamination was not determined, but may have originated from agricultural activities or septic system seepage in the adjacent upslope area. Affected residents are now obtaining drinking water from the municipal system.

Well records indicate low to trace yields in a number of wells. There are no water use conflicts reported for the aquifer and no other documented concerns in relation to water quantity found in the Water Protection Section files. There are no MWLAP observation wells constructed within the aquifer.

4.1.10 Aquifer 616: Cordova Bay IIC(9)

Aquifer 616 is in the Elk Lake area on the Saanich Peninsula, encompassing the area underlying the lake and land beyond its eastern and northwestern shoreline (see cross-sections A_3-A_4 and A_4-A_5 in Appendix B, and Aquifer Classification Maps 1 and 2 in Appendix C). The western boundary of the aquifer is found approximately 50 to 270 m east of Old West Saanich Road. The eastern boundary of the aquifer is in the Cordova Bay area along Lochside Drive and Wesley Road, extending southward approximately to Royal Oak Drive.

The partially confined aquifer is composed of unconsolidated fine to coarse sand and gravel and is 7.8 km^2 in size. The water bearing layer is interpreted to be formed primarily from Quadra sand. Gravel, also reported in well logs, is interpreted to be locally coarse deposits of the Quadra sand grading into the upper coarse facies of the Cowichan Head Formation. A confining layer of combined clay and till was recorded in the majority of wells, while clay or till are observed individually at a smaller number of locations, having been eroded to a greater or lesser extent during subsequent glacial advancement and retreat (Blyth and Rutter, 1993a). Dark organic silts were also noted in well logs, predominantly along the western margin of Elk Lake, derived either from Holocene lacustrine sediments or from clays and silts of marine origin deposited during the period of higher sea levels prior to post-glaciation isostatic rebound.

The aquifer boundary was delineated based predominantly on the spatial occurrence of wells constructed in the shallow surficial sediments, as indicated within available well records. Surficial and bedrock geology maps reinforced or confirmed boundary inferences made from the well records, providing an indication of the surficial extent of sediments of glaciofluvial origin in areas where fewer wells have been constructed. The lake area was included as a part of the aquifer as it is considered a hydrologically connected source of recharge and discharge, and because the glaciofluvial and fluvial water-bearing sediments are thought to be contiguous across the basin (see cross-section A_3-A_4 in Appendix B).

The Cordova Bay aquifer is considered separate from the Cowichan Head (615) and Keating (612) aquifers found further to the north because the surficial sand and gravel sediments were not evident in the records of wells located between these two aquifers. The present boundaries of the Cordova Bay aquifer were modified somewhat from those determined by Zubel (1980). The portions of the aquifer to the west of Elk Lake, and the aquifer to the east of Elk Lake, including the concentration of wells in the Cordova Bay area, were initially also delineated separately. The separate areas were combined due to an internal B.C. Ministry of Environment study which examined the possible hydraulic connectivity between Cordova Bay and Elk Lake (Le Breton, 1981). The study showed the presence of a groundwater divide formed by a shallow topographic rise of land running roughly parallel to Santa Clara and Del Monte Avenues approximately 8 m (25 ft) above the lake level between Elk Lake and the eastern coast of the Saanich Peninsula; potential hydraulic connectivity between the areas to either side of this divide was inferred due to the low relief of the topographic divide, and deepening of the surficial layer over subsurface bedrock channels, which are thought to allow water to flow from the Elk Lake area toward Cordova Bay.

The aquifer is considered moderately productive. The median well yield is 0.38 L/s (6.0 gpm)(see Figure 3), based on the records from 24 out of the total 31 wells (77% of wells). The range of estimated yields is from a low of 0.026 L/s to a high of 31 L/s (0.42 to 485 gpm). The materials comprising the aquifer include sands and gravels generally associated with higher yields. Nine wells of those concentrated along Cordova Bay Road were originally developed by the Municipality of Saanich in 1941. Pumping tests completed at the time resulted in specific capacities ranging from 0.83 to 4.1 L/s/m (4 to 20 USgpm/ft)(Zubel, 1980). There is no pumping test data available for the aquifer area to the west of Elk Lake. Information on the transmissivity of the aquifer is also not available.

The water table is shallow. The median depth to water is 7.3 m (24 ft), and ranges from 0.30 m to 18 m (1.0 to 59 ft) based on 15 of 31 well records (48% of wells). The total depth of wells in the aquifer ranges from 9.1 m to 59 m (30 to 194 ft), and the median well depth is 23 m (75 ft)(see Figure 2). The total thickness of the unconsolidated sediments overlying the bedrock in this area ranges from 12 to 59 metres (41 to 194 ft).

The vulnerability of the aquifer is considered low, due to the presence of a confining layer most of the area. The majority of wells are confined by both a clay and till layer, reported in 14 (45%) of the water wells. Till was observed in 3 wells (10%), clay was observed in 9 wells (29%), whereas in 5 wells (16%) no confining layer was observed or there was insufficient information to determine the presence of confining materials.

Where present the clay and/or till ranges in thickness from 1.2 m to 36 m (4.0 to 100 ft), resulting in a median confining layer thickness of 8.8 m (29 ft). These surficial deposits are interpreted to be Victoria clay and Vashon till (Blyth and Rutter, 1993a). The presence of isolated windows within the confining layer and the shallow depth to the water table may locally increase the vulnerability of the aquifer. The degree of hydraulic connectivity between Elk and Beaver Lakes and the underlying aquifer is not understood at this time; the large exposed lake surface might facilitate more direct recharge as well as pollutant transport from the lake to the aquifer water table.

Water from the aquifer is used for multiple purposes. Records indicate that 13% of wells are domestic, while the remaining well usage is unspecified or unknown. Water from the aquifer is thought to be used predominantly for irrigation and non-potable purposes, as a municipal drinking water supply is accessible for the majority of this area. The exception is for residences to the west of Elk Lake, along Oldfield Road, between Elkfield and Brookhaven Roads, along Elkfield Road, and at the north end of Forest Hill Road, areas which are outside of the District of Saanich Water Supply Area (District of Saanich, 2003). A significant user of groundwater for irrigation is thought be the Cadboro Bay golf course located at the eastern boundary of the aquifer; Trio Ready Mix operate a gravel pit on Cadboro Bay Road where well water is used for industrial operations. However the well water supply has had to be augmented by purchases of municipal surface water within recent years, due to reduced well water supplies during the late summer to early fall (I. McLaren, General Manager, Trio Ready-Mix, personal communication, August 7, 2003).

Available records indicate a low well density of 4 wells per km^2. There may be areas of higher well density, including wells for which records are not currently available, in particular in the area of Cordova Bay and Fowler Roads. Groundwater demand and reliance upon the aqufer are expected to be moderate overall. Surface water licences in the aquifer area include four licences on Elk Lake (one for domestic use, one for irrigation and two historical municipal water works licences). Colquitz River, which originates at the south end of Beaver Lake, has one water licence for irrigation purposes (Land and Water B.C., Inc., 2003).

For a well in the Cordova Bay area there has been an anecdotal report of well interference and declining water levels during summer periods, over the last five to ten years, that appeared to correspond to the construction of newer wells and increased use for commercial and residential users in the area (I. McLaren, General Manager, Trio Ready-Mix, pers. comm., August 7, 2003). Continuous monitoring data from active MWLAP observation well number 71 located along the eastern edge of the Cordova Bay aquifer show that February to April is generally the period of highest well water levels, while the lowest water levels are observed from September to November. Well water levels in the observation well reached a minimum during the fall of 1994, and subsequently increased reaching a maximum, for 27 year period of record, in winter 1999. Since that time there has been a decline in winter maximum water levels and the water level has reached increasingly low levels during the fall period. There are no other documented concerns in relation to water quantity found in the Water Protection Section files, and no reported water use conflicts other than those described above.

There are no documented health-related water quality concerns for the aquifer found in the Water Protection Section files. MWLAP observation well numbers 72 and 73 were utilized to monitor changes in aquifer water level from 1976 to 1987 at which time these observation wells were abandoned. Observation well number 71 is still active.

4.1.11 Aquifer 617: West Saanich Road IIC(7)

Aquifer 617 is located in Saanich along West Saanich Road north of the junction with Wallace Drive (see Aquifer Classification Map 1 in Appendix C). Composed of confined, unconsolidated fine to coarse sand and gravel deposits, the aquifer has a total area of 0.11 km^2. As over much of the Saanich Peninsula, the water bearing sediments are interpreted to be Quadra Formation and gravel from the upper unit of the Cowichan Head Formation (Ronneseth, 1986; Zubel, 1980; Callan, 1968). The aquifer is a small isolated deposit of these sediments that does not appear to be spatially contiguous with other sub-till unconsolidated deposits in this area, such as comprise the Keating (612), Cordova Bay (616) or Durrance (613) aquifers, as determined through well logs, surficial geology maps and field assessments. Overlying the aquifer are Vashon and Capilano confining sedimentary deposits including till and marine clay of varying thickness (Blyth and Rutter, 1993a).

The aquifer boundary was delineated based predominantly on the spatial occurrence of wells constructed in unconsolidated sands and gravels that occur beneath a clay or till layer, and was confirmed by surficial geology maps (Blyth and Rutter, 1993a). The majority of wells in the surrounding area are constructed in bedrock, in some cases having drilled through the surficial deposits to obtain a larger water supply.

The aquifer has an overall low productivity. Although it is comprised of typically moderate to high yielding unconsolidated sand and gravel, estimated well yields range from 0.11 L/s (1.7 gpm) to 0.95 L/s (15 gpm), resulting in a median estimated yield of 0.32 L/s (5 gpm)(see Figure 3).

The water table is moderately shallow. The static water level was recorded in three of five wells at the time of well construction; the median depth to water in these wells is 12 m (40 ft). The median well depth is 18 m (60 ft)(see Figure 2), and the well depth ranges from 12 to 30 m (39 to 100 ft).

The aquifer is thought to have a low vulnerability to contamination from human activities on the land surface. A confining layer of clay or till has been observed in all of the wells.

Well records indicate that 40% of wells are used for domestic purposes, while the remaining well usage is classified as unknown. Water may be used for household needs as well as for domestic irrigation. Residences within this area are outside of the boundary of the District of Saanich Water Service Area and do not have access to a municipal water supply, which is the primary rational for delineating an aquifer of this small extent (District of Saanich, 2003).

The overall groundwater demand and reliance upon the aquifer for supply are thought to be moderate. There are a total of 5 wells constructed in the aquifer, corresponding to a high well density of 44 wells per km^2. However, the majority of wells in this area are constructed deeper into the underlying volcanic bedrock. There are no concerns in relation to water quantity, quality or groundwater use conflicts for the aquifer documented in the Water Protection Section files. There are no MWLAP observation wells in this aquifer.

4.1.12 Aquifer 680: Wark-Colquitz IIB(12)

This bedrock aquifer is found on south-eastern Vancouver Island, and is the second largest aquifer in the CRD, covering a 209 km^2 land area that includes much of the municipalities of Colwood, Langford, and all of Esquimalt, Victoria, Oak Bay, Saanich, View Royal and the District of Highlands (see cross-sections A_3-A_4, A_4-A_5, A_5-A_6 and C_4-C_5 in Appendix B, and Aquifer Classification Maps 1 and 2 in Appendix C). The aquifer boundaries were determined based on the location of major bedrock contacts shown on the geology map by Massey (1994). The marine coastline along the Juan de Fuca and Georgia Strait forms the southern and eastern aquifer boundaries, and the western boundary is formed by the coastline at Finlayson Arm, in the Saanich Inlet. The northern boundary lies on the southern Saanich Peninsula in the area of Elk and Durrance Lakes; while the south-western boundary extends from Finlayson Arm, along Goldstream River and Langford Creek to Langford Lake, and southeast along the Survey Mountain Fault boundary to Esquimalt Lagoon (Yorath and Nasmith, 1995; Massey, 1994). The majority of the aquifer is made up of Paleozoic crystalline igneous and meta-igneous rocks of the West Coast Crystalline Complex, which includes the Wark-Colquitz Complex. Lesser bedrock units, mainly concentrated along the western area of the aquifer, include meta-volcanic and meta-sedimentary rocks of the Leech River Complex (Massey, 1994); rocks of the Leech River Complex also occur in the eastern area of the aquifer between Oak Bay and McNeill Bay. At the south end of Cordova Bay, are isolated outcrops of the volcanic Karmutsen Formation (Vancouver Group) that makes up the adjacent aquifer (614) to the north (Yorath and Nasmith, 1995; Massey, 1994). The four bedrock types (Wark gneiss, Colquitz gneiss, Leech River Complex and Karmutsen formation) were delineated as a single aquifer, partly because the information provided from the well logs was insufficient to distinguish between the major bedrock units. Clapp (1913) noted that the Colquitz gneiss intruded as a batholith upon the Wark gneiss, and the two rock types are mixed and largely indistinguishable as separate rock bodies over the aquifer area. Additionally, all of the bedrock has undergone a similar degree of metamorphism, therefore the occurrence and properties of fractures, which are the primary conduits for water flow in the rock, are expected to be similar between the metamorphic bedrock types.

The majority of well records describe the bedrock of this aquifer as green, white, and black "granite." Other records describe the occurrence of diorite and gabbro with feldspar and quartz veination; dark volcanics including red and black basalt; and sedimentary rock such as brown, black and green siltstone, brown and grey sandstone, with lesser occurrences of chert, mainly in the uplands of the Gowland-Tod mountain range in the District of Highlands. Limestone (thought to be associated with the "marble" of the Wark-Colquitz complex) is described within approximately 50 wells, in the Mill Stream area, south of Teanook and Matsan Lakes, along Millstream Lake Road, and as far east as Prospect, Elk and Beaver Lakes on the Saanich Peninsula. Numerous well records also indicate subsurface layers of trace water-bearing "soft" rock, which may be weathered granitic bedrock or grus, described by Clapp (1913), possibly concentrated within zones of high fracture density.

The productivity of the aquifer is considered low. The median estimated well yield (based on 1007 wells or 96% of well records) is 0.32 L/s (5.0 gpm)(see Figure 3), and the estimated well yield ranges from 0.0032 to 16 L/s (0.050 to 250 gpm). Approximately 3.3% of the wells produce yields greater than 3.0 L/s (50 gpm), 51% of the wells have estimated yields between 0.3 and 3.0 L/s (5 – 50 gpm), and 46% have estimated yields < 0.3 L/s (5 gpm). Transmissivity, based on pumping tests of four high capacity wells in the District of Highlands, ranges from 3.15 x10^{-4} m^2/s to 7.25 x10^{-4} m^2/s (2190 to 5040 USgpd/ft); while the storativity ranges from 7.28 x10^{-4} to 1.38 x10^{-3} (Thurber Engineering Ltd., 2003). The aquifer is expected to yield low water quantities, via joints and fractures in the bedrock, rather than through primary porosity. Karst topography, associated with limestone and marble, may also provide conduits for water flow; for example, small caves and sinkholes are found in the area of Munn Rd. and Millstream Lake Rd.

The median depth to water is 6.1 m (20 ft) and ranges from 0.30 to 110 m (1.0 to 360 ft), based on records from 151 of 1051 well records (14 % of the wells). The median well depth is 61 m (see Figure 2), the minimum well depth is 4.3 m, and the maximum well depth is 250 m (200, 14 and 820 ft respectively). The bedrock surface is relatively shallow; the median bedrock depth is 1.8 m (6.0 ft) ranging from 0 to 65 m (0 to 214 ft). The majority (74%) of water bearing fractures are observed at depths up to 61 m (200 ft); while the highest yielding fractures are observed between depths of 30 to 61 m (100-200 ft). A qualitative assessment of well lithology suggests that fracture yield increases with depth of occurrence i.e. more water is encountered with increasing well depth; however, a preliminary examination of the data does not confirm any correlation between the relative depth and yield of major fractures. Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations. The source of aquifer recharge is thought to be from infiltration and runoff of precipitation throughout the surface watershed area overlying the aquifer, or locally from surface stream and river infiltration. Local tributaries and wetlands are also expected to be areas of aquifer discharge.

The aquifer as a whole is considered moderately vulnerable to contamination from surface pollutants. The aquifer is partially confined by Capilano sediments and Vashon till, in the form of unconsolidated sand, gravel, silt, till and clay (Monahan and Levson, 2000; Blythe and Rutter, 1993a, 1993b and 1993c). Marine clay ranging from <1 m up to 20 m thick is observed at elevations below 60 m over much of Victoria and Esquimalt and glacial diamict, including compacted silty sand and gravel, has been mapped in parts of Saanich, including along the eastern margin of aquifer 680 at Cadboro Bay (Monahan and Levson, 2000). Upland areas (above approximately 60 m elevation) in particular on the western side of the aquifer are considered to have a much higher degree of intrinsic vulnerability, as they are generally overlain by shallow weathered bedrock or colluvium, with little or no confining properties (Monahan and Levson, 2000; Blythe and Rutter, 1993a, 1993b and 1993c). In 28% of the wells (294 of 1051 wells) there is a confining layer of clay, till or combined clay and till. Approximately 60% of the wells (625 wells) indicate no confining layer is present. In an additional 13% of the wells there was insufficient information to confirm the presence or absence of a confining layer. The median confining layer thickness 3 m (10 ft), and the range is from 0.15 to 32 m (0.5 to 118 ft).

Reliance upon the aquifer and groundwater demand are interpreted to be moderate. There are records of 1051 wells completed into this aquifer, corresponding to a well density of 5 wells/km^2. Well use is thought to be low within the majority of the aquifer area in the municipalities of Victoria, Oak Bay, Esquimalt, View Royal, Colwood and Langford. However, overall water demand is interpreted as moderate due to the high density and usage of wells in the District of Highlands, on the western part of the aquifer.

The groundwater is used predominantly for drinking water in areas such as District of Highlands, and parts of Saanich and View Royal where connection to a municipal surface water supply is not available (Capital Regional District, 2002). A total of 505 wells (48% of all wells) are classified for domestic use, 12 wells (1.1%) are used for irrigation, and 6 wells (0.57%) are classified for other purposes (including commercial use). Well usage is classified as unknown for 527 wells (50%) which are thought to be largely for domestic use, and one well has been slated for observation of water levels in the Millstream Road area (Thurber Engineering Ltd., 2003). Water for domestic use and irrigation is also obtained from Mill Stream, Langford Creek, Goldstream River, Hazlitt Creek, Craigflower Creek, Colquitz River, Blenkinsop Creek and Elk, Beaver, Prospect, Blenkinsop, Durrance, Pease, Eagles, Teanook, Fork, Maltby, Pike, McKenzie, Thetis, Second, Third, Mitchell, Florence, Colwood, and Langford Lakes. There are seventy-three issued water licences for these water bodies, for the purposes of domestic use, conservation, storage, power, irrigation, waterworks and land improvement (Land and Water B.C. Inc., 2004). Within the City of Victoria and immediately surrounding areas, many of the historically constructed wells are likely not used, or are abandoned, and active wells are thought to be used mainly for irrigation supply (Doug Leslie, City of Victoria Planning Dept., pers. comm., June 3, 2004).

There are no water use conflicts reported for the aquifer. However, due to the linear, rather than radial, flow characteristics of water in fractured bedrock aquifers, potential exists for well interference along major fracture networks (Thurber Engineering Ltd., 2003).There are no concerns regarding water quantity documented in Water Protection Section files. High iron concentrations have been reported in some areas (Bruce Woodbury, Administrator, District of Highlands, pers. comm., April 29, 2004). Concentrations of iron and manganese above the Guidelines for Canadian Drinking Water Quality aesthetic objectives have also been reported in some domestic wells and monitoring wells in the vicinity of Mount Work, West Saanich Road and the Prospect Lake area (Mary Anne Fillipone, Supervisor, CRD Hartland Environmental Contaminated Sites Environmental Programs, pers. comm., November 2004). Laboratory analytical data from the Millstream Road area indicate the water is moderately hard (Thurber Engineering Ltd., 2003), likely due to the presence of limestone and calcite veination. Locally, the aquifer has been impacted from leachate from the Capital Regional District (CRD) Hartland Landfill, where leachate collection and observation well networks have been established to monitor and prevent contaminant transport off-site (Mary Anne Fillipone, Supervisor, CRD Hartland Environmental Contaminated Sites Environmental Programs, pers. comm., June 23, 2004). Numerous contaminated sites exist overlying the aquifer; however no associated impact to water wells has been documented. There are no documented health-related water quality concerns affecting wells in the aquifer and no active or inactive MWLAP observation wells.

4.1.13 Aquifer 681: Willis Point IIA(10)

This aquifer is found at Willis Point, on the east side of Squally Reach, Saanich Inlet, and includes Cole Hill, the Partridge Hills, and the area along the southwestern and northeastern shores of Tod Inlet (see cross-section B_1-B_2 in Appendix B, and Aquifer Classification Map 1 in Appendix C). The aquifer is comprised of bedrock of the Bonanza Group, a predominantly volcanic unit composed of basalt and andesite flows, rhyolite, and breccia, that also includes sedimentary rock such as tuff, sandstone, conglomerate and limestone. The unit forms a triangular wedge from Squally Reach inland to just west of Wallace Drive, where it contacts the Karmutsen and Quatsino Formations (aquifer 614), and southward to near Willis Point Road where the Bonanza group contacts the gneissic Wark-Colquitz Complex (aquifer 680) (Massey, 1994). The western and northern aquifer boundaries are formed by the marine coastline of Saanich Inlet. Well records describe the bedrock as interlayered black, grey, brown, green, blue and red volcanic rock, with fewer references to “granite,” shale and sandstone, brittle purple rock, limestone, and conglomerate. A “burnt layer” is described in one well record, possibly associated with the volcaniclastic rock types.

The aquifer has a total area of 7.9 km^2 and has a low productivity. The median estimated well yield is 0.25 L/s (4 gpm)(see Figure 3) based on 164 wells or 99% of wells in the aquifer. The minimum estimated yield is 0.013 L/s and the maximum is 6.3 L/s (0.2 and 100 gpm respectively). The median depth to water is 7.6 m (25 ft), with a range from 0.61 to 59 m (2 to 195 ft) based on data from 31 wells (19% of wells in the aquifer). The greatest well density is along the coast. Therefore the statistics may reflect groundwater conditions at lower elevations. The median well depth is 58 m (190 ft)(see Figure 2), the minimum well depth is 9.1 m (30 ft), and the maximum well depth is 198 m (650 ft). The bedrock surface is located relatively close to ground level, at a median depth of 1.8 m (6 ft). Bedrock is observed at the ground surface (no overburden) in four wells, while the maximum depth to bedrock is 17 m (55 ft). The average depth of reported water-bearing fractures is 40 m (130 ft).

The aquifer is considered highly vulnerable to contamination from human activities at the surface, due to a thin overburden and lack of confining materials in the majority of wells. Most of the aquifer area is overlain by colluvium < 1 m thick, though along the western and eastern margins the colluvium is > 1 m thick (Blyth and Rutter, 1993a). Silty organic deposits overly the aquifer in the area of Durrance Lake, and localized deposits of fluvial sands and gravels occur the historical Tod Creek floodplain near the aquifer's eastern margin. Well records indicate the overburden consists of colluvium, sand and gravel and till or clay in other cases. In 32% or 52 of 165 wells there is a clay or till confining layer. Clay overburden is generally found at elevations ≤ 80 m, suggesting that it is Victoria clay, deposited near the close of the Fraser glaciation when sea levels were higher. There is no discernable spatial pattern for the occurrence of till. 19% of the wells had insufficient information to confirm the presence or absence of a confining layer; and 50% of the wells are unconfined. The median confining layer thickness is 2.6 m (9 ft), and ranges from 0.3 to 14 m (1 to 47 ft).

There is expected to be a moderate level of water demand. There are records of 165 wells completed into this aquifer, corresponding to a density of 21 wells/km^2. There is a high reliance upon the aquifer for supply, based on the well density, and the fact that there is no currently opportunity in this area to connect to a municipal water supply (CRD, 2002). Groundwater in the area is used mainly for domestic purposes. Water for irrigation and domestic purposes may also be obtained from Durrance Lake, Pease Lake, Pease Creek, Tod Creek, and two additional unnamed northward draining ephemeral creeks. There are a total of 6 issued water licences for these water bodies, for the purposes of domestic use, storage, and irrigation (Land and Water B.C. Inc., 2004).

Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations. The inferred direction of groundwater flow, based on the topography of the area, is likely radial from the Partridge Hills and Cole Hill toward lower elevations. The source of aquifer recharge likely from infiltration and runoff of precipitation throughout the surface watershed area overlying the aquifer, or locally from wetland, stream and river infiltration. Local tributaries and wetlands are also expected to be areas of aquifer discharge.

There are no water use conflicts reported for the aquifer, and no concerns regarding water quantity documented in Water Protection Section files. Additionally, there are no documented health-related water quality concerns, though high iron concentrations have been reported for one well (Larry Resnick, well owner, pers. comm., May 18, 2004). There are no MWLAP observation wells constructed in the aquifer.

4.1.14 Aquifer 686: Gordon Head IIIC(7)

The aquifer is found in the Gordon Head area, in the Municipality of Saanich, and is comprised of an approximately 2 km wide drumlinoid ridge that extends from just south of the University of Victoria campus, northeast to Cordova Bay (see cross-section A_5-A_6 in Appendix B, and Aquifer Classification Map 2 in Appendix C). The aquifer covers an area of 7.3 km^2, and is comprised of unconsolidated fine to medium sand and gravel interpreted to be part of the Quadra Formation. Well records describe the unconsolidated deposit as a massive to finely laminated, thick layer of coarse to fine sand with silty-clay lenses, occasionally overlying thinner gravel deposits. Water-bearing strata in the aquifer are believed to be of minimal thickness, and located toward the bottom of the sand and gravel deposit. Marine silt thought to be the Dashwood Drift, and Pleistocene till is found below the water bearing sands or gravels in some areas (Monahan and Levson, 2000), while in others sand and gravel directly overlies the gneissic bedrock of aquifer 680 (Massey, 1994).

The aquifer boundaries were determined based on the spatial location of wells constructed in unconsolidated sand and gravel, by the extent of physiographic expression of the drumlinoid ridge shown on topographic, surficial and Quaternary geology maps (Blythe and Rutter, 1993c; Monahan and Levson, 2000), and by field visits to the area in August 2004. The productivity of the aquifer is considered moderate. The median estimated well yield (based on 4 wells or 50% of well records) is 0.63 L/s (10 gpm)(see Figure 3), and the estimated yield ranges from 0.32 to 2.21 L/s (5 to 35 gpm). The median depth to the water table is 29 m (96 ft), and the depth to water ranges from 22 to 35 m (73 to 116 ft), based on data from 6 of 8 wells (75%). The median well depth is 33 m (108 ft). Depth to bedrock in the area is not known, but is believed to exceed 35 m (110 ft) at the thickest part of the drumlin ridge.

The vulnerability of the aquifer to contamination from surface pollutants is considered low. The aquifer is partially confined by clay and till, present over the majority of the aquifer, including Vashon till a few metres in thickness, and a blanket of Victoria clay from < 1m up to 20 m thick (Monahan and Levson, 2000; Blyth and Rutter, 1993c). Sixty three percent of the wells are confined; two wells are confined by clay, two by till, one by both clay and till and three wells (38%) are unconfined. The median confining layer thickness is 7.9 m (26 ft) and the range is from 2.4 to 21 m (8 to 70 ft). The thickness of clay and till sediments in some areas may have been reduced by erosion or development related excavation, possibly reducing the degree of confinement locally.

Groundwater from the aquifer is not believed to be used as a drinking water source. There are records of 8 wells in the aquifer, corresponding to a well density of approximately one well/km^2. Three of the wells, including the two most recently constructed wells in the aquifer, are used for water level observation and hydrogeologic studies at the University of Victoria (David Nelles, University of Victoria School of Earth and Ocean Sciences, pers. comm., August 20 2004). The remainder of wells are either observation wells, abandoned, not in use or were constructed in the distant past (1952 to 1979) for irrigation or other purposes, and their present status is unknown. The urban to suburban population in this area obtains drinking water from the Capital Region Water District (CRD, 2002). Therefore, demand for, and reliance upon, water from the aquifer is interpreted to be low.

Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations, likely from the centre of the drumlin ridge outward (to the east, west) and northward toward the coast. The source of aquifer recharge is thought to be from infiltration and runoff of precipitation throughout the surface watershed area overlying the aquifer, or locally from surface stream and river infiltration. Hobbs Creek that runs through Mystic Vale on the east side of the University of Victoria campus is the only tributary in the aquifer area. The low productivity of the aquifer may be attributable in part to the high degree of confinement and extensive impervious cover (paved surfaces) over much of the aquifer, which may reduce the degree of aquifer recharge.

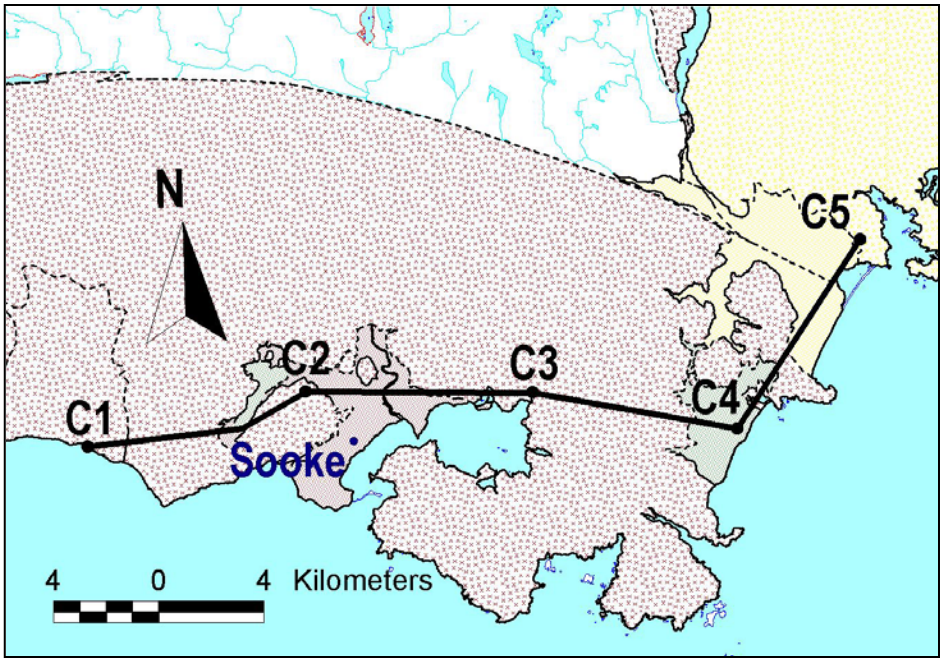
There are no water use conflicts, no concerns regarding water quantity and no health-related water quality concerns related to the aquifer documented in Water Protection Section files. There are no MWLAP observation wells constructed within the aquifer.

4.2 Sooke, Metchosin, Western Communities, and Port Renfrew

Within the Colwood, Langford, Metchosin, Sooke and Port Renfrew areas of the CRD, seven unconsolidated and three bedrock aquifers were delineated and classified. These aquifers are discussed in greater detail below. Appendix B contains hydrogeologic cross-section (C_1-C_5) that extends 33.8 km from Orveas Bay, east of Sooke, across Metchosin to Colwood, northeast of Esquimalt Lagoon, intersecting eight of the major unconsolidated and bedrock aquifers in this area including those at the Sooke River

(599), Parry Bay (683), and Colwood Delta (682). The location of the hydrogeologic cross section is shown on Map 4. Appendix C contains Aquifer Classification Maps 2 and 3 which illustrate the boundaries and spatial extent of identified aquifers in this Sooke, Metchosin and the Western Communities. Aquifer Classification Map 4, also in Appendix C, shows the spatial extent of aquifers in the Port Renfrew area.

Map 4: Location of hydrogeologic cross-section C in the Sooke, Metchosin and Colwood area with aquifers shown (red=high vulnerability, yellow=moderate vulnerability, and green=low vulnerability)



4.2.1 Aquifer 449: Muir Creek IIIC(9)

The Muir Creek aquifer is found in Sooke, where Muir Creek empties into Orveas Bay off the Juan de Fuca Straight (see cross-section C_1-C_2 in Appendix B, and Aquifer Classification Map 3 in Appendix C). This partially confined bedrock aquifer underlies Skookum Gulch and the north-west end of Gordon’s Beach and extends approximately 7.5 km into the forested hills to the north. The aquifer has a total area of 28 km^2 and is comprised of poorly to well cemented arkosic sandstone and gravel conglomerate of the Sooke Formation (Massey, 1994; Muller, 1980). Early work by Clapp *et al*. (1918) suggests that the sandstone unit is a maximum of 240 metres in depth. The Sooke Formation also exists to the east of the aquifer (Map 2 and Massey, 1994); these additional occurrences of the Sooke Formation have not been delineated as separate aquifers at this time as there are no well records on file for these areas.

Overlying much of the Muir Creek aquifer are unconsolidated sediments of the Fraser Glaciation, including Vashon till and Capilano Sediments (Howes and Nasmith, 1983). Vashon till and Capilano sedimetns to the east of the Muir Creek estuary, overlying the bedrock aquifer along Gordon’s Beach, are also variably water bearing, as indicated by the occurrence of surficial wells, but have not been delineated as a separate surficial aquifer.

The sandstone of the Sooke Formation which makes up aquifer 449 unconformably overlies the volcanic Metchosin Igneous Complex (aquifer 618)(see Aquifer Classification Map 3 in Appendix C). Water in the aquifer is thought to occur within discrete joints or fractures in the sandstone and conglomerate, rather than within granular pore spaces. The sandstone bedrock is variably cemented and more or less friable in different areas, possibly resulting in preferential water flow through parts of the sandstone unit, due to variable permeability of the bedrock. This bedrock aquifer has moderate productivity, and the median yield is higher than for the adjacent and underlying aquifer composed of volcanic bedrock (Figure 3). The estimated well yield rangs from a minimum of 0.16 L/s (2.5 gpm) up to a maximum of 1.9 L/s (30 gpm), with a median estimated yield of 0.50 L/s (8 gpm), while some wells yield only trace quantities of water.

This water bearing sandstone unit is moderately deep. For select wells, where the water level was recorded at the time of drilling, the median depth to water is 23 m (74 ft). The bedrock unit begins at a geometric mean depth of 29 m (98 ft), with a range from 0.61 to 46 m (2 to 150 ft), and the median well depth is 46 m (152 ft)(see Figure 2). The aquifer is thought to have low vulnerability to contamination from human activities at the surface. Confinement is provided by overlying clay and till sediments. A blanket (> 1 meter thick) of till is present over the majority of the aquifer area, interpreted as Vashon till, and Capilano sediments, including Victoria clay. Clay and till are observed in the wells which are concentrated along the coastal edge of Orveas Bay. Fourteen wells (78%) possess a clay or till confining later, with a median thickness of 16 m (54 ft).

There are records of 18 wells completed into this aquifer, corresponding to a well density of 1 well/km^2. Therefore the overall level of groundwater demand and use is considered low. The majority of wells are concentrated along the south-eastern boundary (see Aquifer Classification Map 3 in Appendix C). While the northern portion of the aquifer, for which MWLAP does not have any well records at present, is largely undeveloped forest. Groundwater from the aquifer is thought to be used mainly for drinking water and domestic irrigation. Although the number of wells tapping into the aquifer is relatively low, there is no opportunity in this area to connect to a municipal water supply, increasing the overall dependence upon the groundwater resource. Irrigation and domestic drinking water may also be obtained from Kirby, Muir and Tugwell Creeks, or purchased and stored in bulk by area residents (K. Ronneseth, MWLAP Water Protection Section, personal communication, September 3, 2003).

Within the aquifer groundwater is assumed to flow from upland areas to adjacent lowlands. Low to trace yields noted for some wells are the primary water quantity concern identified for the aquifer; while there are no identified concerns regarding the quality of water for human consumption. There are no MWLAP observation wells presently established within the aquifer.

4.2.2 Aquifer 599: Sooke River IIIA (11)

The aquifer is found in Sooke, and encompasses the Sooke River flood plain, and the lowlands surrounding Kemp, Poirier, Mackenzie and Young Lakes. The aquifer also includes the coastal region north of Sooke Harbour and portions of the Sooke Bay coast including Muir Point and Parson’s Spit, extending inland to a maximum of 4.5 km (see cross-sections C_1-C_2 and C_2-C_3 in Appendix B, and Aquifer Classification Map 3 in Appendix C). This unconsolidated aquifer has a total area of 19 km^2 and is partially confined by till and clay.

The aquifer is made up of a shallow surface layer of unconsolidated gravels and sands of the Capilano sediments and Vashon till. Vashon till is believed to form the water bearing layer in 4 of a total of 20 wells

(20%). The Vashon till is exposed over only a small area of the land surface within the upper north-western portion of the aquifer, being covered over the majority of its extent by the more recent Capilano sediments. The Capilano sediments include sand, gravel, silt and clay; this glaciomarine deposit forms the surficial layer over the majority of the aquifer and is water bearing in 16 (80%) of the wells.

The highest water yields are derived from the Capilano sediments, as observed in an artesian spring and a sequence of shallow wells in the vicinity of Young and MacKenzie Lakes, examined in greater detail in a report by Kohut (1982). The Capilano sediments are also found to be moderate to high yielding along the Sooke River flood plain. The difference in expression and thickness of the unconsolidated layers over the spatial extent of the aquifer is attributed to erosion during and subsequent to the last glacial period.

Aquifers 604 and 605 thought to be comprised of Saanichton gravel are found underlying and separated from aquifer 599 by a layer of Vashon till. Additionally, within this part of Sooke the glacio-sedimentary deposits of the Fraser Glaciation overlie igneous bedrock, including the Metchosin Igneous Complex which comprises the underlying bedrock and surrounding higher elevation ridges and peaks and is separately delineated as aquifer 606 (Massey, 1994).

The aquifer boundary follows the outline of the surficial unconsolidated units as reported on the bedrock and surficial geology maps by Muller (1980), Massey (1994) and Blyth and Rutter (1993b). The boundaries were extended along some margins where well records indicate the continuation of the sedimentary deposit beyond the previously mapped limit. The unconsolidated sediments of this aquifer are confined to lower elevations of less than 100 metres above sea level, and in most areas less than 80 m, which demarks the approximate maximum extent of post-glaciation sea level prior to isostatic uplift (Howes and Nasmith, 1983).

The aquifer is made up of unconsolidated coarse gravel to fine sand and is considered moderately productive. Estimated well yields range from a minimum of 0.013 L/s (0.2 gpm) up to a maximum of 3.8 L/s (60 gpm), with a median estimated yield of 0.32 L/s (5 gpm)(see Figure 3). Higher yields are reported from a spring and shallow wells in the vicinity of Young and McKenzie lakes. High yields have also been observed from a select number of the wells penetrating the glaciofluvial sand and gravel Capilano sediments along the Sooke River flood plain. There are also some wells with very low to trace yields.

The median water level, determined from the records of 9 out of 20 wells (45% of wells), is 3.7 m (12 ft) from the surface, ranging from an artesian spring where the water flows freely at the surface, to a well with the maximum depth to water of 15 m (50 ft). The water bearing sediments are considered shallow. Excluding the natural spring, the geometric mean depth to the water bearing layer is 9.4 m (31 ft). The median well depth is 14 m (45 ft)(see Figure 2), the minimum well depth is 3.4 m (8 ft), and the maximum depth is 34 m (50 ft). For most wells the depth to bedrock, and thus the thickness of the unconsolidated layer is unknown. From selected well logs which tap into the underlying bedrock aquifer, the unconsolidated layer is estimated to reach a maximum thickness of approximately 79 m (260 ft). Within the aquifer, groundwater is assumed to flow from upland areas to adjacent lowlands.

The aquifer is considered highly vulnerable to contamination from human activities at the surface. The aquifer is shallow and only partially confined; clay or till is present within 8 of 20 (40%) of the wells, with a median confining layer thickness of 6.1 m (20 ft), ranging from 0.30 m to 15 m (1-50 ft). For the remaining 60 % of the wells the presence of a confining layer is not indicated or the well log contains insufficient lithological information to determine the degree of confinement.

The groundwater is used predominantly for drinking water and irrigation, with an overall low estimated degree of use due to the low number of wells in the aquifer. In this part of Sooke there is limited opportunity to connect to a municipal water supply, suggesting a high reliance upon the aquifer for supply. Water for domestic drinking and irrigation purposes may also be obtained from nearby surface water bodies including Charters River, Saseenos Creek, Lannen Creek, Ayum Creek, De Mamiel Creek, Sooke River and Young, Mackenzie, Poirier and Kemp Lakes. A total of 46 water licences exist for the above water bodies for the licensed purposes of domestic use, waterworks, irrigation, storage, and land improvement (Land and Water B.C. Inc., 2003).

Other than very low reported yields in some wells, there are no other water quantity concerns and no water use conflicts documented in Water Protection Section files. A high iron concentration and sulphur smell has been reported for a single well. There are no documented health-related water quality concerns, and no MWLAP observation wells in the aquifer.

4.2.3 Aquifer 604: Young Lake IIIC (7)

Aquifer 604 is found in Sooke within the lowlands surrounding Kemp, Poirier, Mackenzie and Young Lakes (see cross-section C_1-C_2 in Appendix B, and Aquifer Classification Map 3 in Appendix C). The aquifer is comprised of unconsolidated coarse sand and gravel sediments. The stratigraphy of wells that penetrate to the maximum depth of the unconsolidated sediments suggest that the Quadra Formation is the lower-most water bearing sedimentary unit. A gravel layer ranging in thickness from <1 to 31 metres (3 to 100 ft) interpreted as Saanichton gravel (part of the Quadra Formation) is documented in 7 wells. At depth in some wells a conglomerate unit has been reported above or between water bearing gravels, suggesting that some cementation or diagenesis of the Saanichton Gravel has occurred. The cemented gravel layer is not considered part of the Sooke Formation because of the relative shallowness of the deposit, and due to the appearance of water bearing unconsolidated gravel below it.

Aquifer 604 is small in size (2.0 km^2), confined, and found beneath a larger and shallower aquifer (aquifer 599) comprised of Capilano sediments and Vashon till. The gravel of aquifer 604 is, in all cases, separated from the upper sedimentary strata by a till layer interpreted as Vashon till, providing it with a high degree of protection from surface contamination.

The aquifer boundary follows the valley trending southwest from Young and Mackenzie Lakes toward Kemp Lake. This relatively deep unconsolidated gravel aquifer may extend further through the De Mamiel River Valley curving around Broom Hill to connect up with aquifer 605; therefore the present aquifer boundary could be extended if more information becomes available. The higher elevation ridges, bluffs and peaks of the surrounding area are predominantly formed from basalt of the Metchosin volcanic unit; the 100 m contour demarks the approximate maximum elevation of unconsolidated deposits.

The productivity of the aquifer is considered low. Although the aquifer is comprised of unconsolidated coarse gravel and sand associated with moderate to high water yields, the estimated well yield ranges from a minimum of 0.063 L/s (1 gpm) up to a maximum of 3.2 L/s (50 gpm), with a median yield of 0.13 L/s (2 gpm – see Figure 3).

The water level (recorded for two of seven wells) ranges from a minimum of 11 m to a maximum of 26 m (35 and 85 ft respectively). The water bearing sediments are considered shallow. The geometric mean depth to the water bearing layer is 33 m (109 ft). The median well depth is 39 m (127 ft – see Figure 2); the minimum well depth is 31 m (102 ft) and the maximum depth is 47 m (155 ft). For each of the wells tapping into the aquifer, the depth to bedrock, and thus the thickness of the unconsolidated layer, is unknown. From selected well logs, the unconsolidated layer in this vicinity is inferred to reach a maximum thickness of approximately 79 m (260 ft).

The aquifer is thought to have a low vulnerability to contamination from human activities at the surface. The aquifer is confined and found beneath a shallower surficial aquifer (aquifer 599). A clay or till confining layer is present within all wells in the aquifer, and the median confining layer thickness is 22 m (72 ft), ranging from 6.1 m to 30 m (20 to 100 ft). Within the Kemp Lake area an additional cemented gravel layer was noted between the till and unconsolidated gravel strata. Depending upon the degree of cementation, this gravel could provide a further degree of confinement. However its occurrence is not consistent throughout the existing records. The cemented gravel may be isolated in extent, reducing its effectiveness as a confining layer.

Groundwater from the aquifer is used predominantly for drinking water and irrigation with a low level of interpreted use. There are records of 7 wells completed into this aquifer, corresponding to a well density is 3 wells/km^2, the majority of which are concentrated within a small residential area north-northwest Kemp Lake. Although the number of wells tapping into the aquifer is relatively low, in this part of Sooke there is limited opportunity to connect to a municipal water supply. Water for domestic drinking and irrigation purposes may be obtained from wells or from nearby surface water bodies including De Mamiel Creek, and Young, Mackenzie, Poirier and Kemp Lakes. A total of 29 water licences exist for the above surface water bodies for the licensed purposes of domestic use, camps, waterworks, irrigation, storage, and land improvement (Land and Water B.C. Inc., 2003).

There are no water use conflicts reported for the aquifer, and no reported concerns regarding water quantity or quality in Water Protection Section files.

4.2.4 Aquifer 605: Sooke Bay IIIC (7)

Aquifer 605 is found south of Broom Hill, adjacent to the marine coast in the area northeast of Sooke Bay (see Aquifer Classification Map 3 in Appendix C). The Sooke Bay aquifer, with an area of < 1 km^2, is below the size generally considered significant enough to warrant delineation, however it has been mapped due to its association with aquifer 604 at Young Lake. The Sooke Bay aquifer is comprised of unconsolidated gravel. These gravels are believed to be Saanichton gravel, a coarse upper facies of the Quadra Formation.

The Young Lake and Sooke Bay aquifers are comprised of the same materials, are found within the same general geographic area, and are overlain by the same sequence of sedimentary strata (refer to the discussion of aquifer 604 for a more complete description of the overlying and underlying lithological units). The deposit comprising the aquifer 605 may link up with aquifer 604 depending upon the lateral extent of the sub-till gravel deposit.

The productivity of the aquifer is considered low; the median estimated well yield is 0.13 L/s (2 gpm). Groundwater is used predominantly for drinking water and irrigation, with low level of expected use, as there are records of only 3 wells completed into the aquifer. Water for irrigation and domestic use may be obtained from wells, or from nearby surface water bodies including a small unnamed lake and an ephemeral stream originating south of Broom Hill.

The water level, reported for a single well, is 18 m. The median well depth is 31 m (102 ft). The aquifer is thought to have a low vulnerability to contamination from human activities at the surface as it is confined by overlying clay or till layers with a median thickness of 15 m (50 ft). There are no reported concerns regarding water quantity, no health-related water quality concerns or water use conflicts documented for the aquifer within Water Protection Section files, and no MWLAP observation wells in the aquifer.

4.2.5 Aquifer 606: Sooke Metchosin IIIA(12)

This bedrock aquifer is the largest aquifer in the CRD, encompassing a 537.6 km^2 area in the municipalities of Metchosin, Colwood, Langford and Sooke, including the East Sooke Peninsula (see cross-sections C_1-C_2, C_2-C_3, C_3-C_4 and C_4-C_5 in Appendix B, and Aquifer Classification Maps 2 and 3 in Appendix C). Jordan River defines the western boundary of the aquifer, and the southern aquifer boundary is formed by the marine coastline from Jordan River to Esquimalt Lagoon. The northern and eastern aquifer boundary is defined by the Leech River Fault, in the Sooke Hills, which separates bedrock of the Metchosin Igneous Complex and the Leech River Complex, and is thought to be a natural barrier to groundwater movement (Massey, 1994; Yorath and Nasmith, 1995). The aquifer boundary was delineated to encompass bedrock of the Metchosin Igneous Complex in areas of present groundwater development. The spatial extent could be amended in future to include land west of Jordan River, as far west as Sombrio Point, an area for which there are presently no records of bedrock wells.

The aquifer is made up of rocks from the Metchosin Igneous Complex (Massey, 1994). The Metchosin Igneous Complex is a layered gabbro and leucogabbro (light-coloured feldspar– and quartz–rich gabbro) including sheeted gabbroic and dioritic dykes that extend upward into fine-grained pillow and flow basalts. The unit also contains minor tuff, breccia, and rare limestone (Massey, 1994; Yorath and Nasmith, 1995). Muller (1980) and Massey (1994) indicate that the Metchosin Igneous Complex is comprised of both gabbroic and basaltaltic rock. There was no differentiation of the area into separate aquifers according to bedrock types, both due to the inferred similarity in reported water yield and hydrologic properties of the two igneous units, and due to a lack of sufficiently detailed well logs to distinguish between the basaltic and gabbroic bedrock. Well records describe the aquifer material as dark basalt, or alternating layers of light and dark green igneous bedrock, intercepted by quartz and feldspar veins, and water bearing fractures at depth. Other well logs describe the lithology as blue, red, brown or black volcanic bedrock, or layered hard grey and soft green bedrock. A few records indicate the occurrence of limestone, while some describe the presence of "conglomerate," which may correspond with brecciated rock in shear and fracture zones. Described occurrences of layered "sandstone and shale" are thought mainly to correspond with weathered, feldspar–rich igneous bedrock, or grus, and fine-grained black basalt. Some wells may be drilled through true sandstone and conglomerate of the Sooke Formation, which comprises Muir Creek aquifer 449, a sedimentary bedrock formation that unconformably overlies the Metchosin Complex in parts of Sooke, including at Orveas Bay, Loss Creek and Jordan River.

Overlying portions of the bedrock aquifer are Vashon till and Capilano sediments deposited during the Fraser glaciation (Blyth and Rutter, 1993b; Monahan and Levson, 2000), including water bearing strata of aquifers 599, 604, and 605. Water bearing surficial deposits associated with shallow wells along the coastal margin of Orveas Bay, and on the East Sooke Peninsula were not delineated as separate aquifers due to the small number of wells and their lack of spatial connectivity. Aquifer 682, formed from glaciofluvial sediments of the Colwood delta, overlies the Sooke-Metchosin aquifer in a glaciofluvial flood deposit that extends from Langford Lake area south-east toward Esquimalt Lagoon. Aquifer 683 similarly overlies much of the lowland areas (<60 m elevation) along the coast at Parry Bay (Witty's Lagoon), and along the historical Metchosin Creek floodplain, east of Metchosin Mountain.

Water depth ranges from a minimum of 0.61 m (2 m) to a maximum of 213 m (700 ft). The median water depth is 6.9 m (23 ft), based on records from 56 of 632 well records (9% of wells). The median well depth is 91 m (299 ft). While the minimum well depth is 7.3 m (24 ft), and the maximum well depth is 262 m (860 ft). The depth to bedrock ranges from 0 to 47 m (154 ft), with a median depth of 3.0 m (10 ft). Within the aquifer, water is thought to flow through discreet fractures rather than through primary porosity. The relatively deep median well depth reflects the low productivity of this aquifer and the need for drillers to drill wells deeper to intercept sufficient water-bearing fractures to supply a domestic well. The majority of water bearing fractures occur within the depth range of 30 to 100 m (100 to 300 ft) from the land surface.

The productivity of the aquifer is considered low. The aquifer is made up of consolidated igneous and volcanic bedrock. Estimated well yields range from a minimum of 0.0025 L/s (0.04 gpm) up to a maximum of 6.3 L/s (100 gpm), with a median yield of 0.095 L/s (1.5 gpm). Higher water yields are likely attributable, for the most part, to the influence of surface water sources, as higher well yields are observed in wells found in close proximity to permanent or ephemeral streams. For example, the highest yields were observed wells found adjacent to Doer Creek or Veitch Creek.

The level of groundwater demand is interpreted to be low. There are records of 632 wells completed into this aquifer, resulting in a well density of 1 well/km^2. Most wells are found along the southern area of the aquifer, within ≤ 6 km of the coast, where suburban and rural development is greatest. Park land and Department of National Defence property covers much of the East Sooke Peninsula, and a significant part of the northern area of the aquifer is undeveloped Crown land or forestry tenures. The groundwater is used predominantly for drinking water and irrigation.

There is a low overall reliance upon the aquifer for supply. However, the greatest reliance upon groundwater is in parts of Sooke and Metchosin where there are limited opportunities to connect to a municipal water supply. Municipal water sources are available over the majority of Colwood in the western area of the aquifer. Water for domestic drinking and irrigation purposes may also be obtained from surface water bodies including Ayum Creek, Barnes Creek, Bilston Creek, Charters Creek, Doerr Creek, Metchosin Creek, Pedder Creek, Pike Creek, Veitch Creek, Waugh Creek, Vera Brook, Jordan River, Leech River, Sooke River, Glenairly Spring, Glen Lake, Langford Lake, and Quarantine Lake. A total of 66 water licences exist for the above water bodies for the licenced purposes of domestic use, enterprise, waterworks, irrigation, storage, and land improvement (Land and Water B.C., Inc. 2004).

This partially confined aquifer is considered highly vulnerable to contamination from human activities at the surface. Confining sediments, thought to be Victoria clay or Vashon till, are present in 260 wells (41% of the wells); for an additional 22% of the wells there is insufficient information to confirm the presence or absence of a confining layer, and within 37% of the wells there is no confining layer noted. Where present clay or till range in thickness from 0.46 to 85 m (1.5 to 138 ft) with median thickness of 4.3 m (14 ft). The surficial and quaternary geology maps indicate that much of the aquifer area is covered by a thin (< 1 m) veneer of unconsolidated colluvium or weathered broken rock with little or no confining properties; a blanket (> 1 m thick) of silty till is found over the aquifer at elevations < 80 m to 100 m, where most of the groundwater development has occurred (Blyth and Rutter, 1993b; Monahan and Levson, 2000). The great depth of the wells and thickness of the bedrock layer above the water level are expected to provide a measure of protection of the water source from surface pollutants. In contrast, the vulnerability of the aquifer may be increased by the fact that water can travel rapidly through bedrock fractures, compared to the speed of water travel through the pore spaces of unconsolidated sediments. Much of the upslope recharge area of the aquifer is presently undeveloped forest.

Groundwater flow is assumed to be from upland areas to adjacent lowland areas. From the topography of the area the inferred regional groundwater flow direction is southeast toward the coast. The source of aquifer recharge is expected to be infiltration of precipitation in the surface watershed area overlying the aquifer. Streams and rivers may also be a source of aquifer recharge or discharge.

There are no water use conflicts reported for the aquifer. Very low to trace yields have been identified for some wells. There are no additional concerns regarding water quantity documented in Water Protection Section files. High iron concentrations have been reported for one well. However, there are no documented health-related water quality concerns. There is one active MWLAP observation well in the aquifer, in the Metchosin area.

4.2.6 Aquifer 682: Colwood Delta IIIB(11)

The aquifer is made up of layered sand and gravel from the Colwood Delta, that encompasses a total area of 24.1 km^2 in Colwood, Langford and Metchosin. The aquifer occurs north of Langford Lake and covers the lowlands (≤ 75 to 90 m elevation) surrounding Langford and Glen Lake. From here the aquifer extends southeast to Esquimalt Lagoon and southwest toward Dewdney Flats in Sooke and Happy Valley in Metchosin (see cross-section C_4-C_5 in Appendix B, and Aquifer Classification Map 2 in Appendix C). The aquifer boundaries were delineated based on the occurrence of sands and gravels identified as belonging to the Colwood Delta formation, as indicated on the surficial and Quaternary geology maps of the area (Monahan and Levson, 2000; Blyth and Rutter, 1993b and 1993c), and upon the occurrence of wells constructed in the unconsolidated deposit. The marine coastline comprises the south-eastern boundary of the aquifer, from Albert Head to Gotha Point at Esquimalt Lagoon.

Well records describe the deposit as alternating layers, up to 10 m (25 ft) thick, of clean to silty, fine to coarse brown or grey sand and pea gravel, interrupted by brown or blue clay strata, and underlain by till. In the Metchosin Gravel Pit area, below the Colwood Delta formation are multiple layers of till and Quadra sand, containing groundwater under artesian pressure (Howes and Nasmith, 1983). Sand and gravel sediments of the delta diminish in thickness or pinch out just north of Esquimalt Lagoon, where spring discharges flow overland and coalesce into ephemeral streams that drain from the sloped land surface seaward (Seacor Environmental Inc., 2003; Payne Engineering Geology, 1997; Payne Engineering Geology, 1996). Bedrock underlying the Colwood Delta is comprised of basalt and gabbro of the Metchosin Igneous Complex, which forms aquifer 606, and granitic metamorphosed bedrock of the Wark-Colquitz Complex delineated as aquifer 680 (Huntley, 1995; Massey, 1994).

There are 34 wells in the aquifer. The median well depth is 4.3 m (14 ft), the minimum well depth is 1.8 m (6.0 ft), and the maximum well depth is 55 m (179 ft). Depth to bedrock varies from 2.4 m (7.9 ft) to > 55 m (180 ft). The median depth to water is 5.9 m (20 ft), with a range from 1.5 to 29 m (5 to 94 ft) based on data from 10 wells (29% of wells in the aquifer). City of Colwood monitoring wells southwest of Esquimalt Lagoon indicate a shallow water table in this area, with an upward hydraulic gradient, and artesian properties noted in some wells (Payne Engineering, 1996). One monitoring well is artesian, capped and the changes in pressure monitored monthly; five monitoring wells have water levels <1.0 m from the surface year-round, based on water level monitoring from 1997 to 2003 (David Reay, City Engineer, City of Colwood, pers. comm., July 2003).

Photo 3: Drilling through sand and gravel of the Colwood Delta in Langford, April 2004; Ken and Gordon Krenbrink (right) of Tri-K Drilling Ltd.

The productivity of the aquifer is considered moderate. The median estimated well yield (based on 7 wells or 21% of well records) is 0.76 L/s (12 gpm). The minimum estimated well yield is 0.32 L/s (5.0 gpm) and the maximum estimated well yield is 6.3 L/s (100 gpm). At the Construction Aggregates Ltd. gravel pit on Metchosin Rd. a well constructed at the property in the 1950's or 1960's (actual date of construction unknown) had an estimated yield of approximately 6.3 L/s (100 gpm); in comparison, wells constructed in 2001 yielded ≤ 5 gpm. This difference in yields over time could be due to heterogeneity of the aquifer, due to development related excavation, or an increase in impervious cover over the aquifer, which may have altered the rate or locations of recharge. Wells constructed for Langford Municipality in 2001 and 2004 within the aquifer area obtained low water yields from the sand and gravel overburden and were constructed into bedrock prior to obtaining sufficient yields for irrigation purposes (Dave Newman, Langford Engineering, pers. comm. July 12, 2004). Slug testing of monitoring wells at Royal Roads University found conductivity of the sand and gravel unit to range from 1.2×10^{-4} m/s to 6.7×10^{-6} m/s (Seacor Environmental Inc., 2003). If the aquifer is assumed to range from 1.2 m to 15 m in thickness, using conductivity values shown above, the transmissivity of the aquifer ranges from 8.0×10^{-6} m^2/s to 0.18 m^2/s.

The aquifer is considered moderately vulnerable to contamination from human activities at the surface. The aquifer is partial confined by clay, till, silt or combined clay and till, observed in 18 wells (53% of the well logs). The overburden type is undetermined for 5 wells (15%) and there is no confinement observed in 11 wells (32%). The confining layer thickness has a median value of 5.2 m (19 ft) and ranges from 0.61 to 40 m (2.0 to 130 ft). These sediments are thought to be Victoria clay and Vashon till (Blyth and Rutter, 1993b). The majority of the aquifer area, including around Langford and Glen Lakes, is covered by a blanket (> 1 m thick) of glacial diamicton; marine clay overlies the aquifer close to the coast at Esquimalt Lagoon; and in the Sooke/Dewdney Flats area, glaciofluvial sands and gravels are confined by glaciolacustrine clay and silt (Blythe and Rutter, 1993b and 1993c). The Quaternary geology map confirms the existence of thicker marine clay overburden in the Esquimalt Lagoon area (Monahan and Levson, 2000). Well records also indicate that the upper strata of the Colwood Delta contain silt and clay layers, which may provide additional confinement for underlying water-bearing strata. Present and historical development in the area may increase the aquifer's intrinsic vulnerability, by reducing the thickness of confining overburden and exposing the unconsolidated unit to direct introduction of contaminants at the surface.

Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations. In the area of the aquifer extending southeast from Langford and Glen Lakes groundwater is expected to flow southeast toward the coast at Esquimalt Lagoon, as suggested in a hydrologic assessment of the Royal Roads property and groundwater monitoring in the suburban area to southwest of Esquimalt Lagoon (Seacor Environmental Ltd., 1001; Payne Engineering Geology Ltd., 1997). Above Langford Lake, groundwater flow may be northward, towards Goldstream River. The source of aquifer recharge is thought to be from infiltration and runoff of precipitation in upland regions including the slopes of Skirt Mountain, Mount Wells, Centre Mountain, Braemar Heights and Triangular Hill, from direct precipitation over the aquifer area, or locally from wetland, stream and river infiltration. Local tributaries and wetlands are also expected to be areas of aquifer discharge.

There is thought to be a low level of water demand and reliance upon the aquifer. There are records of 34 wells completed into this aquifer (not including observation/monitoring wells at Royal Roads and Esquimalt Lagoon), corresponding to a density of 1 well/km^2. Three wells located at Construction Aggregates Ltd. Metchosin gravel pit on Metchosin Rd. are abandoned or not in use. Nineteen wells on record are historical dug wells constructed in the 1940's to 1960's, which may be abandoned, or infilled, and no longer in use. Although in parts of the aquifer area, including Sooke and Metchosin, rural residents may have a limited opportunity to connect to a municipal water source, many of the contemporary wells in these areas are constructed into volcanic bedrock (aquifer 606).

Groundwater in the area is used mainly for domestic and irrigation purposes. The City of Colwood does not utilize wells for irrigation or municipal water supplies at present (David Reay, City Engineer, City of Colwood, pers. comm., July 14, 2004). Water may also be obtained from Langford Lake, Glen Lake, Florence Lake, Colwood Lake, Bilston Creek, the Goldstream River, and smaller perennial or ephemeral creeks located in the aquifer area. There are a total of 31 issued water licences for the above surface water bodies, for the purposed of irrigation, storage, land improvement and domestic use (Land and Water B.C. Inc., 2004).

There are no water use conflicts reported for the aquifer, and no documented concerns regarding water quantity. Light extractable petroleum hydrocarbon (LEPH) and polycyclic aromatic hydrocarbon (PAH) contamination of groundwater has been observed in the area surrounding a former underground fuel storage tank at Royal Roads University (Levelton Engineering Ltd., 1999; Levelton Engineering Ltd., 2001). Additionally, the shallow ground water table in the residential area southwest of Esquimalt Lagoon has contributed to incidences of septic system waste surfacing and high faecal coliform counts in storm-water runoff (Payne Engineering Ltd., 1996). There is no indication that localized contamination of the aquifer has affected domestic wells, and there are no documented health-related water quality concerns reported in Water Protection Section files.

There is one inactive MWLAP observation well constructed in the aquifer. There are seven observation wells west of Esquimalt Lagoon, in the area of Goldfinch Rd., Heatherbell Rd., Seafield Rd. and Portsmouth

Dr., constructed and monitored by the City of Colwood since August 1997 to observe changes in groundwater depth and quality (David Reay, City Engineer, City of Colwood, pers.comm., July 2003; Payne Engineering, 1997). There are an additional twenty-two 50 mm diameter monitoring wells at Royal Roads constructed by Thurber Engineering and Seacor Engineering in 1999, 2002 and 2003 (Seacor Engineering Ltd., 2003).

4.2.7 Aquifer 683: Parry Bay IIIC(8)

This unconsolidated sand and gravel aquifer is 8.9 km^2 in area. It is found in Metchosin, along the margins of Metchosin Creek, southwest of Centre Mountain, and encompasses the lowlands south of Metchosin Mountain and northeast of Montreul Hill, approximately 2.5 km inland from the coast at Parry Bay (Witty's Lagoon Park) (see cross-sections C_3-C_4 and C_4-C_5 in Appendix B, and Aquifer Classification Map 2 in Appendix C). The surficial geology map describes the aquifer area as a glaciolacustrine plain, with a blanket (> 1 m thick) of glacial diamicton overlying glaciofluvial sand and gravel fan deposits (Blyth and Rutter, 1993b). The aquifer is made up of sand and gravel from the lower and middle strata of the Parry Bay formation (Blyth and Hebda, 1993). In inland areas, the aquifer may also include water bearing Capilano sediments such as Quadra sand, and Holocene (≤ 10,000 y BP) fluvial deposits such as those found within the Metchosin Creek flood plain (Blyth and Rutter, 1993b). Underlying the aquifer is Pleistocene (>65,000 y BP) till, and bedrock of the Metchosin Igneous Complex, which forms aquifer 606 (Blyth and Hebda, 1993; Massey, 1994).

The productivity of the aquifer is considered moderate. The median estimated well yield (based on 18 wells or 75% of well records) is 0.32 L/s (5.0 gpm). The minimum estimated well yield is 0.016 L/s (0.25 gpm) and the maximum estimated well yield is 1.3 L/s (20 gpm). Based on 4 wells or 17% of wells in the aquifer, the median depth to water is 2.7 m (9.0 ft), with a range from 1.2 to 15 m (4.0 to 50 ft). The median well depth is 17 m (57 ft), the minimum well depth is 1.8 m (6.0 ft), and the maximum well depth is 64 m (210 ft). Most wells in the aquifer are not drilled entirely through the surficial sediments into the underlying bedrock; however, depth to bedrock is thought to vary from 7.6 m (25 ft) to > 28 m (92 ft) based on existing well records.

The aquifer is thought to have a low vulnerability to contamination from human activities at the land surface. Well records indicate confinement is provided by clay, till, silt or combined clay and till, observed in 22 wells (92% of wells in the aquifer). The median confining layer thickness is 12 m (40 ft), ranging from 0.61 to 35 m (2.0 to 114 ft). These sediments are assumed to be Vashon till and Victoria clay (Blyth and Rutter, 1993b).

There is expected to be a low level of water demand and a low reliance upon the aquifer for supply. There are records of 24 wells completed into this, corresponding to a density of 3 wells/km^2. Five wells on record are historical dug wells constructed in the 1940's to 1960's (actual date of construction unknown), which may be abandoned or infilled and no longer in use. Although, in much of the aquifer area, rural residents have a limited opportunity to connect to a municipal water source, many of the contemporary wells are drilled through aquifer 683 and completed into the underlying bedrock (aquifer 606). Groundwater in the area is used mainly for domestic and irrigation purposes. Water may also be obtained from Sherwood Creek, Sherwood Pond, Hewitt Creek, Metchosin Creek, Cole Creek, and smaller perennial or ephemeral creeks located in the aquifer area. There are a total of 14 issued water licences for the above listed surface water bodies, for the purposed of irrigation, storage, land improvement and domestic use (Land and Water B.C. Inc., 2004).

The source of aquifer recharge is thought to be from infiltration and runoff of precipitation in upland regions including the slopes of Montreul Hill, Blinkhorn Mountain, Single Hill and Metchosin Mountain; from direct precipitation over the aquifer area; or locally from wetland, stream and river infiltration. Surface streams, lakes and wetlands may also be areas of aquifer discharge. Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations. In this case, groundwater flow is likely southeast and toward the coast.

There are no active or inactive MWLAP observation well constructed in the aquifer, and no reported water use conflicts. There are also no documented concerns regarding water quantity, no health-related water quality concerns documented in Water Protection Section files.

4.2.8 Aquifer 684: Goldstream IIIA(10)

The aquifer is a 0.25 km^2 fluvial silty–sand and gravel fan deposited at the mouth of the Goldstream River where it enters Finlayson Arm, at the south end of Saanich Inlet (see Aquifer Classification Map 2 in Appendix C). The sediments are composed of re-worked glaciofluvial sands and gravels from the Colwood delta, deposited in the Goldstream River floodplain (Monahan and Levson, 2000; Blyth and Rutter, 1993b). Northward river flow in the Goldstream basin commenced near the end of the Fraser glaciation, when glacial ice receded from Finlayson Arm (Howes and Nasmith, 1983). Well records describe coarse water-bearing gravel or a coarsening downward sequence of silty sand, boulders, sandy gravel, coarse gravel and boulders underlain by clay. Metasedimentary and metavolcanic bedrock of the Leech River Complex is found below the fluvial sediments (Massey, 1994). The aquifer boundaries were delineated based on the mapped physical extent of the Goldstream River fan deposit, as indicated on the surficial and Quaternary geology maps of the area, and upon the occurrence of wells constructed in the unconsolidated deposit (Monahan and Levson, 2000; Blyth and Rutter, 1993b). The northern boundary of the aquifer is defined by the marine coastline at Finlayson Arm.

The aquifer has a high productivity, is shallow, and likely hydrologically connected to the Goldstream River. The estimated well yields for two wells constructed in the aquifer range from 3.2 L/s to 4.7 L/s (50 to 75 gpm). The depth to water ranges from 1.8 m to 6.7 m (6.0 to 22 ft). The well depth ranges from 12 to 17 m (38 to 55 ft). The depth to bedrock is unknown, based on available data.

The level of water demand and reliance upon the aquifer is considered low. There are only two wells presently constructed in the aquifer, and the majority of the aquifer area is surrounded by Provincial park land; therefore, there is unlikely to be significant further development of the aquifer for domestic use. The aquifer is likely a source of base-flow to the Goldstream River, which is an important salmon-bearing stream on southern Vancouver Island. Therefore significant withdrawals of water from the aquifer and/or construction of new wells may be undesirable from this perspective, if surface water and groundwater impacts are not assessed. Groundwater is used for domestic purposes (drinking water, bathroom facilities) at the Provincial park camp ground. Water may also be obtained from the Goldstream River; although the CRD/Victoria Water District holds the only current licences for withdrawals from Goldstream River (Land and Water B.C. Inc., 2004).

The aquifer is considered highly vulnerable to contamination from human activities at the surface, as it is shallow, unconfined, made up of coarse unconsolidated sediments with a high intrinsic permeability and is possibly hydrologically connected to the surface water system in this area (Goldstream River). Although contiguous confining layers are not indicated in well records, layers or lenses of silt and/or silty clay may be present, reducing the intrinsic vulnerability locally by slowing infiltration of pollutants from the surface.

The source of aquifer recharge is thought to be from infiltration and runoff of precipitation in upland regions on the steep bedrock slopes to the west and east of the estuary, including Mount Finlayson; direct precipitation over the aquifer area; and/or wetland, stream and river infiltration. The Goldstream River and adjacent wetlands are also expected to be areas of aquifer discharge, especially during low flow periods. Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations. Additionally, as there is thought to be a hydrologic connection between the Goldstream River and the aquifer; water flow is likely from the margins of the aquifer toward the centre and northward, in keeping with the direction of river flow.

There are no water use conflicts, no water quantity concerns, and no health-related water quality concerns for the aquifer documented in Water Protection Section files. There are no MWLAP observation wells in the aquifer.

4.2.9 Aquifer 618: Port Renfrew IIIC(8)

This confined bedrock aquifer is found at Port Renfrew, on the south side of Port San Juan, the San Juan River inlet, on the southwest coast of Vancouver Island (see Aquifer Classification Map 4 in Appendix C). The aquifer is 5.8 km^2 in area and is made up of shale and minor sandstone of the Leech River Formation (Massey, 1994). Well records describe the bedrock of this aquifer as brown to black shale, with quartz or sandstone ‘stringers’ or veins; records also describe a clay overburden, and a zone of weathered and broken bedrock or colluvium, overlying more competent shale. A single well describes the bedrock as mixed shale and slate, indicating the bedrock has undergone varying degrees of metamorphosis. In some wells, such as the Port Renfrew municipal production well, water is found within the layer of weathered shale or colluvium that lies between the bedrock and the overlying till and clay sedimentary overburden (Gary Hendren, Local Services Engineering Coordinator, CRD Environmental Services, pers.comm., August 13, 2004; Thurber Consultants Ltd., 1986). The marine coastline comprises the northwestern and northern aquifer boundaries. The southern boundary follows the divide of the surface watershed overlying the developed aquifer area and may change in future to encompass areas of new well development.

South of the delineated aquifer, along the coast at Botanical Beach and at Providence Cove, conglomerate and sandstone bedrock of the Sooke Formation unconformably overlies the Leech River Complex (Massey, 1994). Bedrock of the Sooke Formation comprises aquifer 499 in Sooke; however, in the area of Port Renfrew there are no records of wells constructed into the younger sedimentary unit.

Overlying the metasedimentary Leech River Formation, northeast of the delineated aquifer, are Quaternary to Holocene (2 My BP - present) glaciofluvial and fluvial flood plain sediments associated with the San Juan River and its tributaries (Province of B.C., 1958). This sedimentary deposit has been delineated separately as aquifer 685, and wells constructed in the unconsolidated deposit are a source of domestic water supply for the Pacheedaht First Nation and the Village of Port Renfrew (Rodney Thur, Pacheedaht Band Administrator, pers.comm., August 13, 2004; Thurber Consultants Ltd., 1986).

The productivity of the aquifer is considered low. The aquifer is comprised of metasedimentary bedrock typically associated with low to moderate yields, and estimated well yields, only available for 2 of 12 wells (17% of well records), and both have reported yields ≤ 0.06 L/s (1 gpm). A number of the wells appear to have been abandoned and the casings pulled, either due to low well yields, cave-ins or subsidence of the friable bedrock at depth in the wells. The median water depth is 15 m (50 ft), ranging from 1.8 to 30 m (6 to 98 ft). The well depth ranges from 12 to 137 m (40 to 450 ft) and the median well depth is 37 m (120 ft). The depth to bedrock ranges from 0 m (bedrock at surface), to 39 m (129 ft).

The vulnerability of the aquifer to contamination from human activities on the land surface is considered low. Recent, detailed, information on the surficial and Quaternary geology of the area is not available. Howover, historical surficial geology mapping describes the overburden as ≤ 1 m thick colluvium, and less commonly glaciomarine till from < 1 m to ≥ 1 m in thickness (Province of B.C., 1958). All but one of the wells on record are confined by marine clay. Upslope areas may have a higher intrinsic vulnerability, as the overburden is predominantly colluvium, or broken/weathered bedrock with little to no confining properties. The aquifer may be vulnerable to salt water intrusion, in particular due to the high secondary porosity arising from the friable character of the metasedimentary bedrock. The majority of the upslope/recharge area of the aquifer is undeveloped Crown Land or forestry tenures.

The level of water demand and reliance upon the aquifer is considered low. There are records of 12 wells completed into the aquifer, corresponding to a density of 2 wells/km^2. Groundwater from the aquifer is believed to be used mainly for domestic purposes. This area has a high annual rainfall, a low degree of urban or rural development and an abundance of large to small tributaries and lakes including the San Juan River, Tom Baird Creek, Pioneer Creek, Defiance Creek and East Defiance Creek that are thought to provide some water for domestic, commercial and industrial purposes. There are twelve water licences issued for the water bodies listed above, for the purpose of irrigation, stock watering, enterprise, storage and domestic use (Land and Water B.C. Inc., 2004).

Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations. The source of aquifer recharge is thought to be from infiltration and runoff of precipitation in upland regions, particularly the steep bedrock slopes in the south area of the aquifer. Recharge is also likely derived from direct precipitation over the aquifer area, and/or infiltration from wetlands, streams and rivers. Local tributaries and wetlands are also expected to be areas of aquifer discharge. Based on the present aquifer boundary, delineated according to the area of development, water flow is inferred to be northeast toward the Port San Juan inlet.

One unconsolidated well in this area, constructed in marine sand, gravel and clay, was abandoned as it yielded saline water; it is not clear whether this was due to salt water intrusion, the presence of connate water trapped within the sediments, or salinization of meteoric water in contact with marine sediments. Arsenic concentrations above the Guidelines for Canadian Drinking Water Quality have been measured seasonally in the Port Renfrew municipal production well, which penetrates the bedrock of this aquifer with water obtained from the overlying unconsolidated shale-gravel or colluvium of aquifer 685; treatment of the well water consists of filtration through a greensand filter, and efforts are presently underway to identify a suitable location for an alternate municipal supply well (Gary Hendren, Local Services Engineering Coordinator, CRD Environmental Services, pers.comm., August 13, 2004). There are no additional health-related water quality concerns documented in Water Protection Section files. There are no water use conflicts associated with the aquifer and no concerns regarding water quantity documented in Water Protection Section files. There are no MWLAP observation wells in the aquifer.

4.2.10 Aquifer 685: Pacheedaht IIIA(14)

This partially confined unconsolidated aquifer is found at Port Renfrew on the southwest coast of Vancouver Island, and is made up of Quaternary to Holocene (2 My BP to present) glaciofluvial and fluvial flood plain and fan deposits of sand and gravel associated with the San Juan River and its tributaries (see Aquifer Classification Map 4 in Appendix C). With an area of 41.2 km^2, the aquifer is the largest unconsolidated aquifer in the CRD. Its boundaries were delineated based on the spatial extent of fluvial and glaciofluvial deposits, as indicated on surficial geology maps of the area, and upon the lateral topographic boundaries of the floodplain (Province of B.C., 1958). The marine coastline at the mouth of the San Juan River estuary forms the western boundary of the aquifer. Only seven wells are known to be constructed into this sand and gravel aquifer, including four shallow wells on the Pacheedaht First Nation reserve (Gordon River Indian Reserve No. 2), and the Port Renfrew municipal production well.

Fluvial and glaciofluvial sediments are believed to extend to depths of ≥ 40 m and may be layered with silt or clay deposits, particularly near the maritime coast. One of the deeper (9.1 m or 30 ft) wells at the Pacheedaht reserve goes through a confining clay or till layer, below which are found water-bearing sediments (Rodney Thur, Pacheedaht Band Administrator, pers.comm. August 13, 2004). Additionally, the Port Renfrew municipal production well penetrates alternating layers of sand, silt, marine clay and gravel indicating that there may be several confining layers and multiple water–bearing strata, that could be considered separate aquifers if more information was available. For example, a shallow Port Renfrew municipal production well (no longer is use, well detail unavailable) is affected by tidal fluctuations; whereas the deeper (24 m) active production well is unaffected by tides, although this may be due to better surface sealing of the well (Thurber Consultants Ltd., 1986). The depth or extent of confinement of the aquifer upstream in the San Juan River floodplain is not known based on available data. The San Juan River floodplain is underlain by bedrock of the Leech River Complex (Massey, 1994).

The productivity of the aquifer is considered high. A moderately shallow (24 m deep) well at the Port Renfrew River Hatchery, 6 km northeast of Port Renfrew, has an estimated yield of 13 L/s (≥ 200 gpm) (Marice Tremblay, Port Renfrew River Hatchery, Manager, pers.comm., May 2004). The median estimated well yield is 2.0 L/s, and the range is from 1.3 to 13 L/s (42, 20 and 200 gpm respectively). Despite the high inferred aquifer productivity, the Pacheedaht Band's main water supply is a dug well only 5.2 m (17 ft) deep, that is subject to seasonal low water levels in late summer to early fall, exacerbated by tidal influence on the well which often brings water levels to below the height of the pump intake. There are plans to replace the existing well due to the problems described (Mike Pichichero, Health Canada, Health Inspector, pers.comm., August 11, 2004; Rodney Thur, Pacheedaht Band Administrator, pers.comm. August 13, 2004).

The water table is considered shallow. The static water level ranges from 1.3 to 4.6 m (4.2 to 15 ft). The median well depth is 8.5 m (28 ft), ranging from 3.7 to 24 m (12 to 160 ft). Depth to bedrock is thought to be up to or greater than 41 m (134 ft).

The aquifer is considered highly vulnerable to contamination from human activities on the land surface. Only two of the wells are known to be confined by clay or till sediments and the surficial geology mapping for the area suggests that fluvial/glacial sediments of the aquifer are exposed at the land surface with little to no confining overburden (Province of B.C., 1958). Upslope recharge areas are also largely unconfined, and overlain by a surficial layer of highly permeable colluvium, or broken/weathered bedrock with little or no confining properties. The aquifer may also be hydrologically connected to the San Juan River. Possible saline intrusion has been noted in wells of bedrock aquifer 618 southwest of the Pacheedaht aquifer (685). Although the intrinsic vulnerability of the aquifer is high, there is a low level of development in the aquifer area; the majority of the upslope/recharge area of the aquifer is undeveloped Crown Land or forestry tenures.

The level of water demand and reliance upon the aquifer is considered low. There are only seven known wells completed into this 41 km^2 aquifer, corresponding to a density of <1 well/km^2, only four of which are confirmed to be in use. There may be additional wells constructed in the aquifer for which MWLAP does not have records. Water wells at the Port Renfrew River Hatchery are a source of secondary water supply, the primary hatchery supply being obtained from Granite Creek (Maurice Tremblay, Hatchery Manager, Port Renfrew River Hatchery, pers. comm.., June 7, 2003).

Groundwater from the aquifer is believed to be used for mainly for domestic purposes, in addition to supplying water to the Port Renfrew fish hatchery. This area has a high annual rainfall, a low degree of urban or rural development and an abundance of large to small tributaries and lakes including Pioneer Creek, East Defiance Creek, Defiance Creek, the San Juan River, and Tom Baird Creek that provide some water for domestic, commercial and industrial use in the area. There are twelve water licences issued for the water bodies listed above, for the purpose of irrigation, stock watering, enterprise, storage and domestic use; notably there are no licenced water works for municipal surface water withdrawals (Land and Water B.C. Inc., 2004).

Groundwater is expected to flow from high elevation recharge areas to discharge areas at lower elevations, and from upstream to downstream within the river floodplain. Based on the delineated aquifer boundary, water is thought to flow from upland regions toward the central San Juan River channel, and westward toward the ocean, in the direction of river flow. The source of aquifer recharge is thought to be from infiltration and runoff of precipitation in upland regions, particularly the steep bedrock slopes to the north and south of the aquifer. Recharge is also likely derived from direct precipitation over the aquifer area, and/or infiltration from wetlands, streams and rivers. Local tributaries and wetlands are also expected to be areas of local aquifer discharge.

The main dug well serving the Pacheedaht First Nation community is subject to seasonal low supply and is likely to be replaced in future due to both water quality and quantity concerns (Mike Pichichero, Health Canada, Health Inspector, pers.comm., August 11, 2004; Rodney Thur, Pacheedaht Band Administrator, pers.comm. August 13, 2004). It is thought that water quantity in this well is a concern mainly due to the shallowness of the well (6 to 9 m or 30 to 40 ft), rather than due to a problem with aquifer productivity, therefore the concern was not documented within the aquifer ranking.

A deeper well (9.1 m) well belonging to the Pacheedaht First Nation is not in use at present due to sulphurous odour and iron concentrations above the Guidelines for Canadian Drinking Water Quality aesthetic objective (Mike Pichichero, Health Canada, Health Inspector, pers.comm., August 11, 2004; Rodney Thur, Pacheedaht Band Administrator, pers.comm. August 13, 2004; Kerr Wood Leidal Associates Ltd., 2003). Possible saline intrusion has been noted in an unconsolidated well in the area of aquifer 618, < 0.5 km southwest of aquifer 685. Arsenic concentrations above the Guidelines for Canadian Drinking Water Quality have been measured seasonally in the Port Renfrew municipal supply well, which is constructed into the deeper, confined portion of the aquifer on the south side of the San Juan River floodplain; treatment of the well water consists of filtration through a greensand filter, and efforts are presently underway to identify a suitable location for an alternate municipal supply well (Gary Hendren, Local

Services Engineering Coordinator, CRD Environmental Services, pers.comm., August 13, 2004; Thurber Consultants Ltd., 1986).There are no additional health-related water quality concerns documented in Water Protection Section files.

There are no reported water use conflicts, and no MWLAP observation wells in the aquifer.

5. Discussion

This project focussed on the identification and classification of developed aquifers within CRD on southern Vancouver Island. The project was completed in two phases during the summers of 2003 and 2004. Data used to map and classify aquifers in this region included over 4,170 well records, geologic and topographic maps, and numerous previous geologic and hydrogeologic studies of the area (see References). In total, 24 aquifers were mapped, 16 comprised of unconsolidated sediments, and 8 comprised of sedimentary, igneous or metamorphic bedrock.

Aquifer Classification

Classification of the aquifers involved characterizing each aquifer based on properties such as productivity, vulnerability, type of use and dependence upon the groundwater resource. The study findings are summarized below, in relation to the primary aquifer classification criteria.

Level of Development

Within the CRD, the level of development of fifteen aquifers was found to be low, while the remaining nine aquifers had a moderate level of development. The low to moderate level of development reflects, in part, the availability of municipally supplied surface water over much of the study area. On the Saanich Peninsula, and in parts of Colwood and Metchosin, areas of higher well density were often thought to reflect early settlement and historical aquifer development, rather than present groundwater use. Areas with a higher density of recently constructed wells include Willis Point and the District of Highlands. The low level of aquifer development in Sooke and outlying communities such as Port Renfrew may result from the fact that there are fewer reported wells in these areas, or that the population density is lower.

Level of Vulnerability

Aquifers were assessed in terms of their intrinsic vulnerability to contaminants introduced at the land surface, based on aquifer and overburden lithology. This assessment did not consider aquifer vulnerability relative to land use criteria or potential contaminant sources. Within the Saanich Peninsula and Victoria areas, the vulnerability of aquifers was generally low to moderate, due to the low topographic relief, and the presence of confining sediments such as Victoria clay, generally at elevations ≤60 m, and Vashon till, typically observed below 80 to 100 m (Monahan and Levson, 2000; Blyth and Rutter, 1993a). Localized erosion and removal of confining sediments was thought to increase the vulnerability of many aquifers, resulting in their classification as moderately vulnerable.

Aquifers in Sooke, the Western Communities and outlying areas were found at both ends on the vulnerability scale (from high to low), depending on the relative extent of confining glacial, glaciomarine and fine lacustrine sediments, which was again largely a function of elevation. Larger bedrock aquifers (e.g. aquifer 606) often encompass land at higher elevations, where the overburden is a thin layer of colluvium with little to no confining properties; thus aquifers that include upland areas, such as aquifer 606 in Sooke-Metchosin and aquifer 681 at Willis Point are considered highly vulnerable. Bedrock and unconsolidated aquifers at lower elevations in the Sooke area are thought to have a moderate to low vulnerability, depending on the overburden type and percentage of confined wells. The aquifers at the Goldstream and San Juan Rivers (684 and 685) were considered highly vulnerable, based on a lack of confining sediments and due to the potential hydrologic connectivity between the aquifers and major rivers in the aquifer area.

Productivity

On the whole, the productivity of aquifers in the CRD was found to be low to moderate. Two aquifers, one at the Goldstream River and the other at the San Juan River (aquifers 684 and 685 respectively), both associated with major river floodplains, are considered highly productive. Nine aquifers are considered moderately productive, and the remaining thirteen are thought to have a low productivity. Aquifers with a low productivity include smaller unconsolidated deposits or bedrock aquifers. Aquifer 449 at Muir Creek, made up of sedimentary sandstone and conglomerate, is the highest yielding bedrock aquifer; the yield of wells in bedrock aquifers was often found to be greater in proximity to surface water bodies such as lakes and streams.

Aquifer Area and Lithology

Aquifers in the CRD ranged in size, from small pockets of sand and gravel < 1 km^2 in area, to large bedrock bodies such as the aquifer Sooke-Metchosin which covers 538 km^2. Aquifer 685 (Pacheedaht) is the largest unconsolidated aquifer in the region, followed by aquifer 682 (Colwood Delta) and 599 (Sooke River). The remaining aquifers, such as those on the Saanich Peninsula, made up of sand and gravel of the Quadra Formation and Cowichan Head Formation, are small in size, as these deposits tend to be discontinous in that area. Aquifer 606 (Sooke-Metchosin), comprised of igneous and volcanic bedrock is the largest aquifer in the CRD. Other large bedrock aquifers include aquifer 680 made up of metamorphic gneiss of the Wark-Colquitz Complex, and aquifer 608 in the North to Central Saanich area, formed from igneous granitic rock. Three aquifers (449, 607 and 618) are comprised of sedimentary to metasedimentary bedrock such as shale, sandstone and conglomerate.

Table 6 compares some of the statistical properties of the unconsolidated and bedrock aquifers identified in the CRD. On average, wells in bedrock aquifers are drilled 68% deeper than wells in unconsolidated aquifers. The confining layer thickness was found to be 98% greater overlying unconsolidated aquifers compared to bedrock aquifers. Larger numbers of wells were found in bedrock aquifers, but this is mainly a function of their greater size, as shown by the similarity in well density between the two lithological groups. The median well yield was, not surprisingly, greater for unconsolidated aquifers; although the difference is not large.

Table 6: Comparison of bedrock and unconsolidated aquifer properties

Aquifer property	Unconsolidated		Bedrock	
Total number of aquifers	16		8	
Average number of wells in aquifer	23		470	
Median aquifer area	2.7	km^2	22	km^2
Median well density	8	wells/km^2	9	wells/km^2
	L/s	gpm	L/s	gpm
Median well yield	0.35	5.5	0.22	3.5
	m	ft	m	ft
Median well depth	16	54	51	166
Median water depth	7.2	24	6.5	21
Median bedrock depth	19	62	4.3	14
Median confining layer thickness	8.5	28	4.3	14

Demand for the Resource, Reliance Upon Groundwater, and Type of Use

The relative demand for groundwater is thought to be low to moderate in the majority of the CRD. None of the aquifers identified are thought to have a high level of water demand, due to the availability of municipal surface water supplies in the majority of municipalities (Capital Regional District, 2002). Water from eight aquifers is thought to be for non-potable use (primarily irrigation), ten aquifers supply drinking water, and six aquifers are thought to provide water for multiple purposes including irrigation, domestic and commercial use.

On the Saanich Peninsula, groundwater is thought to be an important water supply source for irrigation and commercial use. Although municipally supplied surface water is now available in most areas, domestic households, agricultural and industrial operations may remain largely dependent on groundwater locally. The relative demand and reliance upon groundwater in this area was difficult to quantify, because the number of farms or households using groundwater, and the volume of water used on an annual basis, is not known.

There is thought to be a greater reliance upon wells for domestic use in other areas of the CRD, such as at Willis Point, in the District of Highlands and in parts of Sooke, Metchosin, the Western Communities outside of the municipal core boundaries, and beyond the reach of municipal drinking water infrastructure. Similarly, in the Port Renfrew area, groundwater from aquifers is the main water source for domestic and other uses in the Village of Port Renfrew and on the Pacheedaht Reserve. Despite the greater dependence upon the resource at Port Renfrew, overall demand is still expected to be low to moderate, due to the low population density and low number of wells.

Identified Concerns Related to Water Quality or Quantity

Water quality concerns were identified in six aquifers; however these were considered isolated in nature, affecting a small number of wells, and were not thought to reflect local or regional groundwater quality. Identified concerns related to human health included isolated occurrences of bacterial contamination and localized hydrocarbon contamination from underground storage tanks. A high concentration of nitrate, not exceeding the Guidelines for Canadian Drinking Water Quality, but close to the maximum allowable concentration, was identified in one aquifer. Additionally, elevated concentrations of arsenic exceeding the Guidelines for Canadian Drinking Water Quality were reported for one aquifer. Isolated concerns related to the aesthetic potability of water included elevated concentrations of iron and manganese, and intrusion of saline waters in coastal areas.

Isolated concerns related to water quantity were identified in eight aquifers, mainly related to well interference, seasonal low yields or dry wells. Problems of low water quantity were more common for bedrock aquifers; for example, many of the wells in the Sooke-Metchosin aquifer have very low yields (< 1 gpm), due to a low degree of fracturing in the volcanic bedrock.

Hydrogeologic cross-sections

The hydrogeologic cross-sections (Appendix B) were an effective tool to assist in aquifer boundary determination and in aquifer classification. Through the spatial correlation of well logs and surface topography, the subsurface detail was inferred and used as an aid to interpretation of the hydrogeology of the region. Cross sections A and B illustrate the numerous shallow to moderately deep unconsolidated aquifers on the Saanich Peninsula and in Victoria, relative to underlying bedrock aquifers of differing lithology. The partial confinement of aquifers in this region is illustrated by windows or gaps in confining till and sand layers. Cross-section C illustrates the lack of significant surficial sediments, and predominance of low yielding deep bedrock wells in many parts of Sooke, in contrast to the deep surficial deposits observed near the coast in Metchosin and Colwood.

Observation Wells in the CRD

Within BC water levels and water quality in a number of reference wells are monitored on a regular basis as part of the B.C. Observation Well Network (MWLAP, 2001b). The program began in 1961, and has expanded to include active monitoring at 163 wells within 56 bedrock aquifers and 109 unconsolidated aquifers throughout the province. The monitoring program involves the collection, analysis and interpretation of hydrographs and groundwater quality data on a long term basis. Water levels are monitored through the use of continuous data loggers or monthly manual measurements by local observers. Some of the objectives of the program are to assess the effects of aquifer development on water levels, to obtain information on rates and sources of groundwater recharge, or to identify, assess, and resolve concerns regarding the quantity or quality of groundwater, in relation to climatic and anthropogenic influences.

Photo 4: MWLAP technician Russ Liboiron uploads data from Observation Well 65 at the Victoria International Airport, in Sidney, July 2003. The continuous data logger inside the well is powered by the solar panels.

In all there are sixty-eight active and inactive MWLAP observation wells within the CRD, including those situated on the Gulf Islands. Twenty-four established observation wells are actively being monitored and forty-four are abandoned or inactive at this time. Observation wells are actively maintained within six of the twenty-four aquifers identified in the CRD. These observation wells are concentrated on the Saanich Peninsula, with the majority in aquifer 608 (North-Central Saanich), which has eight observation wells. One observation well has been established within the bedrock aquifer 614 (Karmutsen), and another in bedrock aquifer 606 (Sooke-Metchosin). The remaining observation wells are found in unconsolidated aquifers 609 (Littlewood), 610 (Bazan Bay), and 612 (Keating). A summary of active observation wells in the CRD, including the Gulf Islands, is included in Table 7.

Table 7: List of active groundwater level observation wells in the CRD

Aquifer Number	Observation Well Number	Location	Well tag no.	Well depth (m)	Lithology	Longitude (°W)	Latitude (°N)	Period of record	No. years on record	Affected/ unaffected by pumping
608	333	Central Saanich	58854	61	Bedrock	123.474	48.597	1997 - Present	6	YES
608	338	Central Saanich	34371	213	Bedrock	123.417	48.573	1998 - Present	5	YES
608	343	Central Saanich	56374	152	Bedrock	123.446	48.599	2000 - Present	3	YES
614	71	Cordova Bay	2133	14	Unconsolidated	123.375	48.53	1976 - Present	27	YES
NM[1]	258	Galiano Island	44593	91	Bedrock	123.326	48.874	1980 - Present	23	YES
NM	326	Galiano Island	25732	43	Bedrock	123.32	48.879	1994 - Present	9	YES
NM	327	Galiano Island	14582	30	Bedrock	123.335	48.886	1994 - Present	9	YES
NM	125	Mayne Island	20721	30	Bedrock	123.275	48.843	1971 - Present	32	NO
NM	126	Mayne Island	26713	71	Bedrock	123.292	48.861	1973 - Present	30	NO
NM	128	Mayne Island	24845	69	Bedrock	123.283	48.869	1973 - Present	30	YES
NM	341	Metchosin	62648	137	Bedrock	123.575	48.373	1999 - Present	4	YES
608	240	North Saanich	31523	152	Bedrock	123.466	48.637	1979 - Present	24	YES
608	265	North Saanich	30098	30	Bedrock	123.462	48.645	1980 - Present	23	YES
NM	283	Pender Island	51834	93	Bedrock	123.315	48.815	1983 - Present	20	YES
NM	284	Pender Island	51833	93	Bedrock	123.257	48.749	1983 - Present	20	YES
610	58	Saanich	20142	15	Unconsolidated	123.418	48.631	1966 - Present	37	NO
609	60	Saanich	20143	14	Unconsolidated	123.43	48.659	1966 - Present	37	YES
612	61	Saanich	21782	18	Unconsolidated	123.394	48.561	1971 - Present	32	YES
608	62	Saanich	20483	78	Bedrock	123.456	48.677	1975 - Present	28	YES
608	65	Saanich	25891	154	Bedrock	123.413	48.649	1972 - Present	30	NO
608	212	Saanich	32493	41	Bedrock	123.448	48.682	1977 - Present	26	YES
NM	281	Saltspring Island	31939	107	Bedrock	123.458	48.852	1983 - Present	20	YES
NM	290	Saturna Island	48780	43	Bedrock	123.182	48.802	1985 - Present	18	YES
NM	319	Saturna Island	59381	110	Bedrock	123.061	48.782	1992 - Present	11	YES

[1] NM[1]= Not mapped as a part of this project.

6. Conclusions

A total of twenty-four aquifers were identified in the CRD; sixteen are unconsolidated aquifers and eight are bedrock aquifers. These aquifers range in size from < 1 km^2 to 538 km^2. The majority of the unconsolidated aquifers were in the small to moderate size categories, while the size of bedrock aquifers were generally larger.

The presence of unconsolidated deposits within the CRD is attributed to glacial activity within the region in the past 20,000 years. Glacial and glaciofluvial modification of the landscape has resulted in the occurrence of significant water bearing deposits, typically formed from the sands and gravels of Capilano sediments, the Quadra Formation and the Cowichan Head Formation. Delineated aquifers were also comprised of sedimentary, volcanic, igneous, or metamorphic bedrock.

All of the identified aquifers were classified as having a low or moderate level of development, due to a low well density and due to the availability of municipally supplied surface water that is expected to reduce groundwater demand in the most locations. Although there are no highly developed aquifers in the region, areas of high well density do occur, including at Willis Point, in North Saanich (Ardmore), and in the District of Highlands.

Nine aquifers were classified as having a low vulnerability, ten aquifers are considered moderately vulnerable, and five aquifers are considered highly vulnerable. Confined or partially confined aquifers within the study area are overlain by variably thick confining deposits of clay and till. Larger bedrock aquifers are considered more vulnerable, as they often encompass upland regions overlain by colluvium, which is not thought to provide significant degree of protection from contamination.

Two aquifers, both found in major river floodplains such as the Goldstream River and San Juan River, were classified as highly productive. Nine aquifers were considered moderately productive, and the productivity was considered low for thirteen aquifers. The productivity of unconsolidated aquifers was generally higher than for bedrock aquifers.

The type of groundwater use ranged from aquifers where wells are thought to be used mainly for non-potable purposes, such as irrigation, to aquifers that provide water domestic, irrigation, commercial and other purposes.

Water quality concerns were identified in six aquifers; however these were isolated in nature, affecting a small number of wells, and were not thought to reflect local or regional groundwater quality. Identified concerns related to human health included isolated occurrences of bacterial contamination and localized hydrocarbon contamination from underground storage tanks. High concentrations of nitrate reported for one aquifer but were within the Guidelines for Canadian Drinking Water Quality. Additionally, elevated concentrations of arsenic exceeding the Guidelines for Canadian Drinking Water Quality were reported for one aquifer. Isolated concerns related to the aesthetic potability of water included elevated concentrations of iron and manganese, and intrusion of saline waters in coastal areas. Isolated concerns related to water quantity were identified in eight aquifers, mainly related to well interference, seasonal low yields or dry wells.

7. Recommendations

This study has been limited to the identification and classification of aquifers within the Capital Regional District on Vancouver Island. Since the initial phase of the aquifer mapping and classification project in 2003, the locations of wells and aquifers in the Capital Region were added to the data set included on the CRD Natural Areas Atlas. Following the completion of the inventory of aquifers in the study area, the following steps should be considered by the CRD:

1. Present the project results to representatives of the CRD, municipalities and local stewardship groups and stakeholders;
2. Include display themes for all mapped and classified aquifers in the CRD Natural Areas Atlas online resource;
3. Consider exploring ways to promote local well stewardship, to educate well owners about water conservation practices, regular testing of the quality of their well water, and proper well maintenance, operation and abandonment. This may be done in partnership with MWLAP or the local health unit.

The Ministry of Water, Land and Air Protection should consider establishing observation wells within priority aquifers in Victoria, Sooke and outlying areas, including aquifers 599 (Sooke River), 618 (Port Renfrew), 680 (Wark–Colquitz), and 685 (Pacheedaht), which are not currently being monitored by observation wells in the B.C. Observation Well Network.

The identification and classification of aquifers is the first phase in groundwater resource protection. Community education, awareness, and education on water conservation, development and implementation of best management practices, and consideration of groundwater protection measures in local planning are further measures that could be taken to protect and preserve groundwater resources in the CRD for future use.

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9. Glossary

Accretion:	The slow addition to land by deposition of water-borne sediment or along margins of continental land masses.
Alluvial Deposits (Alluvium):	A general term for clay, silt, sand, and gravel deposited during recent geologic time by a stream or river (by running water), as sorted sediments in the bed of the stream, floodplain or delta or as a fan at the base of a mountain slope.
Ambient Groundwater Flow:	The rate of flow and direction of flow of groundwater under unpumped, natural conditions.
Annual Hydrograph:	A continuous graph showing the streamflow or groundwater level over a year or over years.
Aquifer:	A geological formation, group of formations, or part of a formation that comprises sufficient saturated permeable materials to yield economical quantities of water to wells and springs.
Aquifer Vulnerability:	An intrinsic measure of how easily an aquifer can be contaminated from activities at the land surface, based on the aquifer's geologic and hydrologic characteristics only. Vulnerability for an aquifer is defined regardless of the type and intensity of the human activities at the land surface.
Aquitard:	A geologic formation, group of formations, or part of a formation that does not comprise sufficient permeable materials to yield economical quantities of water to wells and springs. An aquitard can, however, contribute a significant amount of water over a large area to an aquifer. Aquitards typically consist of till, silt or clay.
Asthenosphere:	The lower part of the earth's crust that is thought to have a low strength and rigidity compared to the upper crust (lithosphere).
Bacteria:	One-celled microorganisms, some of which cause diseases in plants or animals.
Base flow:	The sustained low flow in a stream. Generally base flow is the inflow of groundwater to the stream. Flows in a stream during the dry season is usually made up entirely of baseflow.
Bedrock:	A general term for the rock, usually solid, that underlies soil or other unconsolidated sediments.
Cadastral Maps:	Maps showing the legal property boundaries. Usually large scale maps.

Capture Zone:	The land area around a pumping well which is the source of recharge that contributes water to the well. Also known as the recharge area for the well.
Catchment Area:	The land area that drains water to an outlet point along a stream. Also called a drainage basin or watershed.
Coliform Bacteria:	A type of bacteria present in the intestinal tracts of humans and other warm-blooded animals but also found naturally in soil.
Colluvial Deposits:	Weathered, unconsolidated materials transported and deposited by gravity.
Community Well:	A well supplying water to two or more dwellings or supplying any commercial premise serving the public.
Concentration:	Refers to the weight of a chemical constituent in a given weight or volume of water, e.g., mg per litre (mg/L).
Confined Aquifer:	Where an aquitard overlies an aquifer, the low permeability of the aquitard can help inprotecting the underlying aquifer from impacts of human activities at the land surface. In those cases, an aquifer is said to be "confined".
Database:	A collection of records and files that are logically organized to assist with the analysis and processing of data.
Discharge Area:	The land area where groundwater flows back towards the land surface. Features that are common to discharge areas are springs, wetlands and shallow water tables.
Drainage Basin:	The land area that drains water to an outlet point along a stream. Also called a catchment area or watershed.
Drainage Divide:	The height of land that separates one watershed from neighbouring watersheds. Also called the watershed boundary.
Drawdown:	The difference between the static water level and the pumping water level.
Drilled well:	A well that is constructed with a drilling rig, such as an air rotary or cabletool drilling rig.
Dug well:	A well that is dug by hand or excavated by backhoe.Dug wells are usually shallow and often unsanitary.
Eustasy (eustatic):	Change in sea level over a geologic time period in response to change in the volume of water held or released within glaciers.

E. coli Bacteria:	A type of coliform bacteria found in the intestinal tracts of humans and other warm-blooded animals. One strain of *E. coli*, O157:H7 can cause severe illness in humans.
Estuarine:	Pertaining to an estuary environment, where fresh water from a river or stream meets salt water; for example, in bays, mouths of rivers, salt marshes, and lagoons.
Facies:	The characteristics or features of a rock type or sediment (such as mineral content, structure, particle size) considered representative of a particular environment or process of formation.
Faecal Coliform Bacteria:	A type of coliform bacteria present in the intestinal tracts of humans and other warm-blooded animals. Presence of faecal coliform bacteria in water is a sign of faecal contamination.
Fault:	A fracture or a zone of fractures along which there has been displacement of land on both sides of the fracture.
Floodplain:	The flat land adjacent to a river, formed by deposition of fluvial sediments.
Flowing Artesian Well:	A well where the water level is above the ground surface.
Fluvial Deposits:	Sand, gravel, silt and clay deposited by a river or stream.
Fracture:	A break or crack in the bedrock.
Geometric mean:	A method of calculating the mean value of an array of positive numbers which weights each of the items separately, using the formula: $GM_{y} = n\sqrt{y_1 y_2 y_3 y_4 ... y_n})$
GIS:	Geographic Information System, a computer software and database that stores and analyzes geographic data. ArcInfo is an example of a GIS system.
Glacial drift:	A general term for unconsolidated sediments transported by glaciers and deposited directly on land or in the sea.
Glaciofluvial deposits:	Sand, gravel, silt and clay deposited by glacial rivers or streams.
Groundwater:	Water occurring beneath the ground.
Groundwater Divide:	The uppermost boundary of a groundwater basin.
Grus:	A coarse sand and gravel that is is formed from the weathering of granitic rock.

Hardness:	A measure of the amount of calcium, magnesium and to some extent iron dissolved in the water, expressed in mg/L. Water is considered “soft” when the hardness is < 80 mg/L and “hard” when the hardness is > 200 mg/L.
Homogeneous:	Uniform in structure and composition throughout.
Hydraulic Conductivity:	A property of the aquifer that provides a measure of ease of flow of water through a cross section area under a unit hydraulic gradient. Hydraulic conductivity is usually expressed in metres per day or feet per day.
Hydraulic Gradient:	The slope of the groundwater level or water table (for an unconfined aquifer), or the slope of hydraulic head measurements (for a confined aquifer).
Hydraulic Head:	The level to which water rises in a well with reference to a datum such as sea level.
Hydrogeologic Mapping:	Mapping groundwater and groundwater related features. For example, a contour map of the water table, a map outlining the aquifer boundary and aquifer thickness, or a map showing the rate and direction of groundwater flow in an aquifer are examples of hydrogeologic maps.
Hydrogeology:	The science of subsurface waters and related geologic aspects of surface waters.
Hydrograph:	A continuous graph showing the properties of streamflow or groundwater level over time.
Hydrologic Cycle:	The continued circulation of water between the ocean, atmosphere, and land.
Igneous Rocks:	Rocks that solidified from molten or partly molten materials, that is from a magma or lava.
Infiltration Rate:	The rate at which water permeates the pores or interstices of the ground.
Isostasy (isostatic):	Change over geologic time of the depth of the continental land masses within the asthenosphere in response to the relative weight of overlying glaciers.
Isotropic:	Exhibiting properties with the same values in all directions.
Leaching:	Refers to the movement of chemicals through soil by water.
Level of Groundwater Development:	The level of groundwater use of an aquifer relative to the aquifer’s ability to replenish itself.
Lithology:	All the physical properties, the visible characteristics of mineral composition, structure, grain size, etc. which give individuality to a rock.

Marine Deposits:	Mostly silt and clay materials deposited under a marine environment.
Maximum Acceptable Concentration:	The concentration established for certain chemicals that are known or suspected to cause adverse effects on health. These concentrations are derived to safeguard health assuming lifelong consumption of drinking water containing the chemical at that concentration.
Mean:	The arithmetic mean or average of a set of values is calculated by totalling the values in a set and dividing the total by the number of values in the set.
Median:	The value from a set of measurements that has an equal number of measurement above and below it.
Metamorphic Rocks:	Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth’s crust.
Monitoring Wells:	Well that are typically 5 cm to 15 cm (2 inches to 6 inches) in diameter and are used strictly for monitoring the water quality of the aquifer. Monitoring wells are not pumped except to collect a sample.
Morainal Deposits:	Accumulation of unsorted unconsolidated materials (sand, gravel, clay, silt, boulders) carried and deposited by a glacier.
Non-Point Source Contamination:	Contamination where the source is diffuse (e.g., agricultural runoff).
Observation Well:	A well used for the purpose of observing parameters such as water levels, pressure changes and water quality.
Orogeny:	Process of mountain building, including deformation, folding, faulting and uplift of bedrock bodies, due to tectonic plate movement.
Overburden:	The loose soil, silt, sand, gravel, or other unconsolidated materials overlying bedrock, either transported or formed in place; regolith.
Permeability:	The capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow. Permeability is usually expressed in metres squared (m^2) or feet squared (ft^2). It is closely related to the hydraulic conductivity.
Pesticide:	Under the B.C. Pesticide Control Act, any substance or mixture of substances, other than a device, intended for killing, controlling or managing insects, rodents, fungi, weeds and other forms of plant or animal life that are considered to be pests.

pH:	A numerical measure of the acidity or alkalinity of water ranging from 0 to 14. Neutral waters have pH near 7. Acidic waters have pH less than 7 and alkaline waters have pH greater than 7.
Point Source Contamination:	Contamination where the source is site specific (e.g., landfill).
Porosity:	The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected relative to the total rock or soil volume.
Precipitation:	Condensation of moisture in air masses generally forming rain or snow.
Primary porosity:	Pore spaces that were formed at the time the geologic deposit was formed. The pore spaces in a sand and gravel deposit is an example of primary porosity.
Protolith:	The primary parent material or rock from which a metamorphic rock was formed.
Pumping Interference:	The condition occurring when a pumping well lowers the water level in a neighbouring well.
Pumping Test:	A test that is conducted to determine aquifer or well characteristics. A pumping test is usually conducted to determine the transmissivity and storativity characteristics of an aquifer and the capacity of a well supply.
Purveyor:	A company or municipality that delivers and sells water to clients, usually the residents in the community.
Quality Assurance:	The overall verification program which provides producers and users of data the assurance that predefined standards of quality at predetermined levels of confidence are met.
Quality Control:	The overall system of quidelines, procedures and practices which are designed to regulate and control the quality of products or services with regards to previously established performance criteria and standards.
Recharge Area:	Land area where water infiltrates into the ground and replenishes the aquifer.
Relief:	The maximum elevation difference within a watershed between its highest and lowest point.
Riparian Area:	The strip of land adjacent to the stream.
Run-off:	The process of water that flows overland or at very shallow depths to the stream or lake.

Saline Groundwaters:	Groundwater consisting of or containing salt.
Secondary porosity:	Pore spaces that are formed after the geologic deposit was formed. Fractures and cracks in bedrock are example of secondary porosity.
Sedimentary Rocks:	Rocks formed from consolidation of loose sediments such as clay, silt, sand, and gravel.
Sandstone:	A sedimentary rock composed of mostly sand sized particles.
Shale:	A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.
Sole Source Aquifer:	The only source of groundwater supply in an area.
Specific Capacity:	The rate of discharge of water from a pumping well per unit of drawdown, commonly expressed in litres per second per metre of drawdown or gallons per minute per foot of drawdown. Specific capacity varies with duration of discharge.
Stage (of a river):	The level of the river.
Static Water Level:	The unpumped level of water in the well or in the aquifer.
Steady-State Flow:	State of water flow where rate and direction does not change with time.
Storativity:	Volume of water stored or released from a column of aquifer with unit cross section under unit change in head.
Subaerial:	Environment of sediment deposition or volcanic eruption that is above water (sea level)
Subaqueous:	Environment of sediment deposition or volcanic eruption that is below water (sea level).
Subduction:	The process, at the boundary of two tectonic plates that form the crust of the earth, where one of the plates is forced downward into the mantle.
Surficial Deposits:	Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other unconsolidated materials.
Suspended Sediments:	Sediments such as silt, clay, organic matter that stays suspended in the water.
Till:	Predominantly unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogenous mixture of clay, silt, sand, gravel and boulders ranging widely in size and shape.

Time of Travel:	The time it takes for a particular contaminant to be transported through groundwater flow to a specified location. Time of travel is commonly used to relate the distance of a contaminant source to a drinking water well (i.e., that gas station is located within a 1-year time of travel distance from the community well).
Topography:	The configuration of a surface including its relief and the position of its natural features.
Total Dissolved Solids (TDS):	A term that expresses the quantity of dissolved ions in water. TDS is expressed in milligrams per litre or parts per million. Also called *filterable residue*.
Transmissivity:	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is expressed as metres squared per second, feet squared per day, or gallons per day per foot.
Unconfined Aquifer:	An aquifer where its upper boundary is defined by the water table. Where no aquitards overlie the aquifer, the aquifer is said to be “unconfined”. Unconfined aquifers are generally more vulnerable to impacts from human activities at the land surface, particulary if the water table is shallow.
Unconformity:	A geologic boundary that separates adjacent geologic units that were formed or deposited during different geologic periods; the boundary often indicates a period of erosion or change in structure (e.g. tilting) of the underlying rock body and subsequent deposition or formation of the overlying rock body.
Unconsolidated Deposits:	Deposits overlying bedrock and consisting of soil, silt, sand, gravel, clay and other material which have either been formed in place or have been transported in from elsewhere. Synonymous with Surficial Deposits.
Uniform Flow:	Flow in the same direction and rate.
Volcaniclastic:	A type of sedimentary bedrock formed from granular volcanic materials such as ash.
Water Balance:	The accounting of the input, output and change in storage of water in a watershed or aquifer. Typically determined on an annual basis. Also referred to as a water budget.
Water Budget:	The accounting of the input, output and change in storage of water in a watershed or aquifer. Typically determined on an annual basis. Also referred to as a water balance.
Water Table:	The top of the unconfined aquifer; water level where the pressure is equal to that of the atmosphere; water level in a shallow well.

Watershed:	The land area that drains water to an outlet point along a stream. Also called a catchment area or drainage basin.
Watershed Boundary:	The height of land that separates one watershed from neighbouring watersheds. Also called the drainage divide.
Well Cap:	Cover for the top of the well.
Well Capacity or Well Yield:	The flow of water discharged from a well in gallons per minute or Litres/second.
Well Interference:	Drawdown of water level in a well caused by pumping of a neighbouring well.
Well Screen:	A wire-wound filtering device that allows water, but not sediments, to enter the well.
Well Protection:	Protection of the recharge (or capture zone) area of a pumping well.

Appendix A: Capital Regional District Aquifers - Summary Statistics

Appendix B: Hydrogeologic cross-sections

Appendix C: Aquifer Classification Maps