RDN Electoral Area A

Groundwater Assessment and Vulnerability Study

For:

The Regional District of Nanaimo
Development Services
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By:

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EXECUTIVE SUMMARY

This study has shown that the surface water and groundwater regimes in Area A are very complex, and still not very well understood. An overview of the data gaps indicates that work is still required to better define the water demand, the water supply, the interaction between surface water and groundwater, the aquifers, the water quality, and sensitive ecosystems. The following summarizes the results of the completed groundwater assessment and vulnerability study:

1. Area A includes three main groundwatersheds, referred to as Zone 1, 2, and 3. Zone 1 includes the lower section of Haslam Creek and the Nanaimo River. These river systems are very dynamic, transporting large amounts of water. They occupy the western half of Area A and discharge to the Nanaimo River Delta. Much less water movement occurs in the eastern half of Area A (Zone 2) because it consists predominantly of a flatter region where most of the water flows through a bedrock aquifer towards the Strait of Georgia. The southern tip of Area A (Zone 3) discharges south to Ladysmith Inlet. The following paragraphs summarize the water dynamic in these zones and identify the critical conditions.

Water Dynamic

- **Zone 1**: Covering over 4500 ha, Zone 1 includes the Cassidy Aquifer (Aquifer 161, unconfined), and the Lower Cassidy confined aquifer (Aquifer 160). These two sand and gravel aquifers are collectively up to 30 m thick and are very productive. Zone 1 also includes the South Wellington bedrock aquifer, where residential wells of much lesser yield are located. The Cassidy Aquifer is closely connected to the Haslam Creek and the Nanaimo River. A gauge located just at the western boundary of Area A on the Nanaimo River reports flows ranging between 1 m^3/s and 1300 m^3/s. The water balance reflects the role played by the Nanaimo River**: it is estimated that the river flow corresponds to 95% of the water transferring through Zone 1**. Precipitation, with an approximate amount of 1 m per year, is the main water input. Groundwater will also reach zone 1 through its western boundary, but at a rate estimated to be 13% of the precipitation.
- **Zone 2**: Covering over 1700 ha, Zone 2 is predominantly composed of the Cedar, Yellow Point, North Oyster bedrock aquifer (Aquifer 162), and the Cedar, North Holden Lake confined overburden Aquifer (Aquifer 163). In the uplands, water will converge to local depressions. Otherwise, water will discharge to the Strait of Georgia, mostly as groundwater flowing through the bedrock fractures. Compared to Zone 1, water movement is much less dynamic. The volume of water transferring through Zone 2 is estimated to be only 1% to 2% of the water transferring through Zone 1.
- **Zone 3**: With over 1400 ha, it only covers 2% of Area A, south of the Nanaimo Airport. It corresponds to part of Area A where water drains south, predominantly as groundwater, through the Cassidy and Lower Cassidy Aquifers, towards Ladysmith Inlet.

Water Use and Water Balance

- **Zone 1**: The aquifers provide water for residential, agricultural, commercial, and industrial use. Harmac is the largest water user and extracts an estimated total of

136,500 m^3/day (82,000 m^3/day from a well field and 54,500m^3/day from a surface water intake in the Nanaimo River). This water is removed from the Nanaimo River watershed to supply Harmac facilities, located outside of this watershed. **The volume used by Harmac is equivalent to the total amount of the yearly precipitation over Zone 1**. The second largest water user is the NCID, which, with 1240 m^3/day, represents 0.03 % of the water output for Zone 1 and approximately 1% of the water extracted by Harmac. The total use from the remaining users (residential properties and small systems) is equivalent to the use of NCID.

- **Zone 2**: Water input is solely precipitation, with the exception of water import via water delivery (trucked water). Evapotranspiration represents the largest water output in Zone 2 (62% of water input), followed by discharge to the foreshore (47% of water input). Water use for residential purposes represents a small percentage of the water balance (1%).
- **Zone 3**: The main elements of the water budget in Zone 3 are natural inputs and outputs. Groundwater extraction attributed to human activities represents a small percentage of the output (less than 1%).

Critical conditions

- **Zone 1**: The critical conditions appear to take place during the late summer months when there is no precipitation, the evapotranspiration is high, and water use is high. **During the critical period of the year the water output is estimated to be four times the water input**. During the driest period of the year, Harmac water extraction is estimated to represent 37% of the total water output for Zone 1; it equals the estimated evapotranspiration over Zone 1, and, at approximately 1.6 m^3/s, is of the same order of magnitude as the lowest water discharge of the Nanaimo River (1.2 m^3/s). In Zone 1, the water deficit will translate into a drop of the water table in both the overburden and bedrock aquifers, and low flows of the Nanaimo River and its tributaries. The following consequences are expected:
    - Reduced capacity and increased cost of extracting water from production wells for water system operators;
    - Reduced or lost production of residential wells;
    - Reduced flow in the Nanaimo River and its tributaries: This has an impact on fish species and ecosystems, due mainly to a change of conditions (from wet to dry), a change of temperature, and resulting physical and geochemical conditions (less dissolved oxygen, etc.);
    - Stress on the vegetation and modification of the landscape: Low water tables during long periods of time will reduce soil moisture available to the root systems of the vegetation. The species vulnerable to these modifications will disappear.
- **Zone 2**: The summer and early fall will be the critical period of the year. The bedrock aquifer has very little storage, therefore the water table drops relatively quickly once recharge due to precipitation stops. After mid-summer, bedrock wells will often be unable to meet the demand of residents, requiring water to be trucked in. During this critical period, the risk of salt-water migration will increase because the water levels in the bedrock aquifer will be the lowest, and the needs of the population will be the

greatest. With no water input, except small volumes being trucked in, the water output is approximately 75,000 m^3/day, (74% evapotranspiration, 25% flow to the foreshore, and 1% residential extraction).

- **Zone 3**: No major critical situation has been identified for Zone 3.

2. Both point sources and non-point sources of contamination have been identified in Area A. These cover a wide range of organic, inorganic, and bacteriological contaminants. Sampling, chemical analyses, and monitoring are recommended to assess the impact of the identified sources of contamination on both surface water and groundwater.
3. The management of the water resource in Area A in a sustainable way requires a better understanding of water use and water extraction during the summer and fall. This is a critical time of the year for water users as well as for sensitive ecosystems, such as the Nanaimo River Delta. Overpumping along the coast can produce seawater intrusion resulting in a deterioration of the residential water supply.
4. Aquifer vulnerability mapping shows that areas corresponding to the Cassidy Aquifer are rated highly vulnerable. Otherwise, mapping shows that the remaining area is predominantly rated moderately vulnerable.
5. Best Management Practices (BMPs) are recommended to minimize the risks of degradation of the water source and to promote its management in a sustainable manner.
6. Low flows are critically important to ensure the sustainability of ecosystems in the Nanaimo River, its tributaries, and the surface water network in Area A. A specific effort should be made to define the vulnerability of the most sensitive ecosystems, and to manage the surface and groundwater resources accordingly.

1. INTRODUCTION

1.1. Background

The RDN desires to better understand the groundwater resources in Area A by conducting an overview of the aquifer conditions and vulnerability, and to develop groundwater protection strategies and policies to be considered in the new Area A Official Community Plan.

Area A includes both bedrock and large, shallow, and unconfined aquifers in coarse permeable materials. These aquifers are very productive but are also very vulnerable. The release of contaminants at the surface would reach the water table quickly and could rapidly contaminate large volumes of the aquifers.

Groundwater is used for water supply in the area to meet residential, commercial and agricultural needs. The Nanaimo River also closely interacts with the aquifers when crossing Area A. All these factors show how understanding, management and protection of groundwater are very important elements to be integrated in planning future land use for Area A.

1.2. Completed Work

This report was prepared by a team comprised of GW Solutions Inc. (GW Solutions) and Vancouver Island University (VIU), according to a proposed scope approved by the RDN and included in Appendix 1.

The work was completed based on existing information at the time of reporting.

2. WATER USE – PRESENT AND FUTURE

In order to assess the present and future water supply and water demand, the team completed the following tasks:

- Meeting/interview with the administrator of North Cedar Improvement District (NCID), Lynnia Clark. NCID is the main water purveyor in Area A. The NCID provided access to a report from McElhanney (October 2008) which includes estimates of present and future water demand for the NCID.

- Communication with Vancouver Island Health Authorities (VIHA), Murray Sexton. VIHA compiled available information on the water purveying systems

- Meeting/interview with Island H20 Services, Torrie Jones, and Stan Wood Trucking Ltd., Stan Wood. The interviews were conducted to discuss areas typically requesting bulk water deliveries.

- Literature review, in particular Thurber (2008) and Zubel (1991) and the RDN “Electoral Area “A” Official Community Plan Review, dated September 2008

This section briefly describes the information on water supply and water demand. The data is summarized in Table 1 and Table 2 and also illustrated in Figure 2.

Table 1: Estimated Water Demand - Area A

Water purveyors	Volume pumped (groundwater)	Volume pumped (surface water)	Connections
	(m^3 per day)	(m^3 per day)	
North Cedar Improvement District	1,240		1,166
Decourcey Water Service Area	5		5
Harmac	82,000	54,500	
Triple E campsite	6		6
Cooperville Water System	11		10
Boat Harbour Water Users Society		43	40
Zuider Zee Campground	9		8
Twin Oaks Water System	11		10
Cassidy Manufactured Home Park	72		68
Seabird Manufactured Home Park	78		73
Timberlands Manufactured Home Park	153		144
Nanaimo Airport	15		
Individual wells	1,500		1,500
Total	83,599	54,543	

The BC MOE registry reports 152 current surface water licenses. A table listing these licenses is presented in Appendix 2. The location of the licenses is shown on Figure 1 and Table 2 summarizes the licensed volumes, according to the categories used by BC MOE.

Table 2: Surface Water Licenses

Water Use	m^3/day
Pulpmills	330,288
Irrigation	1,157
Storage	288
Domestic	195
Conserv. Stored Water	35
Watering	20
Land Improvement	19
Stockwatering	13
Enterprise	10
Ponds	1
Total	332,026
All except pulpmills	1,738

Table 2 shows that the largest licensee is the pulpmill, for which the licensed volume is six times their present water use. The second largest use is for irrigation.

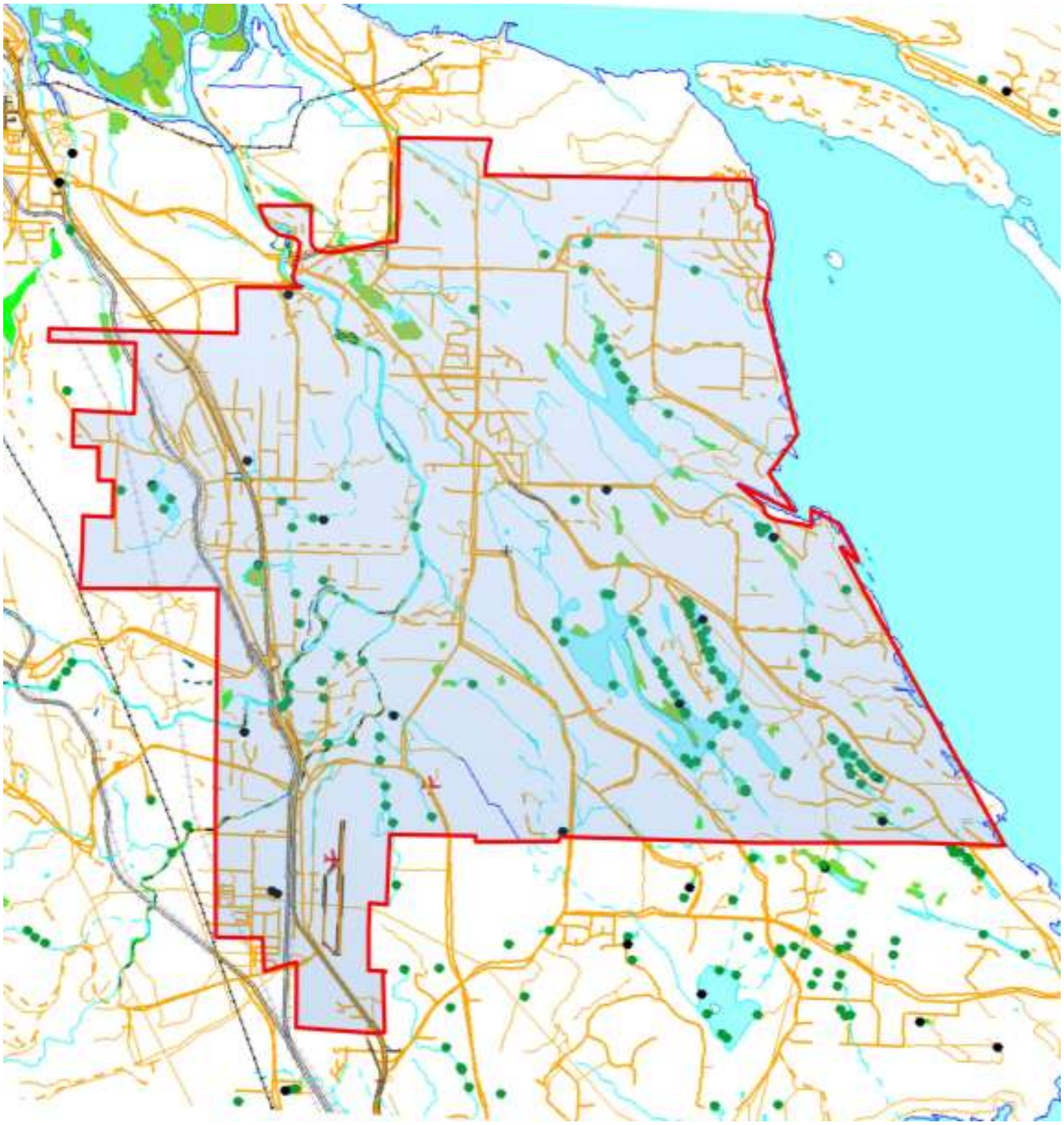


Figure 1: Point of diversion - Surface water licenses

2.1. Residential

The North Cedar improvement District (NCID) is the main residential water purveyor in Area A, serving over 3,000 people. Nine smaller systems provide water to subdivisions, manufactured home parks, campgrounds, etc. They each serve a population ranging between 5 and 150 connections. The remainder of the population in Area A relies on their own water supply, consisting of shallow wells in the overburden and deeper wells in bedrock.

Figure 2 shows the locations of water wells in Area A.

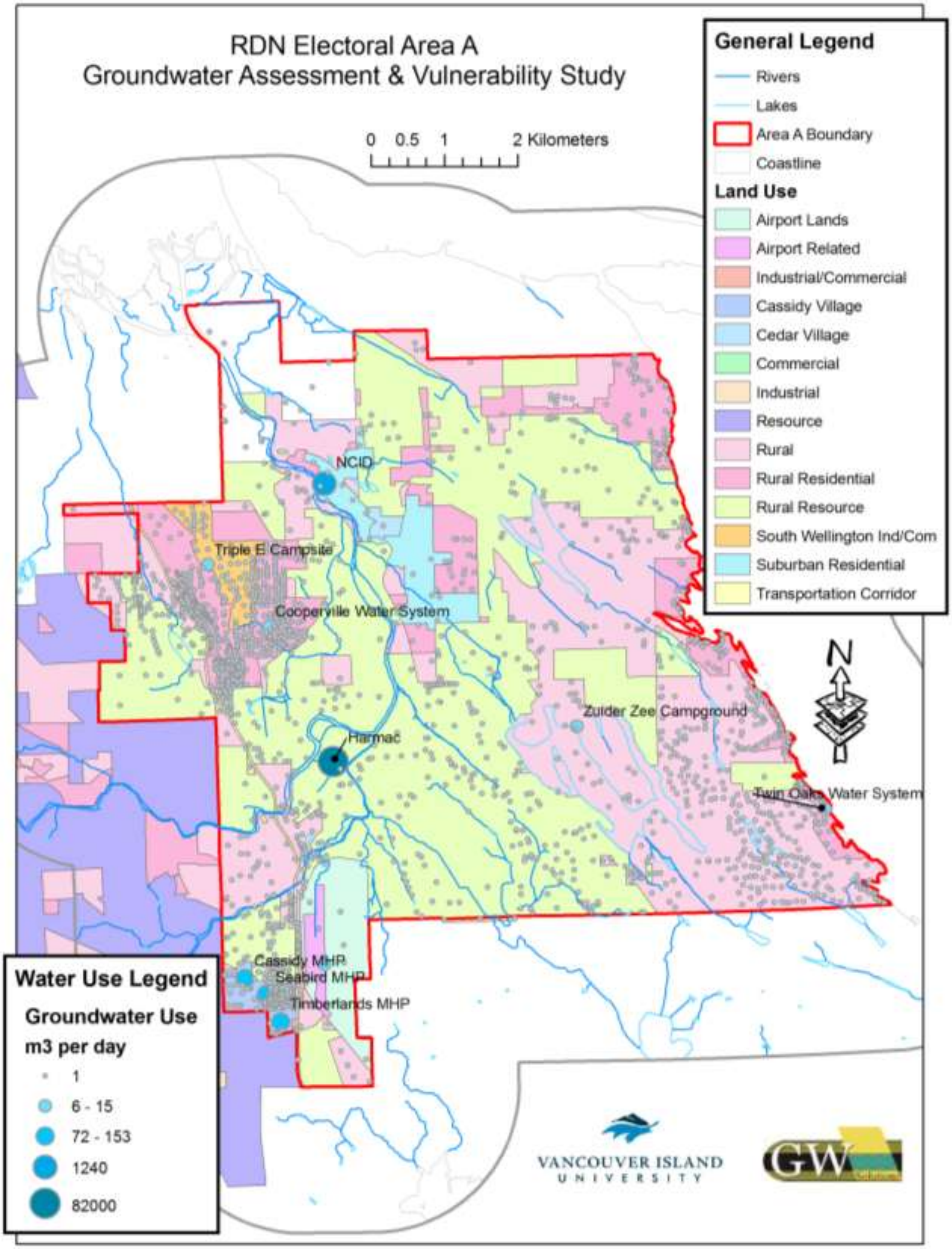


Figure 2: Groundwater users in Area A

Figure 2 shows locations where wells have been dug or drilled to access groundwater. It also shows the areas where water is provided by a communal system. In this case, the symbol may represent more than one well.

2.2. Commercial-Industrial

The water supply to commercial businesses is provided by NCID in the Cedar Village center. In the South Wellington industrial-commercial area the businesses rely on their own water supply because this area is located outside of the NCID boundaries.

Businesses in the elongated Cassidy light industrial-commercial area, across from the Nanaimo Airport also each rely on their own water supply.

The Nanaimo Airport relies on three wells that provide water to the users of the airport and for its operation.

Nanaimo Forest Products Ltd. (Harmac), although not located in Area A, operates water intakes in the Nanaimo River and a series of production wells near the confluence of Haslam Creek and the Nanaimo River. In quantity, Harmac is by far the largest water user in Area A

2.3. Agricultural

Almost half of the Electoral Area is located in the Agricultural Land Reserve and based on BC Assessment Authority records, there are 155 working farms in Area A. Some of these farms and their type of activities are shown in Figure 3, where the majority of the purple stars refer to farming activities. This map was compiled based on information received during public workshops organized by the RDN. Agricultural activities in Area A are limited to relatively small operations. There are no industrial farms such as hog farms in Area A. Agricultural land is most likely supplied with water by wells on properties.

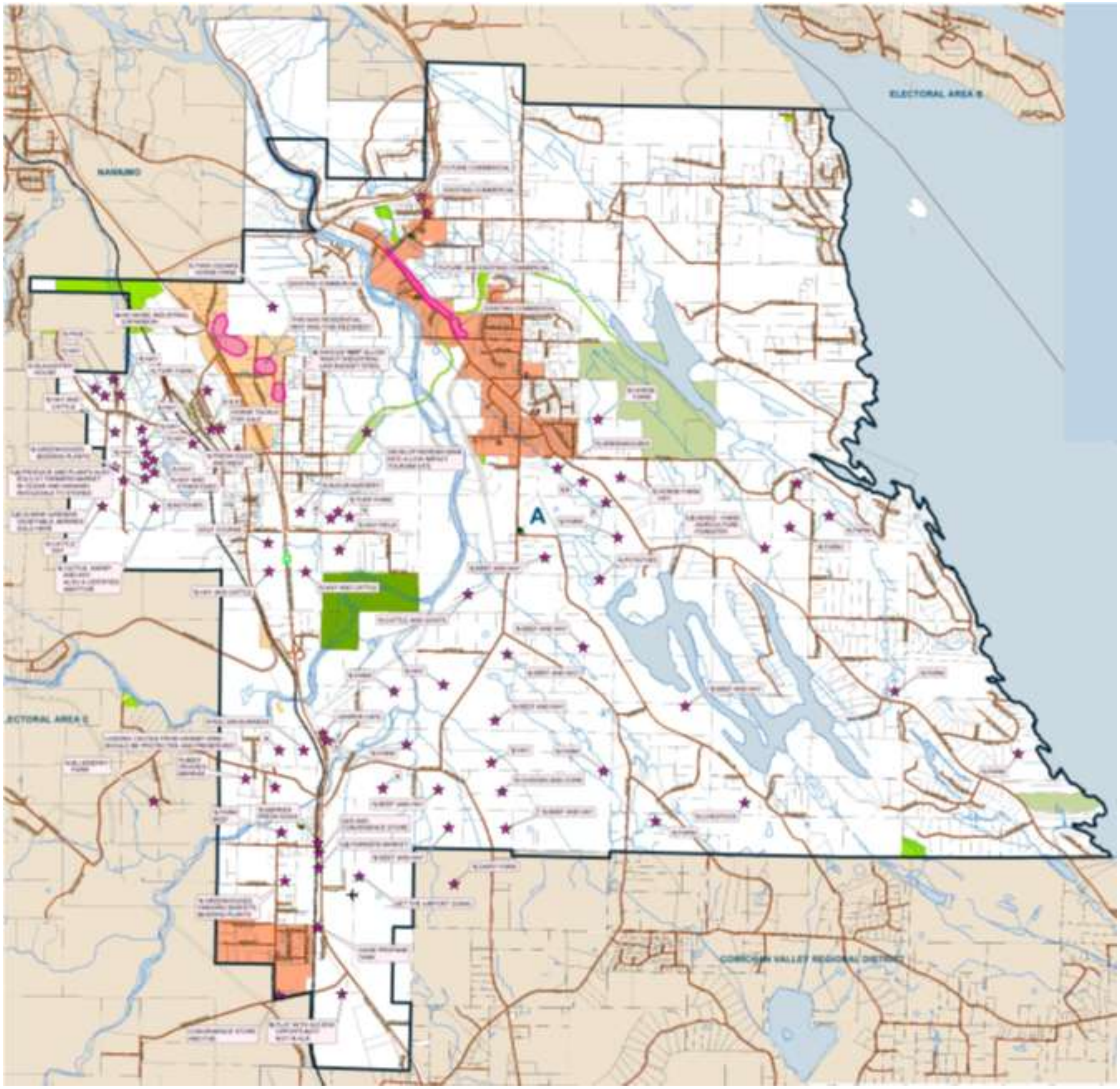


Figure 3: Agricultural Activities (partial information)

2.4. Fisheries

The Nanaimo River Hatchery is operated by the Nanaimo River Stewardship Society and is classified as a Community Economic Development Project (CEDP) hatchery. The hatchery is built on land leased from Harmac and is contracted by DFO under the CEDP umbrella to carry out the enhancement program for the Nanaimo River watershed. The hatchery relies on 2 water sources, the Nanaimo River and a well. All the water extracted for the operation of the Hatchery is returned back locally after use.

2.5. Future Water Demand

The population of Area A was 6,751 in 2006 (RDN Statistics, Statistics Canada) and the estimated value for 2026 is 8,700, (RDN, September 2008). This represents an approximate 28% increase in population in 20 years.

Assuming an increase of the population of 28% by 2026, the corresponding water demand to meet residential and commercial needs in Area A will be approximately 179,000 m^3/day. This is a conservative assumption. In fact, it is difficult to assess whether the water demand will follow the population increase. It is very probable that water management and water conservation measures will reduce the water demand per capita over time. Presently, some large municipalities are succeeding in maintaining the same water supply, countering the increase in demand due to rising population with water conservation measures and by improving the efficiency of their delivery system.

3. WATER AVAILABILITY

Area A is located mainly in the Nanaimo River watershed which receives an average of approximately 2350 mm of precipitation per year. There is a precipitation gradient between the headwaters of the watershed at higher elevation and the coastal area. Figure 4 shows the variation in annual precipitation over Area A.

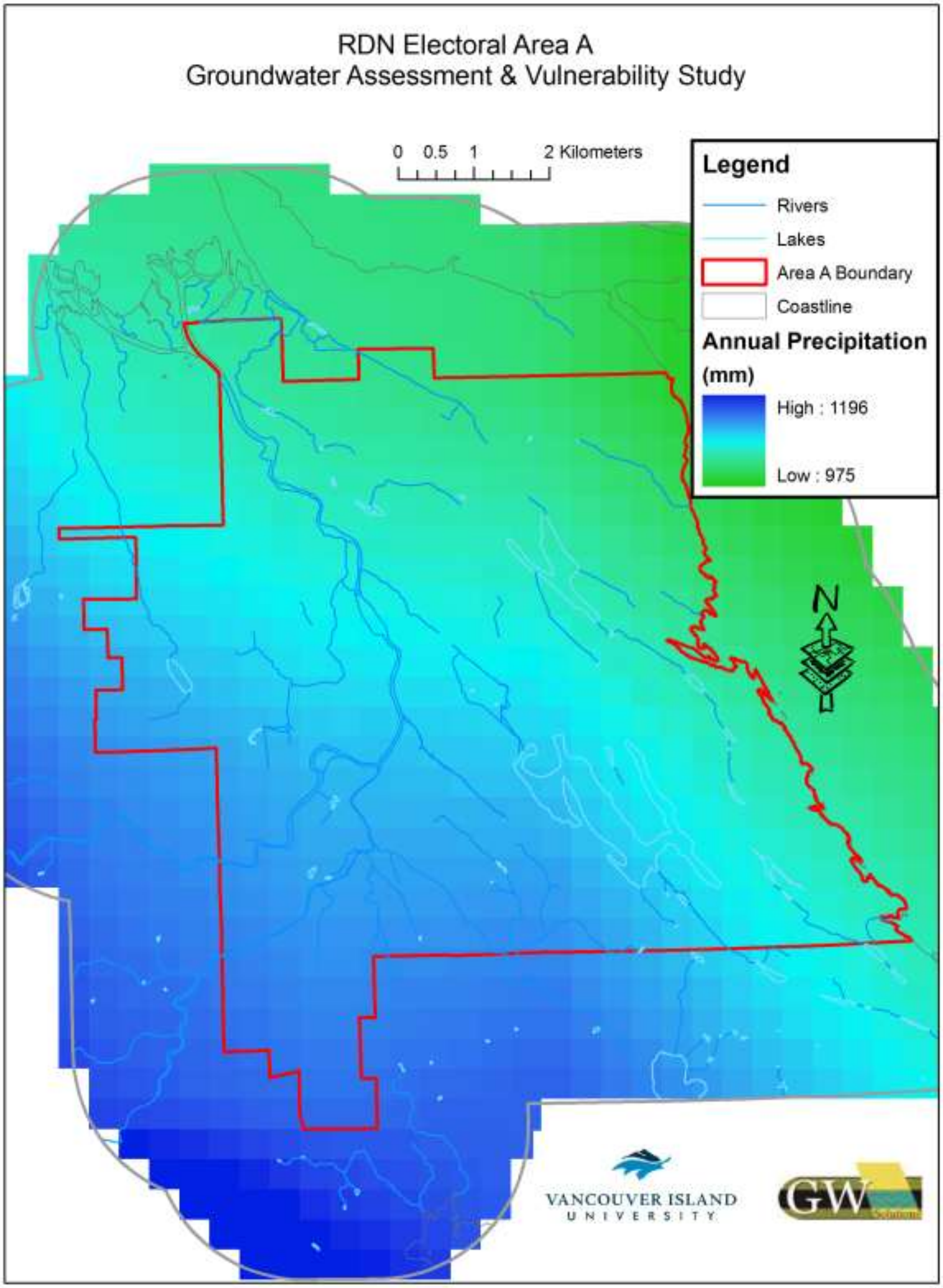


Figure 4: Distribution of precipitation over Area A

A Thornthwaite table is a commonly used tool to describe water availability in an area. It summarizes information on water input (precipitation), water output (evapotranspiration), and variation in storage (soil moisture) over a year. The Thornthwaite table for Area A is presented in Appendix 3, based on climate data from the Nanaimo Airport.

Water is available in Area A as surface water, with two main drainage systems, the Nanaimo River and Haslam Creek. Small surface features (lakes, ponds and wetlands) are also present in the eastern half of Area A. A map showing surface topography and the hydrology of Area A is shown in Figure 5.

Water is also available below the surface, in confined and unconfined aquifers. The thickness of the overburden is shown in Figure 6. It shows that the bedrock was carved by glacial erosion during the last glacial cycle, and the depressions were filled with glacial, fluvial and marine deposits during the transition to the present interglacial cycle. The thickness of these deposits is up to 65 m in the south western part of Area A around the Nanaimo Airport. Another pocket of overburden is also located in the northeast corner of Area A. The remainder of the area mostly consists of a relatively thin veneer of soil overlying bedrock.

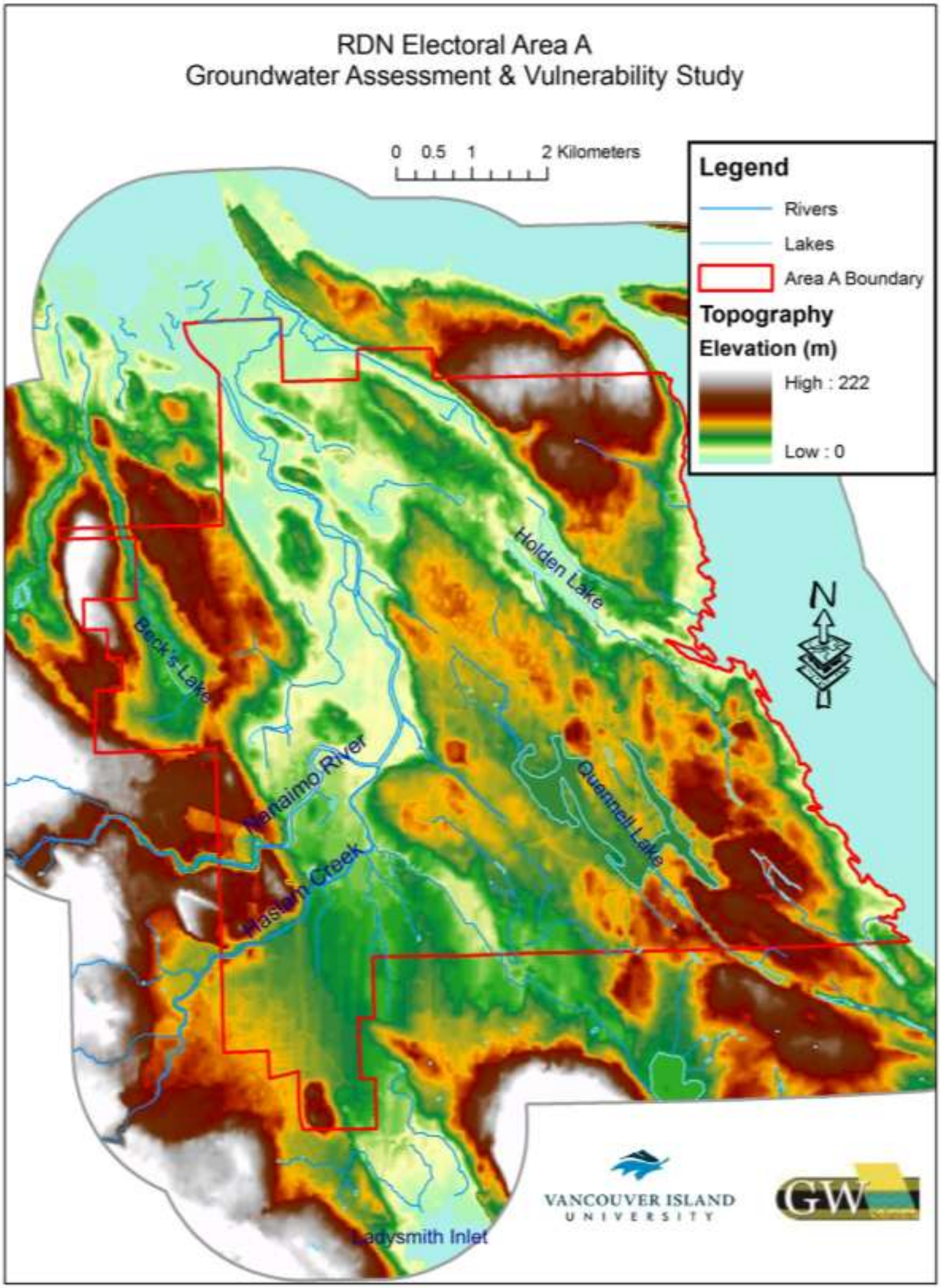


Figure 5: Topography and hydrology

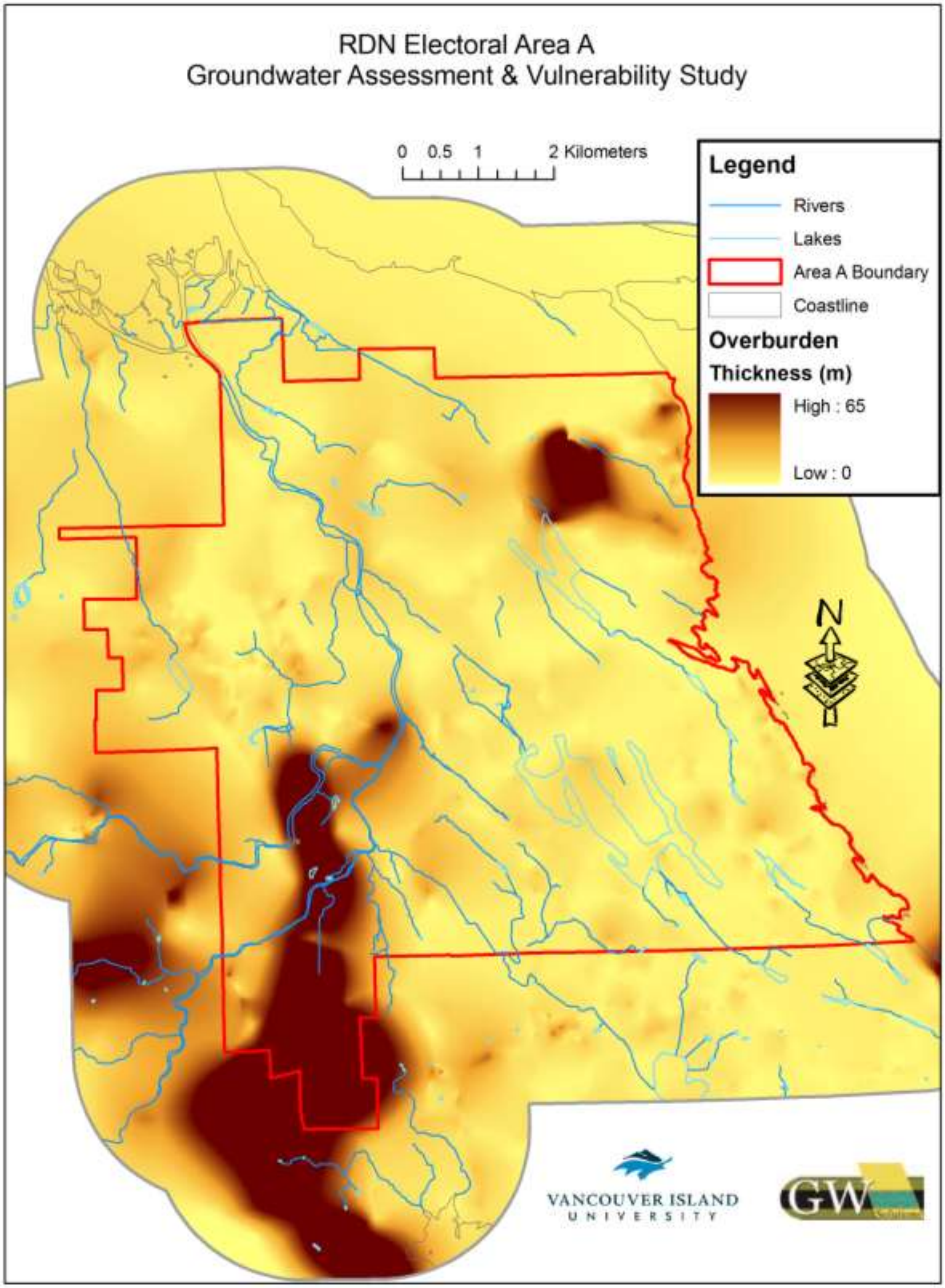


Figure 6: Overburden (drift) thickness

4. WATER MOVEMENT

The movement of water in Area A is driven by gravity, and controlled by topography and the permeable media consisting of granular aquifers and fractured bedrock.

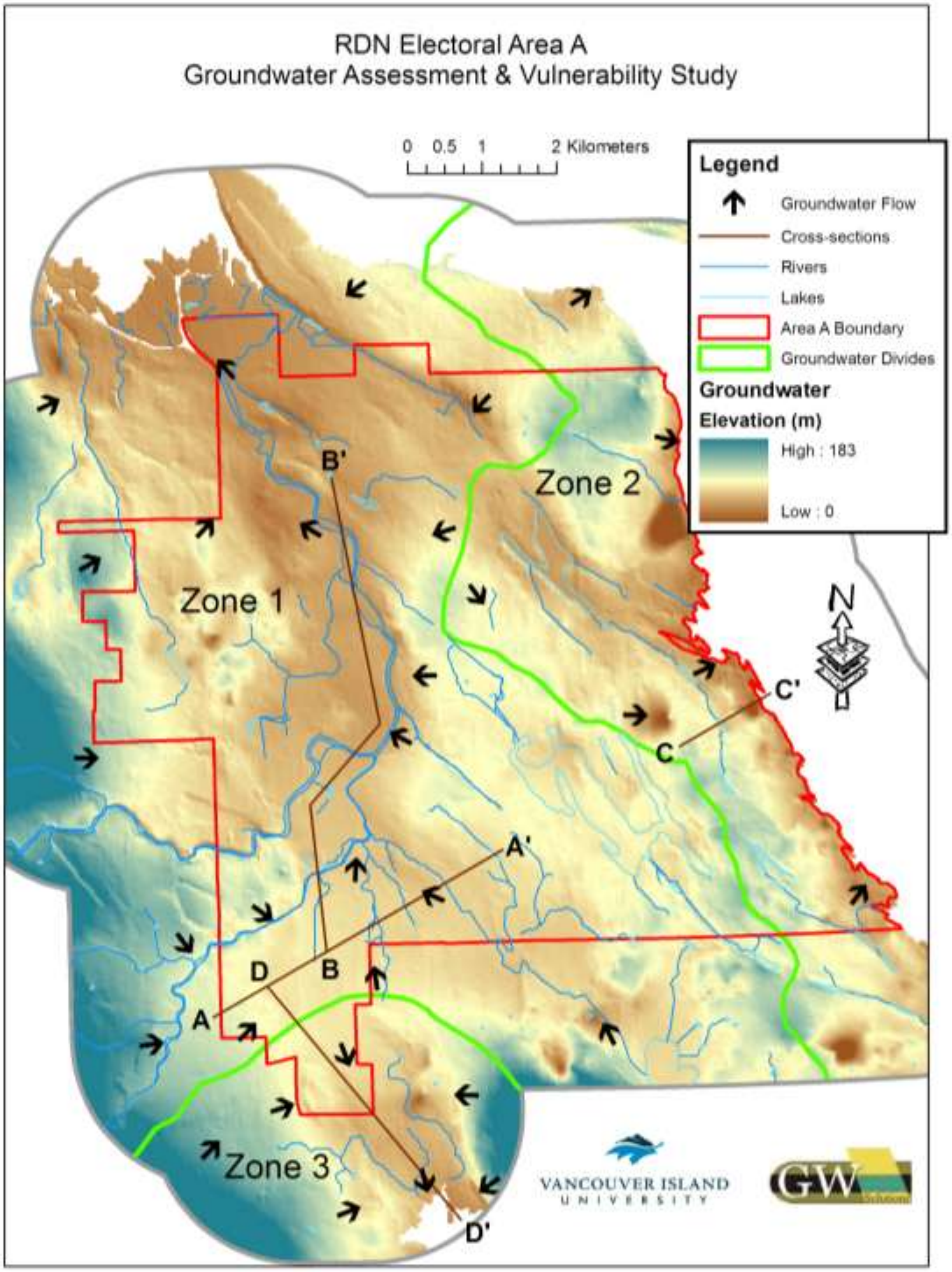


Figure 7: Elevation of the water table (piezometric elevation), approximate groundwater movement (black arrows), and divides (green lines) defining three groundwatersheds (Zone 1, 2 and 3)

Higher topography along the western boundary of Area A is associated with higher piezometric levels driving water to the east, and then towards the north, following the areas of decreasing piezometric elevations, aligned with the corridors of Haslam Creek and the Nanaimo River. In this area, water flows predominantly in the permeable overburden.

In the central and eastern side of Area A, the topography is relatively flat, with a thin veneer of overburden over bedrock. Higher grounds correspond to higher piezometric levels. Water will flow to areas of lower piezometric levels, either associated with local topographic depressions, or towards the foreshore, along the eastern boundary of Area A. In this area, water will flow mainly through the network of fractures in the bedrock and locally within the thin veneer of overburden.

Figure 8 shows the locations of water wells, according to information available in the BC MOE well database. BC MOE has started the task of defining the main aquifers in BC and estimating their production, the water demand, and their vulnerability. This is further discussed in Section 10. For Area A, the identified aquifers are shown in Figure 8. The following aquifers were identified:

- The Cassidy Aquifer (161) is unconfined and composed of sand and gravel.
- The Lower Cassidy Aquifer (160) and the Cedar, North Holden Lake Aquifer (163). They are both confined and composed of sand and gravel;
- Two large bedrock aquifers: The South Wellington Aquifer (165), and the Cedar, Yellow Point, North Oyster Aquifer (162).

Some of these aquifers are shown in cross-sections (Figure 9 through Figure 12). They are referred to by their identification number.

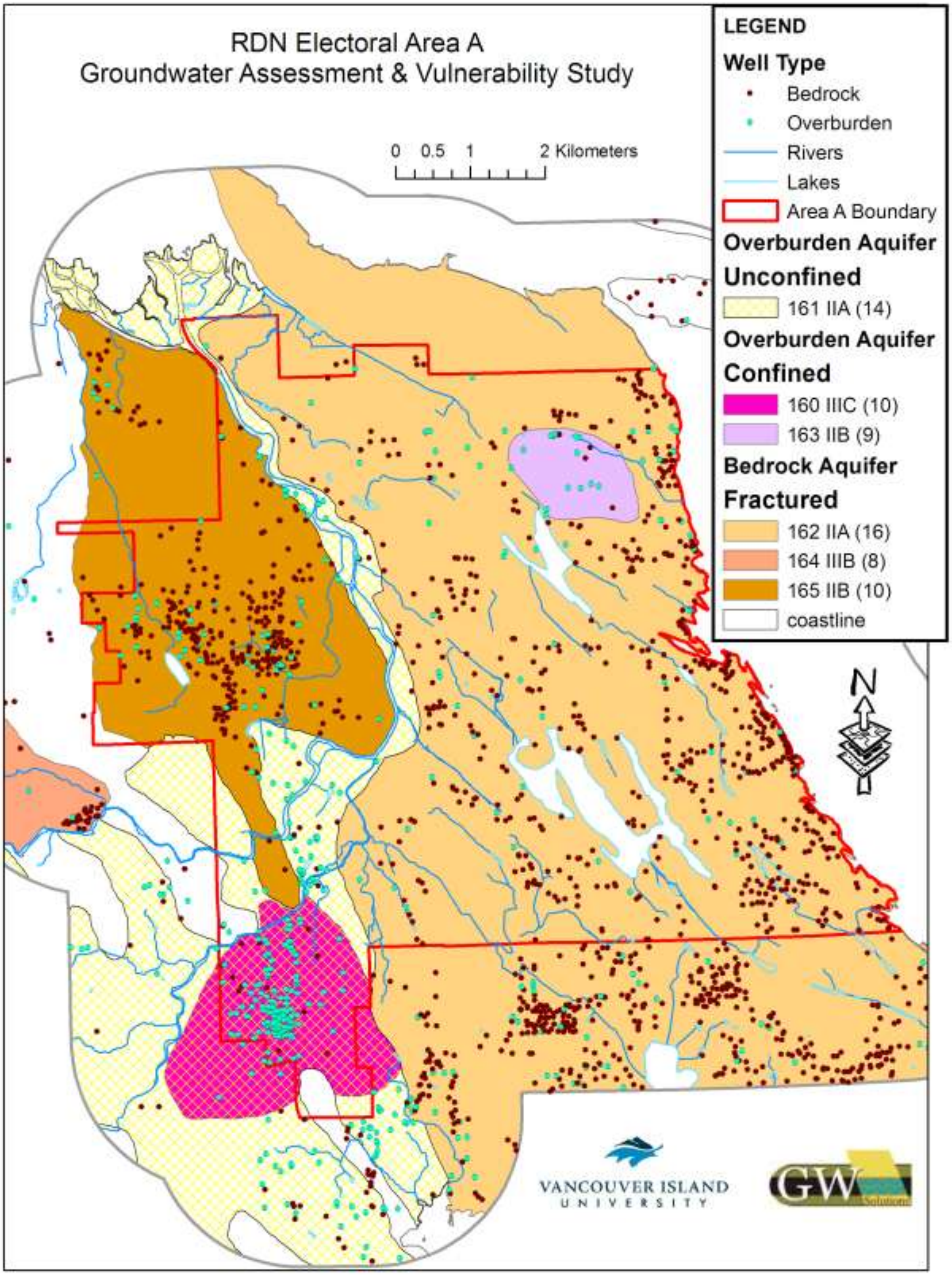


Figure 8: Well location, type, and aquifers

Figure 8 shows that the Cedar, Yellow Point, North Oyster bedrock aquifer (162) covers a large part of Area A., and most of the wells are drilled in bedrock. However, some wells are reported completed in overburden (green dots). These wells are most likely either dug wells or shallow drilled wells completed in the thin overburden.

In the northwest quadrant of Area A, the wells are predominantly completed in the South Wellington bedrock Aquifer (165), with some shallow overburden wells as in Aquifer 162.

The overburden aquifers are present mainly in the western half of Area A, where a deep trough in the bedrock was in-filled by overburden. The north/south alignment of this structure also corresponds to a large fault system, which separates Aquifer 162 from Aquifer 165. A deep confined aquifer, the Lower Cassidy Aquifer (160), occupies the bottom of this buried valley in the south end of Area A. The Cassidy Aquifer (161) is the main and most productive aquifer in Area A. It extends over the lower land in the western half of Area A, and is associated with the lower part of Haslam Creek and the Nanaimo River.

A pocket of thicker overburden is present in the northeast quadrant of Area A. It constitutes the Cedar, North Holden Lake confined Aquifer (163).

With this knowledge of the aquifers, the topography, and the surface water movement, Area A can be split into three zones where water moves in different patterns. The zones are approximately delineated in Figure 7, and their architecture is further illustrated with cross-sections (Figure 9 through Figure 12). The location of the cross-sections is shown in Figure 7.

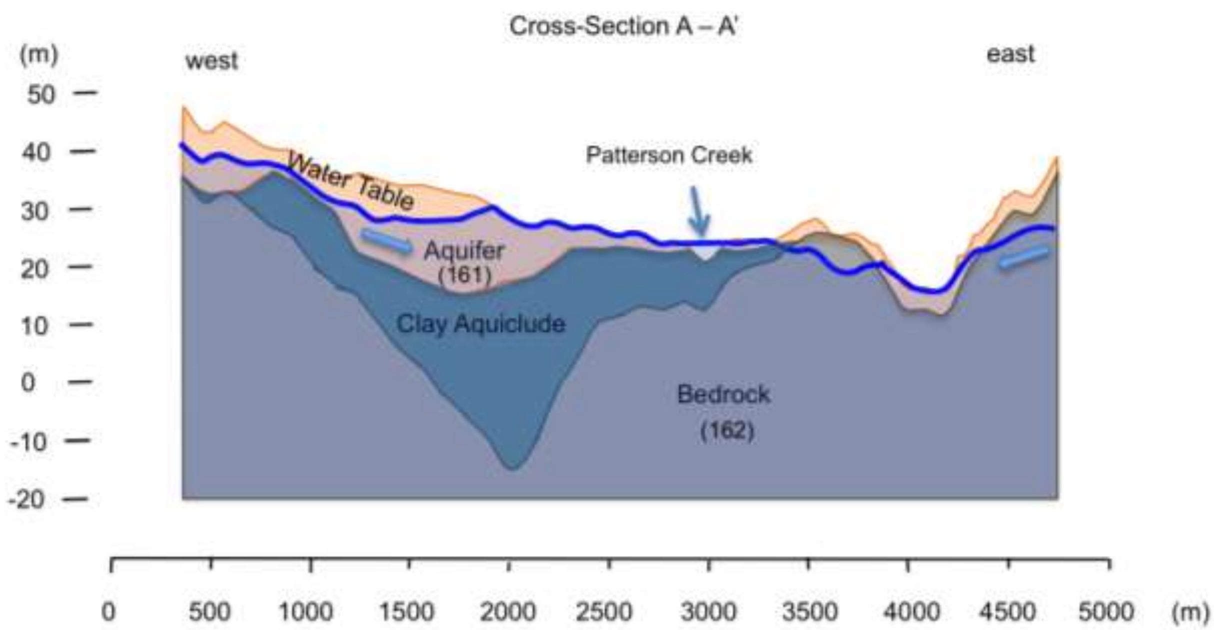


Figure 9: Cross-Section AA' in Zone 1

Cross-section AA' shows the relatively deep trough in the bedrock which has been filled with clay. Aquifer 161 is unconfined and is present to a depth of approximately 20 m. The cross-section also shows the slope of the water table, on the west side, indicating there is a movement of the groundwater from west to east. On its east side, the higher topography creates a higher water table, which produces a groundwater movement in a western direction, as illustrated by the blue arrows on the cross-section.

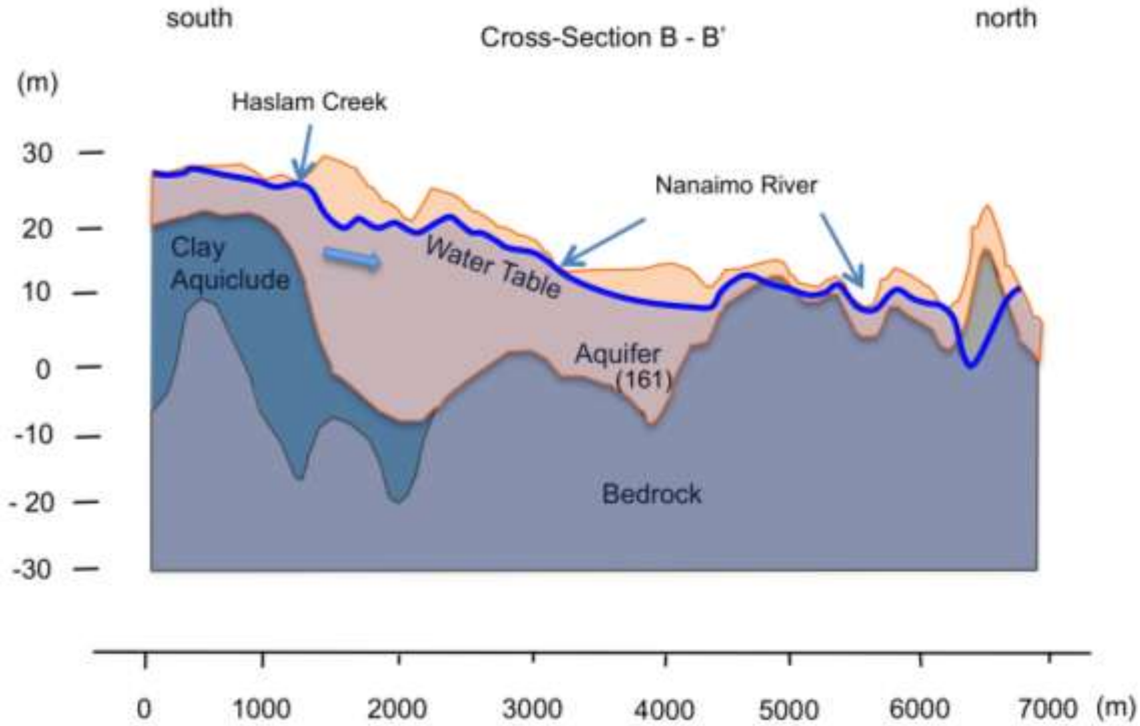


Figure 10: Cross-Section BB' in Zone 1

Cross-section BB' shows that aquifer 161 gets thicker between 1500 m and 4000 m, with a maximum thickness of approximately 30 m. On the northern portion of this cross-section, the aquifer is thinner, typically less than 10 m thick. The aquifer is unconfined and the water table drops generally from south to north. Locally, the water table is very close to surface.

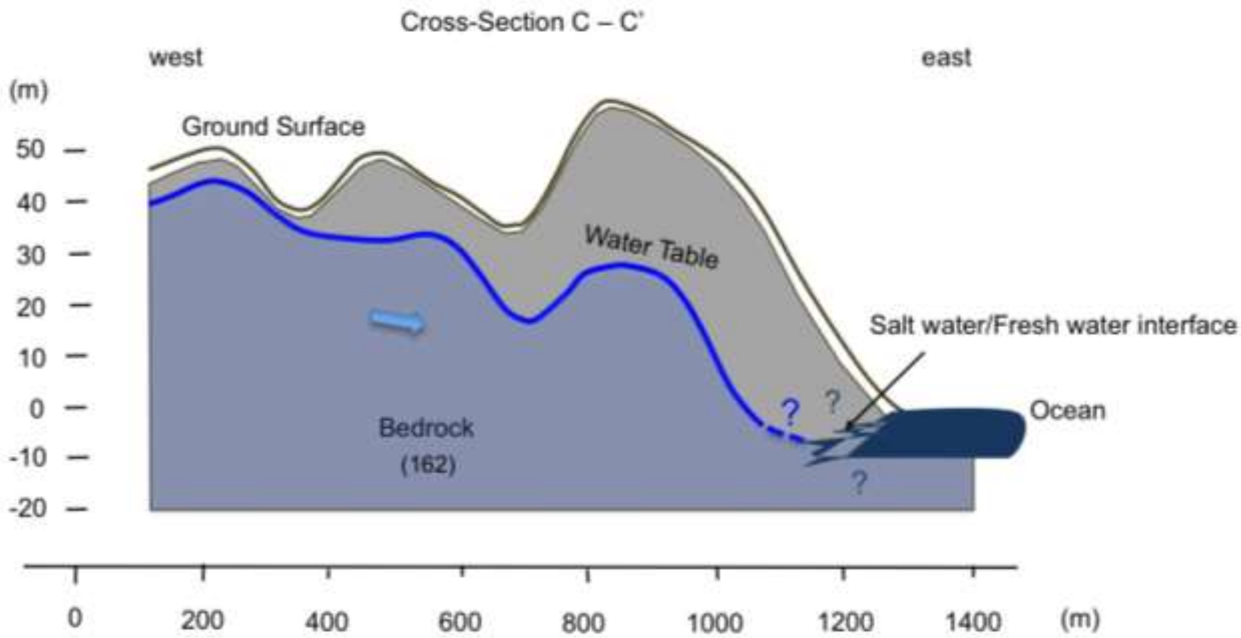


Figure 11: Cross-Section CC' in Zone 2

Cross-section CC' shows the typical groundwater movement in Zone 2. Groundwater is present in bedrock. Any overburden aquifer, where present, is thin and of small lateral extent. The surface of the water table mimics the topography and drops towards the foreshore. There is no capping layer and the aquifer is unconfined. Near the ocean, the salinity of the groundwater will increase in a transition zone referred to as the salt water / fresh water interface. The location of the salt water / fresh water interface is not known and its geometry probably will be very complex, as it is a function of many parameters (fracture network, hydraulic gradients, pumping wells, etc.).

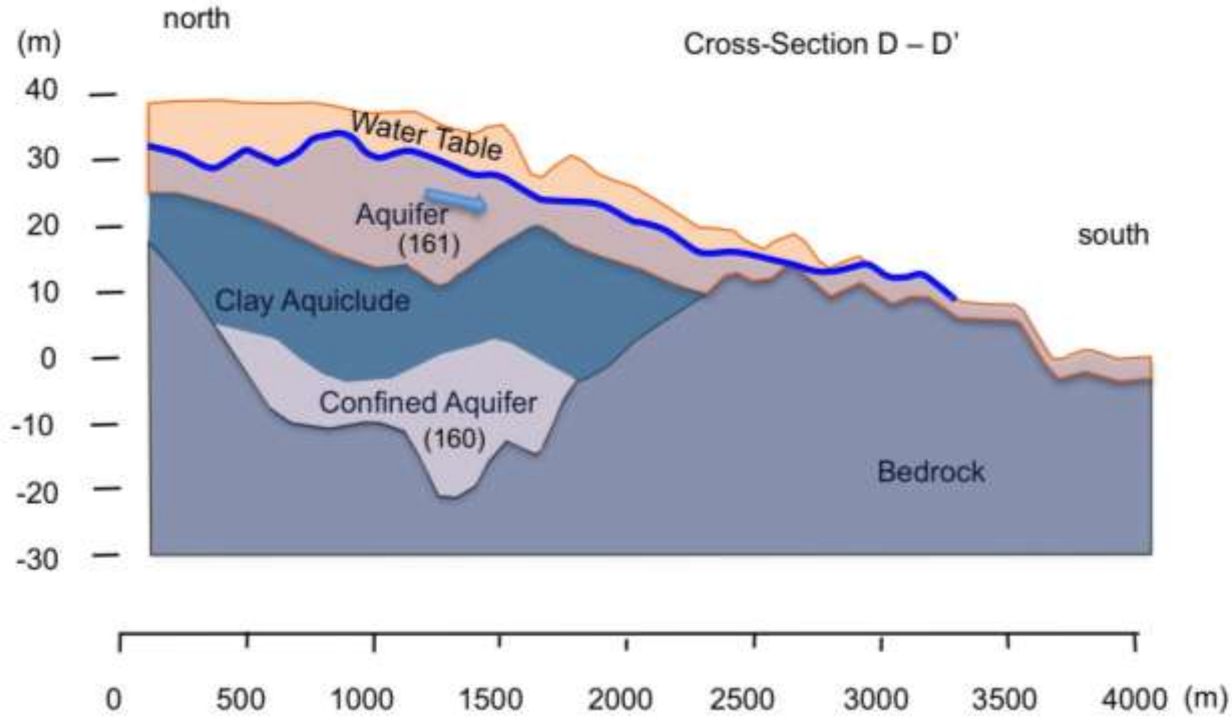


Figure 12: Cross-Section DD', Zone 3

Cross-section DD' shows the typical groundwater regime in Zone 3. A thick sequence of overburden material fills the deep trough in bedrock. A deep aquifer, the Lower Cassidy Aquifer (160), is up to 20 m thick, and is confined by a clay aquiclude. The unconfined Cassidy Aquifer (161) is up to 20 m thick and close to ground surface. It is present over the whole area illustrated by the cross-section, however it gets thinner towards the south. The groundwater flows south, as indicated by the slope of the water table.

4.1. Water movement and budget in Zone 1

The first zone corresponds to the western half of Area A. The typical water budget in this zone is illustrated by Figure 13 and is described as follows:

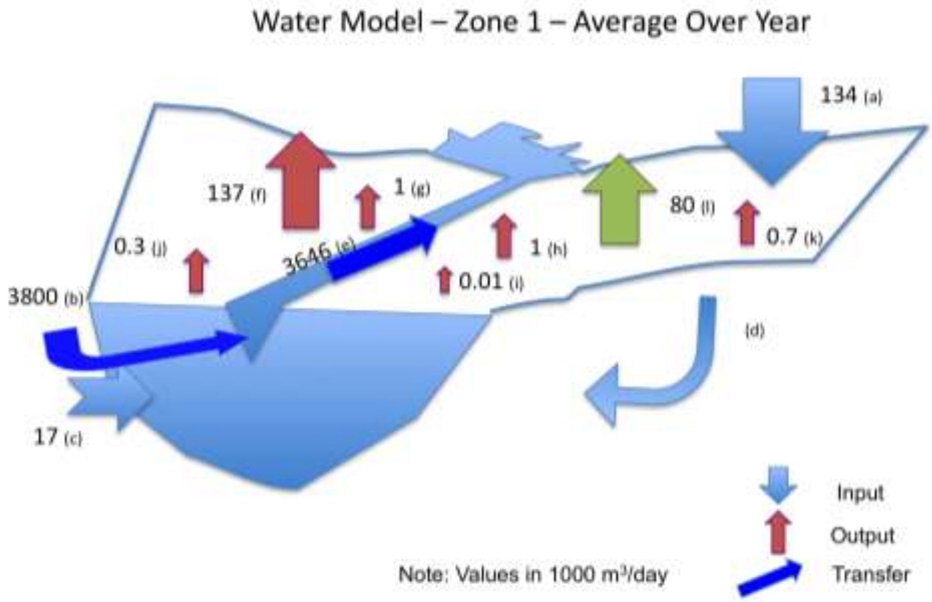


Figure 13: Conceptual water balance - Zone 1 - Average Over Year

Water input:

- Precipitation (a)[1];
- Water coming in "laterally" with the Nanaimo River (b) and in the subsurface through the aquifer (c);
- A portion of the flow coming from precipitation will travel in the subsurface (and is sometimes referred to as "interflow") and will discharge to the aquifers and to the rivers (d). It is not a net input, but part of the water movement.

Water output:

- Water being discharged by the Nanaimo River and it's hyporheic zone (the aquifer associated with the river - e);
- Groundwater extraction by the various water users in the area
  - Harmac well field (f)[2]
  - NCID (g)
  - Rural residential users – individual wells (h)
  - Nanaimo Airport (i)
  - Various small communal systems (e.g.; manufactured home parks – j)
- Surface water licenses [3](k);
- Evapotranspiration (l);

Part of the water coming in as precipitation over the whole area will infiltrate vertically in the subsurface until reaching the water table. It will then move laterally in the sand and gravel aquifers

[1] The water input and output are shown with arrows. For each identified input and output, the number near the arrow gives an estimate of the input or output rate in 1,000 m^3/day and the letter in brackets is used for reference purposes.
[2] Harmac's extraction increases to 136,500 m^3/day if we take into account the surface water intake.
[3] It has been assumed that only 50% of licensed volume is used.

according to the slope of the water table. Generally, the slope of the water table converges towards Haslam Creek and the Nanaimo River which both act as the main drains for the area. This water will join the water coming through the rivers and the aquifers at the boundary of Area A, and will discharge in the Nanaimo River Delta, to the north.

Water is removed from the area directly at ground surface or at relatively shallow depths (to approximately 5 m depth) through evapotranspiration, consisting of water directly evaporating from open waters and the ground and being released by vegetation.

Water is also removed by all the production wells tapping into the groundwater. Some of this water will be reintroduced into the subsurface via the discharge of septic fields or through re-infiltration of irrigation water, and some will be transferred out of the area via discharge pipes (Harmac water supply, sewer pipes).

Water will also be consumed by the population and ecosystems.

Table 3 reveals the importance of the role played by the Nanaimo River system in Zone 1 with nearly 95 % of the water input and output associated solely with this element of the water budget. The next largest element is Nanaimo Forest Products (Harmac). Their water extraction is equivalent to the volume provided by precipitation. In comparison, the volume used by all other water users is minimal, representing less than 3% of the volume extracted by Harmac.

Table 3: Estimated Water Balance - Zone 1

Item	Input	Output
	m^3/day	m^3/day
Precipitation	133,951	
Surface water through boundaries	3,799,872	
Groundwater flow through boundaries	17,280	
River flow to estuary		3,646,080
Nanaimo Forest Products (Harmac)		136,500
NCID		1,240
Residential on wells		1,173
Airport		15
Other small water systems		340
Evapotranspiration		80,395
Surface water licenses (50%)		660
Total	3,951,103	3,866,403

Table 3 was built assuming that the yearly budget was balanced. We presently don't have the data to confirm whether this assumption is valid. Proper collection of information on the surface water dynamic, the groundwater regime, water usage, and climatic data will allow the water budget to be better characterized.

4.1.1. Zone 1 and Critical Conditions

Figure 14 shows an illustration of the water balance for Zone 1 during the critical time of the year (September – October), and Table 4 provides an estimate of the water budget.

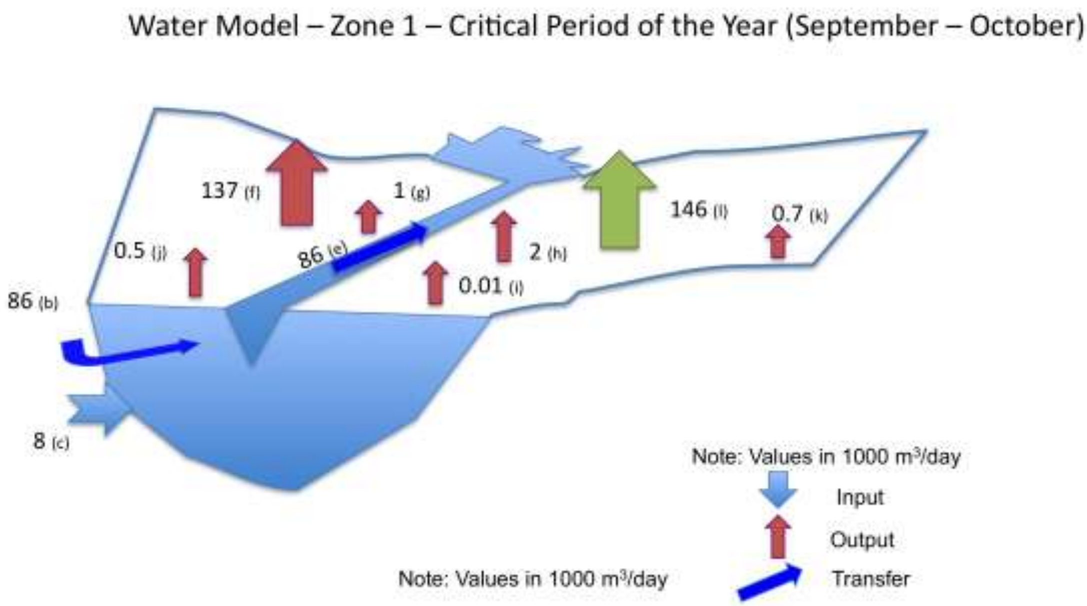


Figure 14: Conceptual Water Balance - Zone 1 - Critical Conditions

Table 4: Estimated Water Balance - Zone 1 - Critical Conditions

Item	Input m³/day	Output m³/day
Precipitation	0	
Surface water through boundaries	86,400	
Groundwater flow through boundaries	8,064	
River flow to estuary		86,400
Nanaimo Forest Products (Harmac)		136,500
NCID		1,240
Residential on wells		1,760
Airport		15
Other small water systems		510
Evapotranspiration		145,629
Surface water licenses (50%)		660
Total	94,464	372,714

Table 4 shows that during the dry period of the year, the water output is estimated to be four times the water input. Evapotranspiration is the largest output and is similar to the volume extracted by

Nanaimo Forest Products (Harmac), each removing approximately 1/3 of the total output. During this period, the estimated Nanaimo River flow is 60% of the volume extracted by Harmac.

4.1.2. Groundwater monitoring and groundwater/surface water interaction in Zone 1

Three monitoring wells are operated by the BC MOE in Area A. Their location is shown in Figure 15. They provide information on the seasonal fluctuation of the water table in Aquifer 161 (Obs Well 312 and 330) and Aquifer 160 (Obs Well 228) for various periods of time and dating back to 1954 for Obs Well 228. The piezometric curves are presented in Figure 16 through Figure 18.

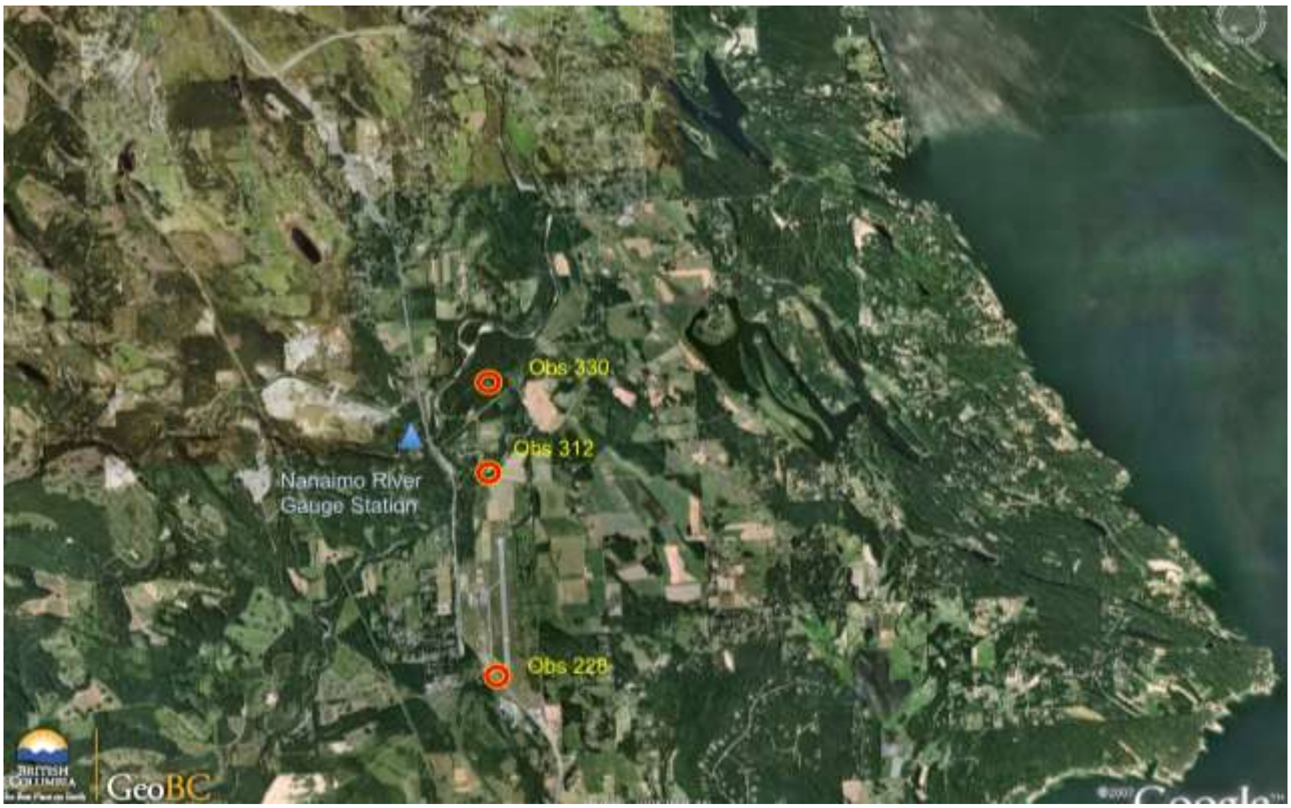
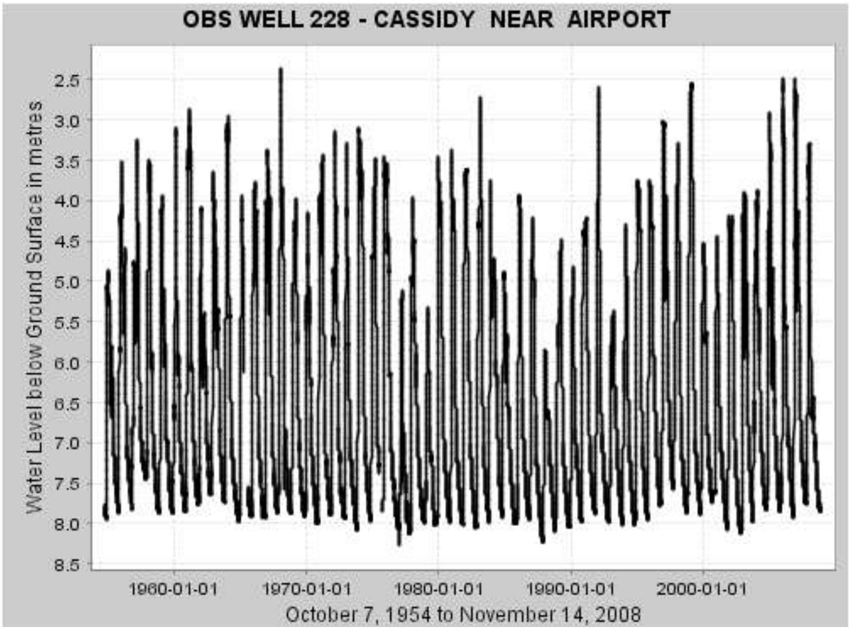


Figure 15: Location of BC MOE Monitoring Wells and Environment Canada Gauge Station



A piezometric curve shows the variation in elevation of the water table, measured as depth to water from ground level, with time. Following periods of precipitation and aquifer recharge, the water table will rise. It will then drop during the summer and the early fall due to discharge to rivers. The "see-saw" type of curve is due to this seasonal sequence of high and low levels reached every year.

Figure 16: Piezometric Curve - Obs Well 228

Observation well (Obs) 228, located near the Nanaimo airport provides the longest record for the area, starting in 1954. It shows a typical yearly amplitude of 4 m to 5 m. The low level of the water table has been very constant with maximum depth to water recorded between 7.5 m and 8 m. The elevation of the high water table, reached during the winter, shows more variations. A slight downward trend is observed between the 1960s and the late 1980s, with the water table not rising to less than 6 m from ground surface. Since, the early 1990s, the water table in the well has recovered to historical elevations, reaching high levels 2.5 m to 3.5 m from ground surface. The aquifer monitored by this observation well does not indicate signs of stress.

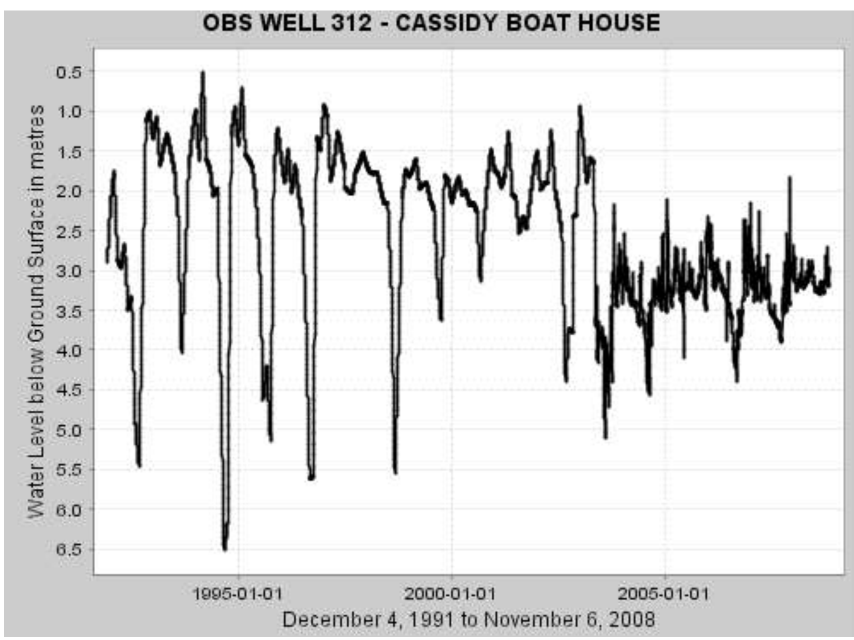


Figure 17: Piezometric Curve - Obs Well 312

For Obs Well 312 (Cassidy Boat House), the recording period is shorter, starting in 1991. This well shows a relatively high water table in the winter, with the water table less than 2 m from ground surface. The water table drops in the summer. In the 1990s, the water level dropped several years to depths greater than 5 m. In the last 10 years, the amplitude of fluctuation is less and the water table does not drop as much in the summer. Therefore, we can conclude that the aquifer does not show signs of stress.

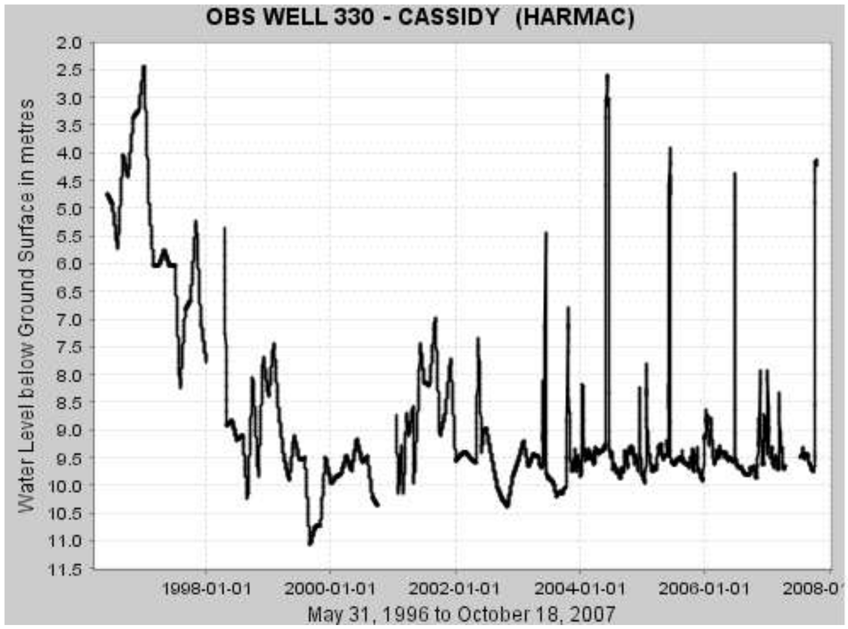


Figure 18: Piezometric Curve - Obs Well 330

Obs Well 330, located within the Harmac well field, provides water table elevations starting in May 1996. It shows a drop of the high water table from 2.5 m to 9 m below ground between 1996 and year 2000. Since then, the water table has remained at a relatively constant level, at depths ranging between 8 m and 10 m. For short periods of time, the water table rises to depths of 2.5 m to 4.5 m, probably when the well field is temporarily not operating. Unfortunately, the monitoring wells do not provide information on water table fluctuation prior to the operation of the Harmac wells.

Although the Cassidy aquifer is perceived as a very productive aquifer, this assumption may mask some issues related to the long-term sustainability of the resource and potential impacts which have not been quantified due to the lack of historical and present day monitoring. There are strong assumptions that the Nanaimo River and Haslam Creek are closely connected with the aquifers where they cross Area A. However, the most downstream gauging stations for both streams are located west of Area A, and upstream from the largest extraction points (Harmac surface water intake, Harmac well field and NCID well field). There is no gauging station on the Nanaimo River near its estuary. Therefore there are no means of comparing the flow in the river upstream and downstream of the water intakes or of assessing how the flow in the estuary is reduced due to surface water and groundwater extraction. Anecdotal monitoring information (Thurber, 2007) reports that monitoring well 330, located near the Harmac well field, showed a recovery of approximately 7 m in June 2004, during temporary shut down of the well field. This indicates that pumping from the well field creates a significant drawdown, compared to the typical fluctuation of the water level in the Nanaimo River. Therefore, the effect of pumping from this well field on the reduction of discharge to the Nanaimo River should be adequately assessed, if this has not been done yet.

The Nanaimo Estuary Management Plan (2003) identified this issue. The following text - in italics - is an excerpt from this 2003 report:

"*The natural flow regime of the Nanaimo River has been altered by licensed water storage and diversion, and through land use practices such as logging. The total licensed storage within the watershed amounts to 5% of the basin's natural runoff. The flow of the Nanaimo River varies both seasonally and annually. The daily extremes from 30 years of streamflow data collected by WSC at 08HB005, a site upstream from 08HB034, record the winter peak flow as 1,550* m^3/s *and the daily low flow in the summer as less than 1.0* m^3/s.

The Nanaimo Lakes in the central portion of the basin create a moderating effect on the flow of the river originating upstream of the lakes. There are also three constructed reservoirs in the basin, two of which are owned and operated by the Greater Nanaimo Water District (GNWD), and one of which is owned and operated by Pope and Talbot Harmac Division.

The GNWD diverts water from the South Fork reservoir to provide the City of Nanaimo with its municipal water supply. Harmac controls the outflow from its reservoir and withdraws water from the river downstream of the reservoir, pumping it to the Harmac pulp mill. The diversion takes place just downstream of the Island Highway #1. By regulating releases from their reservoirs, Harmac and the GNWD maintain a minimum residual flow of 1.38 m^3/s *in the lower Nanaimo River downstream of Harmac's water intake. This minimum flow, which is often exceeded, is 3.5% of the mean annual discharge. Although the typical target is 10%, 3.5% is a good minimum flow for east Vancouver Island (Marion Lightly, pers. comm).*

Historic data, collected by WSC at 08HB034, show that the regulated flows in the Nanaimo River above the Harmac point of diversion are higher in the summer than the natural flows. This effect applies to the river upstream of the Harmac diversion, but not downstream of the diversion point. ***The most critical time for meeting demands on the water resource is during periods of low flow. Fish are particularly affected by low flows, which can reduce fish habitat value (e.g., appropriate vegetative cover and water temperature) and limit the ability of the fish to access habitats.*** [4]

The GNWD is the only licensed municipal waterworks within the Nanaimo River watershed, and they use about 31% of the total extractive demands. Harmac's industrial pulp mill has licenses to draw water from an intake and wells, ***with licenses for almost 67% of the total extractive demands****. Over the past decade, the company has reduced its water demands by 40% due to improved equipment and efficiencies in the mill. Irrigation, domestic, other industrial and conservation uses account for only 1.4% of the licensed extractive demands.*

Minimum flow requirements have been established by DFO and by MoE (Freshwater Fisheries). This is based on the best available knowledge, ***but there are gaps in available data and in the understanding of the fish needs****. The requirements attempt to address the minimum flows needed to maintain habitat during summer and early fall, and pulse flows to trigger the migration of Coho up the Nanaimo River when fish are congregating at the mouth of the river. Proposed*

[4] Italic shows extracts from the 2003 report. Bold typeface is used by the authors of this 2010 report to emphasize some of the most important points.

strategies and objectives for the recovery of steelhead stocks include examining water flows and temperature improvement opportunities below the reservoirs and a review of the implementation of the 1993 Nanaimo River Water Management Plan regarding conservation flow requirements."

Recent information confirms the link between what is observed in the Nanaimo River Estuary and what happens upstream, in its watershed: "One of the freshwater issues for the estuary […] is the quantity of freshwater that flows down the east channel (flows north from the bifurcation near the end of Raines Road). There has always been interest from a biological point of view in having a greater percentage of the water, during base flow periods, enter the estuary via that channel. […] From my observations, the lower river seems to have been impacted by water losses, both natural and licensed, and increased temperatures." Andrew McNaughton, Biologist, pers. com, October 2008).

The Nanaimo River Estuary must be protected not only for the fact that it hosts numerous ecosystems but also because of its economical value. According to Dawe, 2001 (originally from Costanza et al, 1997), estuaries are rated as one of the most valuable land and their economical value is estimated to be over 200 times the value of cropland.

4.2. Water movement and budget in Zone 2

The second zone corresponds to the eastern half of Area A. The typical water movement in this zone is illustrated by Figure 19 and is described as follows:

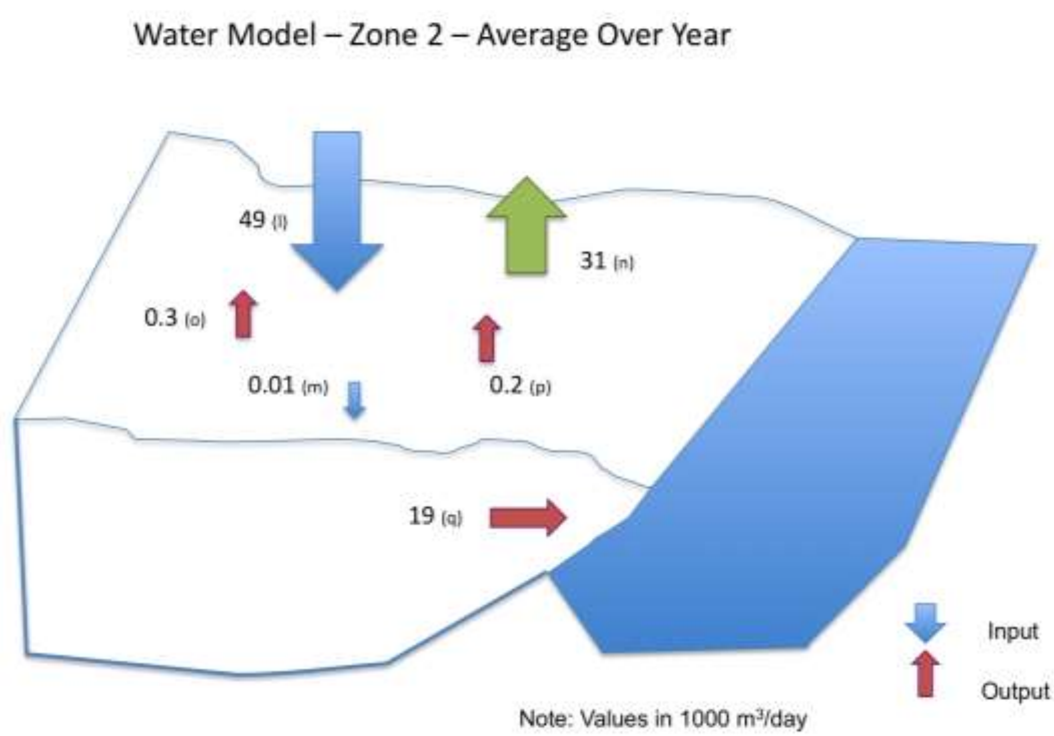


Figure 19: Conceptual water balance - Zone 2 - Average Over Year

Water input:

- Precipitation (l);
- Water delivery (m)

Water output:

- Evapotranspiration (n);
- Groundwater extraction by the various water users in the area
  - Rural residential users, individual wells and small communal systems (o)
- Surface water licenses (p)
- A portion of the flow coming from precipitation will travel in the subsurface and will discharge to the foreshore (q).

Part of the water coming as precipitation over the whole area will infiltrate vertically in the subsurface until reaching the water table. It will then move laterally according to the slope of the water table. Groundwater will predominantly be present and transported in the fractures of the bedrock aquifer in this zone. Generally, the slope of the water table converges either towards small depressions occupied by surface water bodies (lake, ponds, wetlands), or towards the ocean.

Water is removed from the area directly at ground surface or at relatively shallow depths (to approximately 5 m depth) through evapotranspiration, water evaporating directly from open waters and the ground and being released by vegetation.

Water is also removed by all the production wells tapping into the groundwater. Some of this water will be reintroduced into the subsurface via the discharge of septic fields or through re-infiltration of irrigation water. Some will be transferred out of the area via discharge pipes (sewer pipes in the near future). Water will also be consumed by the population and ecosystems.

Table 5 shows that the three main elements of the water balance are the precipitation, the evapotranspiration, and the discharge to the foreshore. The discharge to the foreshore is estimated based on the geometry of the bedrock aquifer, the estimated hydraulic gradient, and assumed hydraulic conductivity. However, hypotheses were made, based on the assumption that the water budget is balanced over the year.

Table 5: Estimated Water Balance - Zone 2

Item	Input m^3/day	Output m^3/day
Precipitation	49,437	
Evapotranspiration		30,662
Residential on wells		310
Discharge to foreshore		18,662
Water import (trucked)	12	
Surface water licenses (50%)		180
Total	49,449	49,814

4.2.1. Zone 2 and Critical Conditions

Figure 20 and Table 6 illustrate the estimated water balance for Zone 2 during the critical time of the year. It shows that the water output is 50% greater than estimated for the year's daily average, because of the high evapotranspiration. The only water input is imported (trucked-in) water.

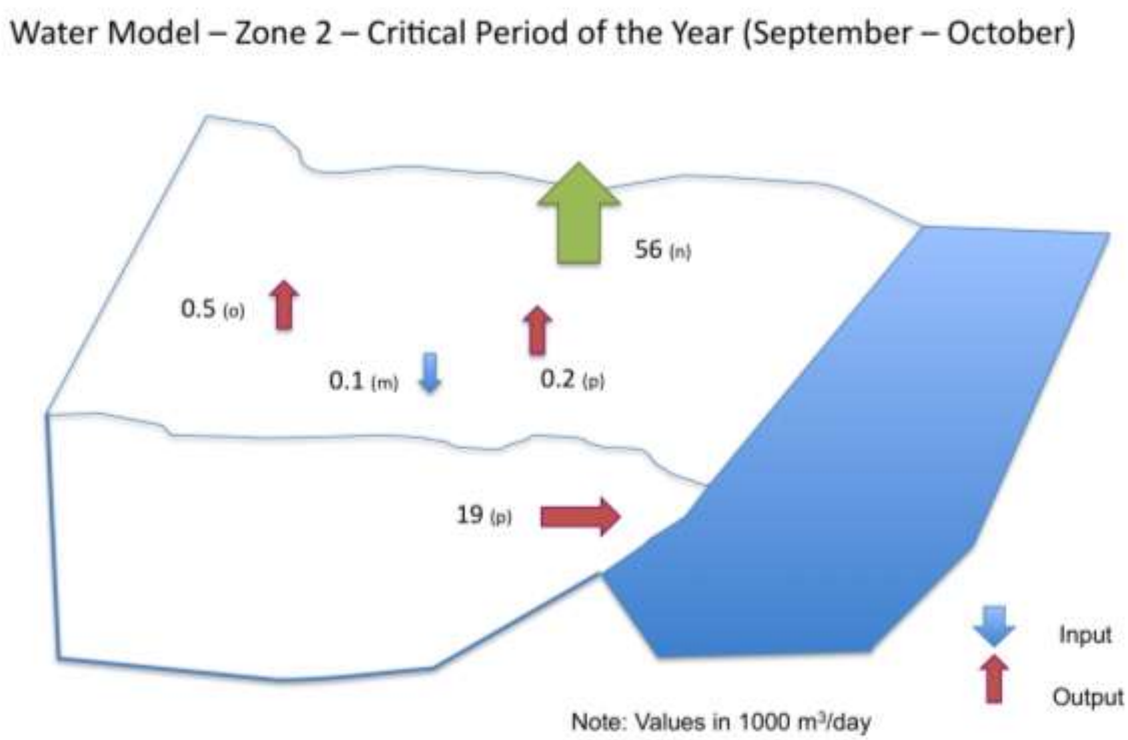


Figure 20: Conceptual Water Balance - Zone 2 - Critical Conditions

The table indicates that the human use of water is very minimal compared to evapotranspiration (1%). This model also shows that the drier period of the year will be the time when the aquifer is more at risk of salt water intrusion, and when surface water bodies and their associated ecosystems could be stressed or jeopardized, as discussed in Section 5.

Table 6: Estimated Water Balance - Zone 2 - Critical Conditions

Item	Input m^3/day	Output m^3/day
Precipitation	0	
Evapotranspiration		55,542
Residential on wells		464
Discharge to foreshore		18,662
Water import (trucked)	75	
Surface water licenses (50%)		180
Total	75	74,849

This table has been established based on available information and assumptions. For example, it assumed that 10 water deliveries by truck occurred daily during the critical period of the year.

4.3. Water movement and budget in Zone 3

The third zone corresponds to a small portion of Area A, at its southern tip. The typical water movement in this zone is illustrated by Figure 21 and summarized in Table 7.

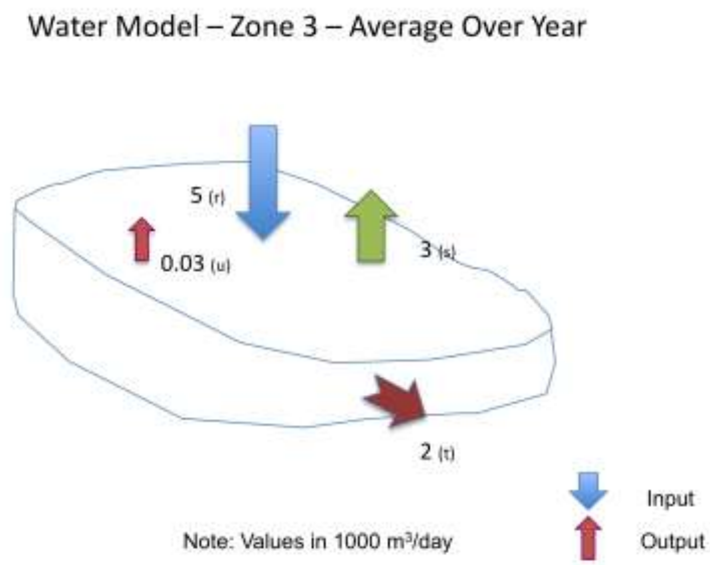


Figure 21: Conceptual water balance - Zone 3 - Average Over Year

Water input:

- Precipitation (r);

Water output:

- Evapotranspiration (s);
- Groundwater discharge to Ladysmith Inlet (t)
- Groundwater extraction by the various water users in the area
    - Rural residential users – individual wells (u)

Part of the water coming as precipitation over the whole area will infiltrate vertically in the subsurface until reaching the water table. It will then move laterally in the Cassidy Aquifer according to the slope of the water table. Generally, the slope of the water table converges towards Ladysmith Inlet.

Water is removed from the area directly at ground surface or at relatively shallow depths (to approximately 5 m depth) through evapotranspiration, water evaporating directly from open waters and the ground and being released by vegetation.

Water is also removed by all the production wells tapping into the groundwater. Some of this water will be reintroduced into the subsurface via the discharge of septic fields or through re-infiltration of irrigation water. Some will be transferred out of the area via discharge pipes (sewer pipes in the near future).

Water will also be consumed by the population and ecosystems.

Table 7: Estimated Water Balance - Zone 3

Item	Input m^3/day	Output m^3/day
Precipitation	4,523	
Evapotranspiration		2,609
Residential on wells		26
Flow to Ladysmith Inlet		1,895
Total	4,523	4,530

The main elements of the water budget in Zone 3 are natural inputs and outputs. Groundwater extraction attributed to human activities represents a small percentage of the output (less than 1%). Therefore, a critical period has not been identified for Zone 3.

5. SUSTAINABILITY APPLIED TO WATER RESOURCES

5.1. The concept of sustainability

Any watershed can be represented as a “closed system” where water comes in, as precipitation, and leaves at its outlet (a river estuary, a foreshore, etc.). Within the watershed, water will move through various paths (as surface water and groundwater) and through all kinds of ecosystems and species. A natural balance will be developed over a long period of time with the establishment of ecosystems along groundwater and surface water flow paths. These ecosystems are present in streams, lakes, wetlands, estuaries and along foreshores, the main conduits and discharge areas of fresh water. Any re-routing or extraction of water at a location along its natural flow path will affect the ecosystem relying on the conditions established at this location in the flow path.

Since the start of the industrial revolution, we have observed that humans can modify equilibriums, which have taken centuries to get established. When dealing specifically with water, this is mainly related to the creation of means to displace and consume water at a much larger rate than was happening by default in nature (e.g.; pumps that can extract water from deep aquifers at thousands of liters per minute, re-routing of rivers and moving water, and large and long pipelines) and the introduction in nature of man-made molecules with toxic effects.

We are observing that our environment is changing (e.g., river low flow rates are getting lower, the temperature of rivers is increasing, water tables are dropping, some species are disappearing, etc.)[5], and we are realizing that these observations result from past and present actions. This created the desire to preserve the environment, and so the concept of sustainability was formed.

The concept of sustainability is a complex concept, because it is dynamic and it evolves, as we understand the intricacy and the relationship between the various elements that define the concept itself. For example, it is only recently that we have started to understand the importance of the interaction between surface water and groundwater, and the fact that surface water and groundwater are one.

A report by the USGS entitled "Sustainability of Ground-Water Resources" http://pubs.usgs.gov/circ/circ1186/ provides a very good introduction to groundwater development, sustainability and water budgets. Some extracts of this document are included in Appendix 4.

5.2. How Much Water is Available?

Water moves through a watershed as a flux. Sometimes water is plentiful (rainy season, large storms, thick snow pack), sometimes there is very little (summer droughts). Some years are wet, and in some years precipitation amounts are considerably lower than average values. The average precipitation is based on what has been measured at climate stations in a watershed over a certain period of time.

[5] Some well known cases are the Ogalala aquifer (USA) and the North China Plain aquifer system (China).

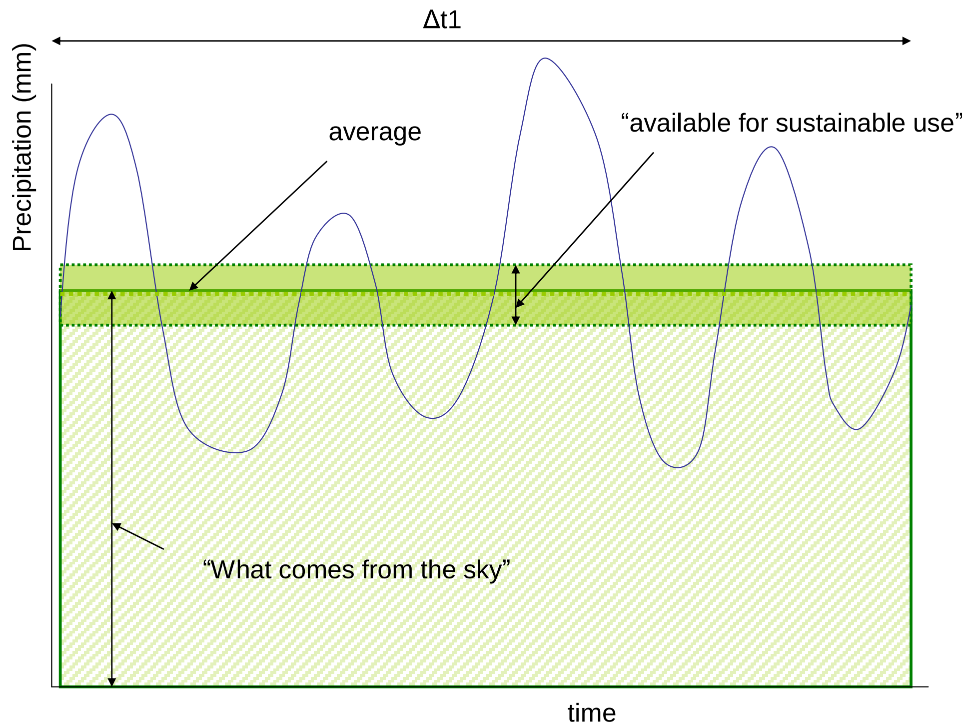


Figure 22: Estimate of sustainably available water, over short time period (a few years)

A common misconception is that water is continuously renewed and, that 'what comes from the sky' (as illustrated in Figure 22 with the hatched area) will continue to be provided and available for use. A second common misconception is the idea that 'If water extraction is equal to the recharge, there will not be any impact and that can go on forever'. What is not understood in this simple concept is that a large portion of this 'recharge' creates the conditions that drive the groundwater flow. Removing what comes from the sky will, over a long period of time, result in a flat water table if what is removed is not returned to the aquifers fully at 100%.

Only a small portion of the precipitation is available for sustainable use.

Time is another factor. Firstly, we need to consider the period for which we have collected data. As shown in Figure 23, information provided through the time period Δt_1 will be different from information provided for a longer time period Δt_2. We also have to consider the time scale at which the groundwater moves through an aquifer. For a given time period Δt_2, there will be a corresponding volume of water that will correspond to the 'excess' in recharge, or the volume of water for which removal will not translate into large disturbances of ecosystems. If we extract more than this volume of water, then we are tapping into a volume of water that is not in transfer. To draw parallel with economic terms 'capital' and 'interest', we are then using the 'capital' and not the 'interest' anymore. Understanding the groundwater flux requires the understanding of the groundwater regime and aquifer dynamic, from the recharge to the discharge zones and both for travel time and for the mass of water in transit.

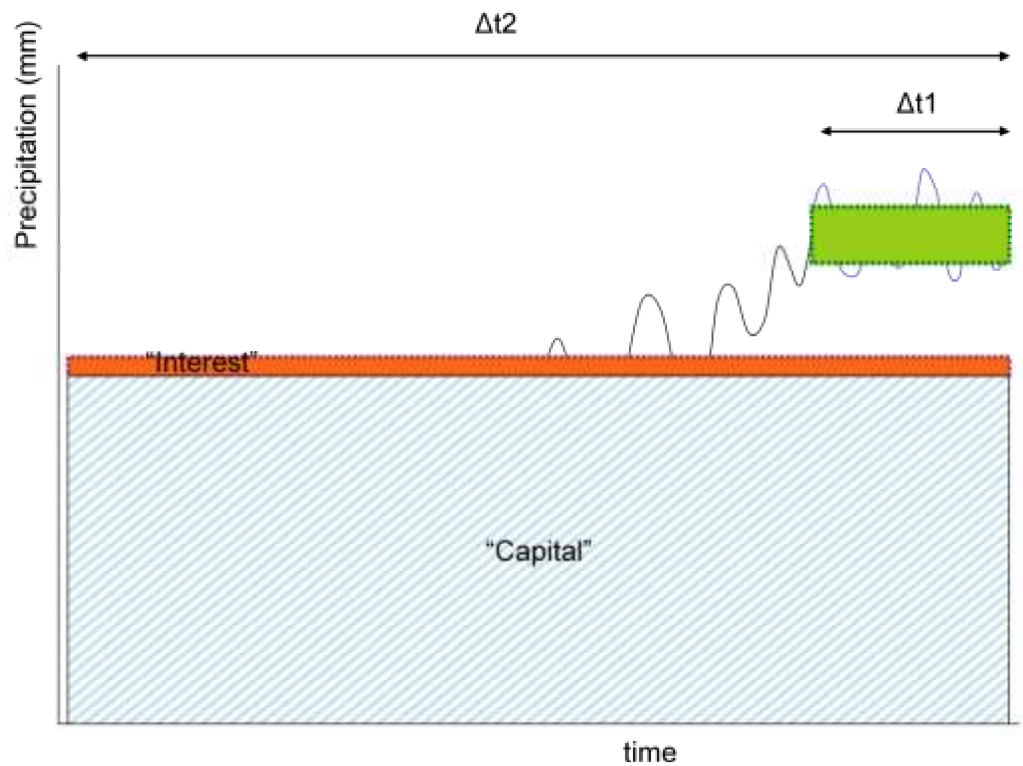


Figure 23: Estimate of sustainably available water over a long period of time

The zone with the green rectangle corresponds to the time period illustrated on the previous graph (Figure 22). Figure 23 shows that when considering a longer time period, the estimated sustainably available water is much lower, as represented by the depth of the orange rectangle, compared to the depth of the green rectangle.

5.3. The concept of sustainability applied to Area A

The following discussion will focus on the sustainability of the natural environment and the watershed. It will not consider sustainability in its social or economic dimensions.

5.3.1. Rivers, Aquifers and Sustainability

Haslam Creek and the Nanaimo River are the two main surface drainage features in area A. They are the 'observable' elements of the global water movement in Area A. However, a large volume of water also transits through Area A in the hyporheic zone of the streams and within the aquifers (Figure 24). This mass of water will remain underground through its entire transport through Area A and will not be noticed by any observer at surface.

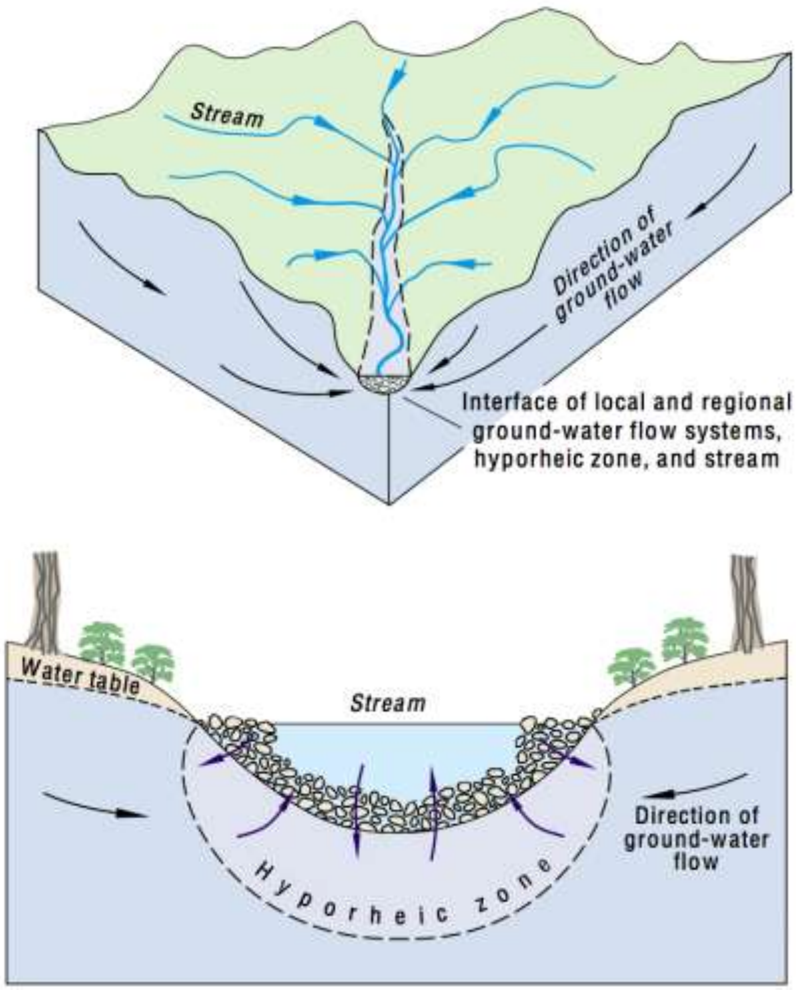


Figure 24: Interaction between surface water and groundwater (USGS Circular 1139)

If we consider the streams and the groundwater flow as one large flow, the surface water in the streambeds is the daylight portion of the water movement. Figure 25 illustrates how the drawdown of the water table due to development of a cone of depression will affect surface water (wetlands, rivers, and lakes).

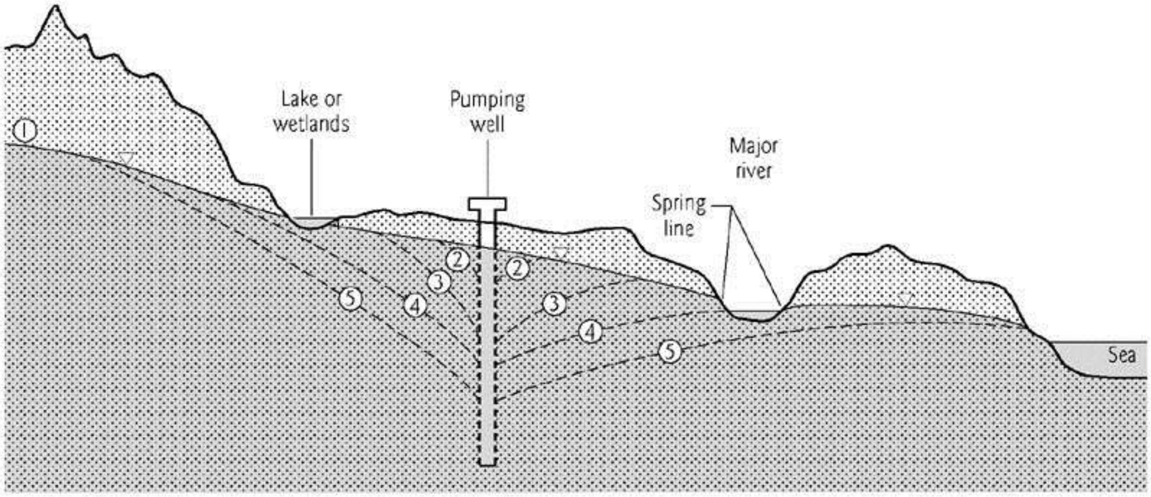


Figure 25: Effects of pumping wells drawdowns on surface water (Younger, 2007). 1) shows the water table pre-pumping; with increasing pumping time, the water table will drop. By the time the cone of depression has reached position 5), all inland freshwater bodies are hydraulically disconnected from the water table.

Typically, when a river and an aquifer are connected, the amplitude of the fluctuation of the water table in the aquifer will be smaller than the amplitude of fluctuations of river level. When the river level is high in the winter, during the rainy season, the water elevation in the river will be higher than the water table in the river banks. On the other hand, in the summer and early fall the river levels will be lowest and the water table will then be higher. This change in relative elevation (river level compared to water table elevation) is due to the slower movement of water in the aquifer and the greater 'storing' capacity of the aquifers.

It is worthwhile to note that the continuous extraction from Harmac well field will control the movement of the water table near the confluence of the Nanaimo River and Haslam Creek. This is observed when the water table in Obs Well 330 and Obs Well 312 rise by approximately 6.7 m and 0.6 m, respectively, following temporary shut-down of the Harmac well field.

5.3.2. Sensitive receptors

Figure 26: Interactions between groundwater and sensitive receptors such as wetlands and streams (Geoscape Canada)

Extraction of water within Area A, if not occurring in a sustainable manner, will affect two main types of receptors:

The groundwater systems

Extraction of groundwater will result in:

- A lowering of the water table (Figure 26(a), with two main effects: An increase of thickness of the vadose zone (Figure 26(b)) and a reduction in water content in the vadose zone. This will affect the ecosystems relying on the surface groundwater interactions, as illustrated in Figure 26, and the vegetation relying on a certain range of soil moisture in the vadose zone. For example, certain trees may have root systems concentrated in the first 3 m from ground surface, where the water table rarely drops below 3 m. If due to extraction of groundwater, the water table drops below 3 m for an extended period of time (e.g.; several months in the summer and fall), then this may create unacceptable stress on these trees, particularly if this situation becomes recurrent, several years in a row.
- A reduction in interflow. Figure 27 and Figure 28 show that the groundwater discharge from an aquifer to a river is a function of the difference in elevation between the water table and the river level. A lowering of the water table (Figure 28) will result in a reduced discharge of

groundwater to the river and smaller river flows. This will decrease the time during which the water table in the aquifer is higher than the river level, the time during which the aquifer will discharge to the river, and the quantity of groundwater discharged to the river. Aquifers present the benefit of delivering to surface streams water of high quality and at constant water temperature, thereby regulating the stream temperature (having a cooling effect in the summer and a warming effect in the winter).

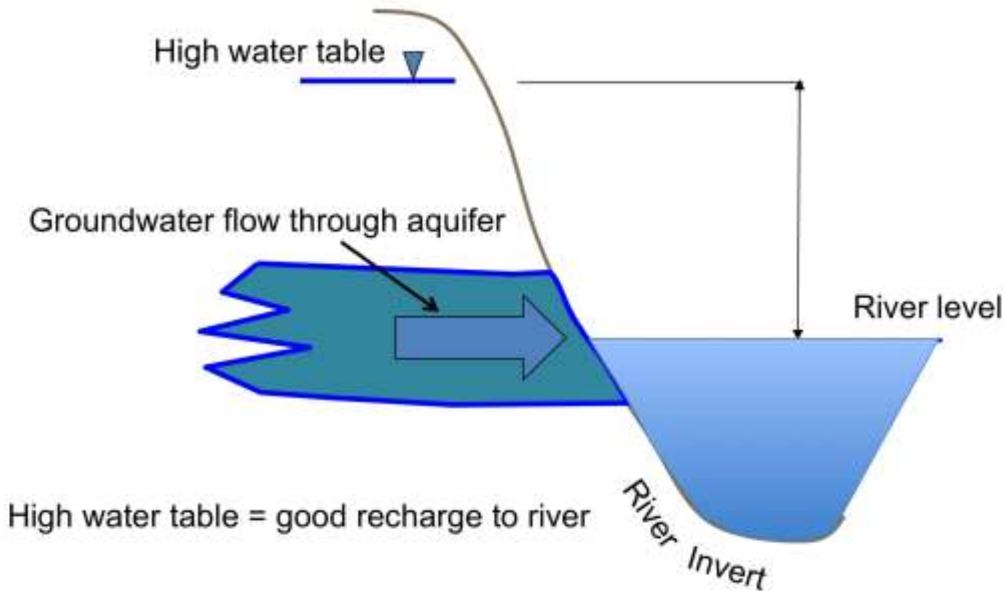


Figure 27: Groundwater discharge to a river - High water table

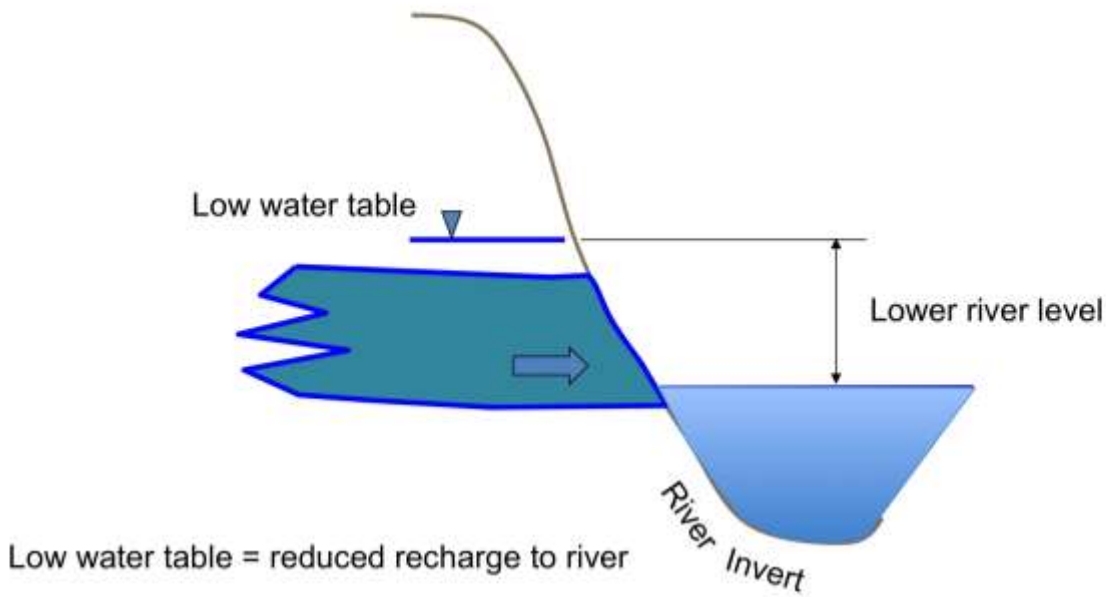


Figure 28: Groundwater discharge to a river - Low water table

The surface water systems

Lowering of the water table due to groundwater extraction will reduce the groundwater discharge to the surface streams. This will have the following effects:

- A reduction of the volume of water transiting in the streams, and an associated reduction in nutrients and elements required to sustain the ecosystems living in the water;
- A reduction of the wet area of the stream (submerged stream banks and river invert) and reduction of the habitat of ecosystems relying on the submerged area for growth and reproduction (e.g. spawning areas);
- An increase in water temperature, and the associated negative effects it has on fish habitat (reduced dissolved oxygen, etc.)

The interconnection between surface streams and aquifers, and the variation of water levels associated with surface water and groundwater, becomes critical when reaching the lowest discharge rates (low flows) in streams. Depending on the geometry of the river invert, a small drop of water level (e.g. 0.1 m or 0.2 m) will become detrimental with regard to water temperature, flows, and effects described above. It may even cause interruption of the surface flow.[6] Figure 29 (a) shows a cross-section along a section of a gaining river where the water table is predominantly controlling the river level. Any drop of the water table will result in a drop of the river level. If the river is shallow, such a drop may result in an interruption of the river flow (Figure 29, (b)).

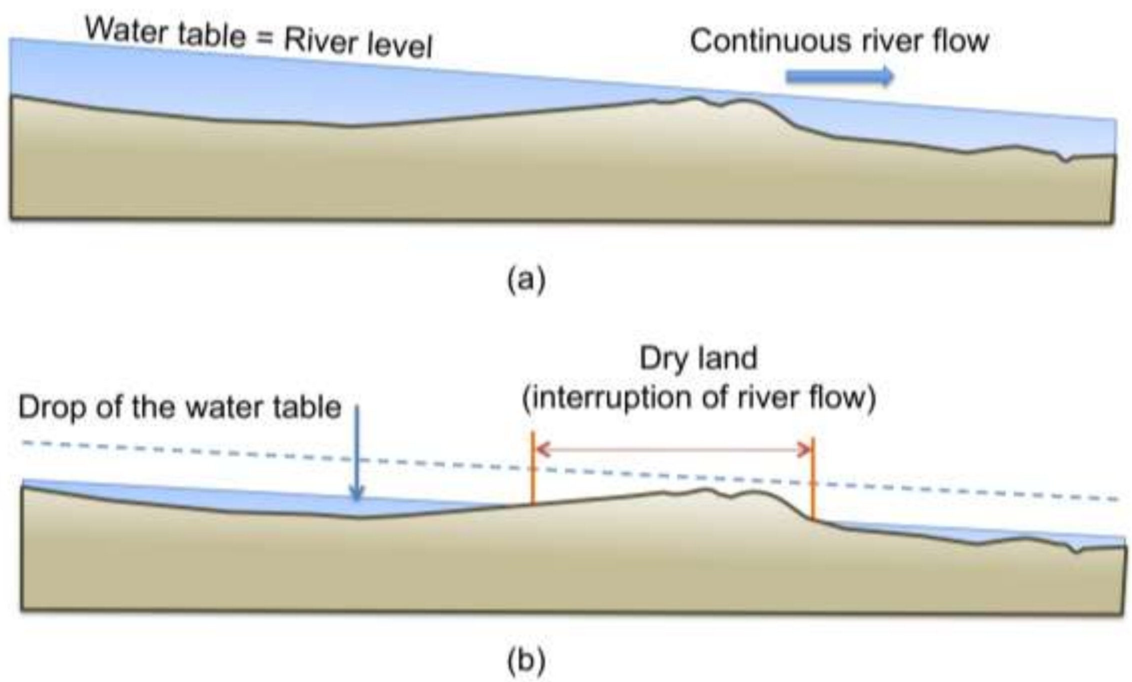


Figure 29: Impact of dropping water tables on river flow

[6] This is unfortunately now the case for many large rivers in the world that do not reach their mouth during extended periods of the year due to over-extraction and overuse of water in their watersheds.

Any river is a complex system including its main stem, tributaries, secondary channels, etc. The Nanaimo River is particularly complex given the size of its delta (Figure 30). Therefore, assessing the conditions for the sustainability of the multiple ecosystems it holds requires a good understanding of the stress levels these species and their habitat can withstand before it becomes detrimental to their survival and reproduction.

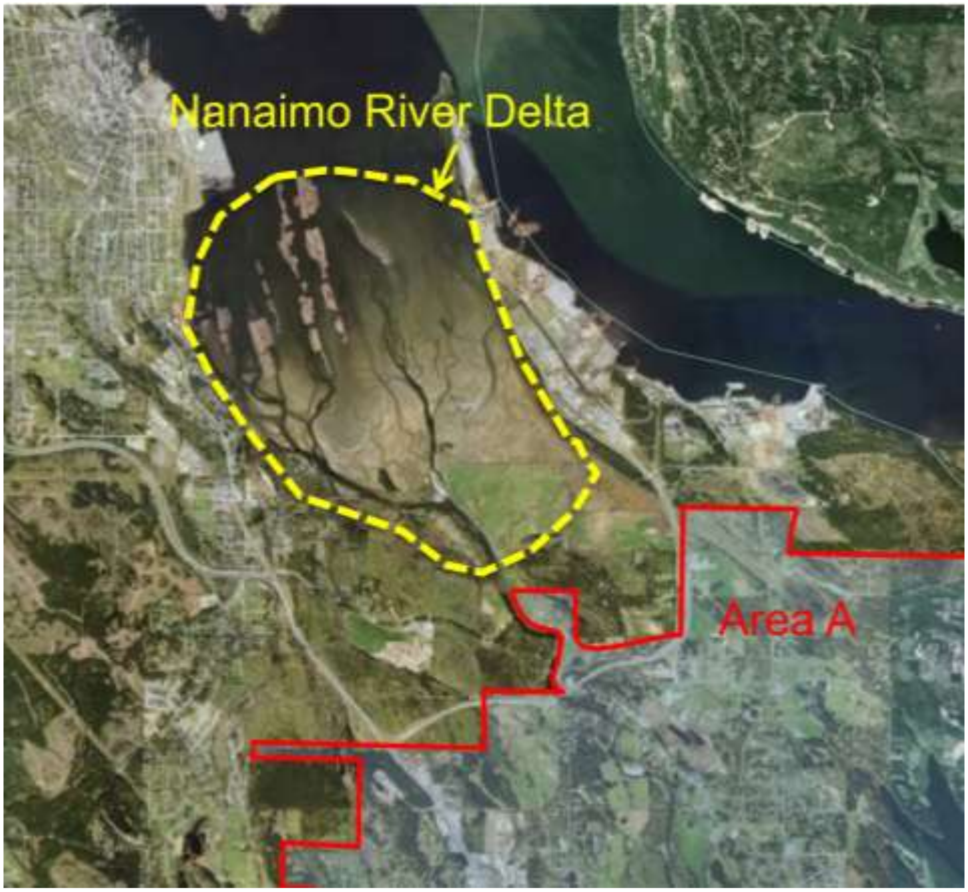


Figure 30: Nanaimo River Delta

Finally, in the coastal part of Area A, declining water levels due to overpumping can result in saltwater intrusion. This is shown in Figure 31, illustrating the risk of salt-water intrusion in an island setting. The same principles apply for the coast of Area A.

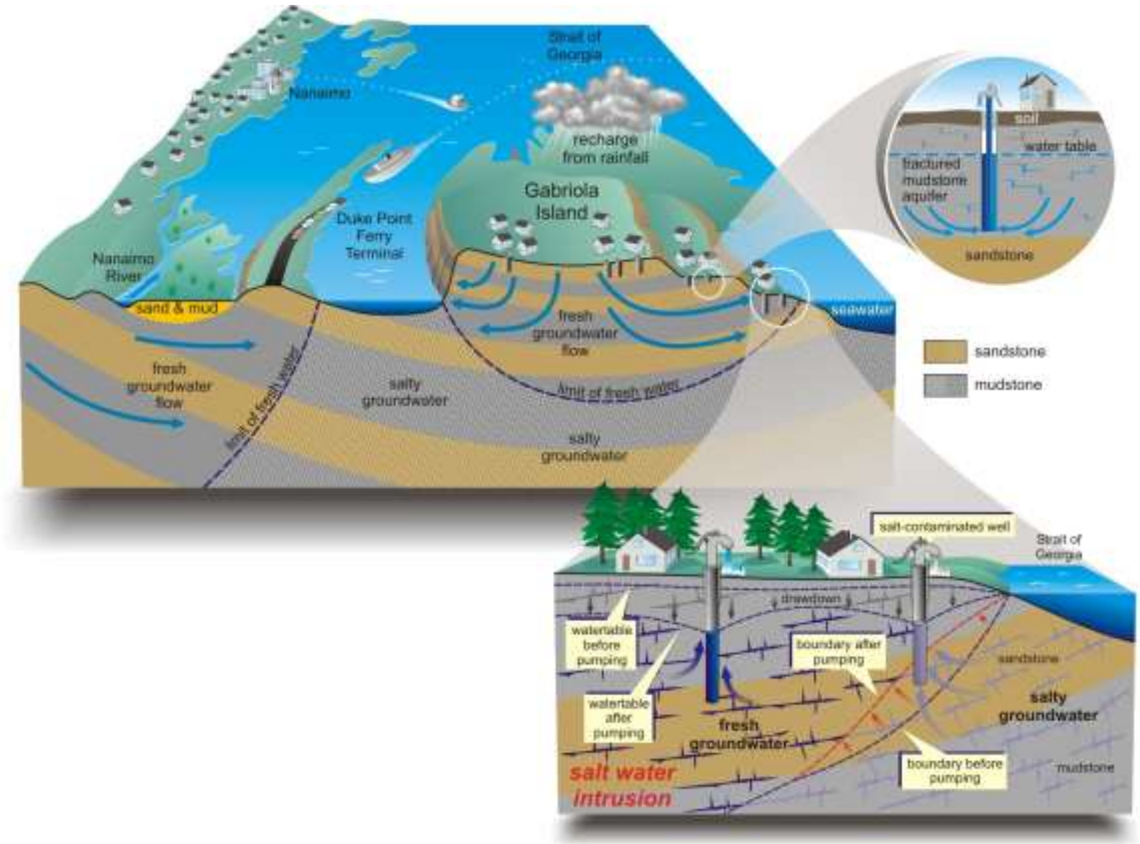


Figure 31: Salt water intrusion due to overpumping (source: Geoscape Nanaimo)

Based on the previously explained definition of sustainability, one can draw the conclusion that, for any watershed, the water is fully allocated. Watershed management consists of understanding the movement of water, at surface and in the subsurface, from the upstream part of the watershed to its outlets, and assessing the short and long term effects of water withdrawal and water displacement on the ecosystems present along the water path. Therefore, there is no magic number that describes the rate at which water extraction is acceptable. Every watershed will have specific hydrogeological conditions and ecosystems and will require its own assessment and monitoring plan, and its own management plan, taking into account the interests of the various players in the watershed. This has to be done in the spirit of water stewardship, in awareness of our responsibility to protect the environment and the ecosystems. This also has to be done using the precautionary principle, because of our limited knowledge of the watersheds, the complexity of the ecosystems and the delay between our actions and our observation of their consequences on the watersheds.

The following measures are recommended to optimize the sustainability of the water resources and the ecosystems in Area A:

- Better understand the relationship between surface water and groundwater;
- Build an inventory of the most sensitive habitats (wetlands, small tributaries, Nanaimo Delta);

- Identify the parameters most representative of identified potential impacts (e.g., water levels, discharge rates, water temperature), and the acceptable ranges for these parameters;
- Design and implement a monitoring program;
- Design a geographically referenced system (database, model) and an infrastructure (including human resources) through which knowledge of the area is recorded, monitored data is updated and interpreted, so that reliable data can be accessed and used by decision makers.

It is also understood that having no impact is an ultimate goal, often constrained by social, economical, and political limitations. Therefore, it is important to establish a water management plan within which potential impacts can be assessed, and based on known information, unknowns, and accepted risks, a decision making process can be set in place where the type and degree of impact can be discussed and accepted. This should involve all of the key stakeholders and be designed, at the onset, to reduce conflicts.

The long term monitoring can then confirm assumptions and trigger corrective actions, should impacts be greater than originally anticipated. It is important to be aware of the fact that impacts are often delayed, and damage to the resource base can have far-reaching and long-term consequences.

5.3.3. Impact of Climate Change

Research on climate change in the Georgia Basin, which includes southern Vancouver Island, has shown a warming pattern which will have an affect on temperatures, precipitation, and snowpack (Whitfield et al 2003); indirectly having an impact on surface water supplies and on recharge to the aquifers on Vancouver Island. It is also predicted that precipitation patterns will change, leading to wetter winters and drier summers (Rodenhuis et al., 2007).

These climate changes will affect the water resources and will need to be taken into account when designing water management plans. This reinforces the importance of collecting data now, in order to be able to assess trends with passing time and be in a better position to understand causes and effects and design remedial plans or water management plans.

Summary

We can extract groundwater from an aquifer and observe a drop of the water table. So what? Does it matter? Understanding the consequences of a dropping water table is key to assessing the sustainability of a groundwater resource. So the question: “Is what we are doing sustainable?” should be modified. The real question defining sustainability is a series of related questions:

- ✓ What are we affecting?
- ✓ By how much?
- ✓ What are the consequences of this modification?
- ✓ Are some of these consequences final and irreversible?
- ✓ Are the consequences acceptable on an environmental or social level?
- ✓ What level of risk are we willing to accept?

6. WATER QUALITY AND WATER QUANTITY CONCERNS

6.1. Water Quality Concerns

In this section, general comments on the water quality in Area A are provided, relying on works completed by others and general observations. The scope of work did not allow a detailed review of water quality information or the sampling and analysis of representative surface water and groundwater samples.

The Nanaimo River Estuary is located immediately to the north and downstream of Area A. Any degradation of the water quality observed in the estuary would in part result from impacts from Area A because, beyond the boundaries of Area A, human activities are minimal in the watersheds of the Nanaimo River and Haslam Creek, except for forestry operations. The Nanaimo Estuary Management Plan (available in draft form dated July 2003) includes the following in a section on water quality:

"The water quality of the Nanaimo estuary has declined significantly as the watersheds have undergone urban and agricultural development. There has likely been some improvement since the days of direct discharge of sewage to the mudflat. Since the time of recent testing (1990) the significant decline in water quality has abated. Many inputs to the estuary have affected the water quality including: industrial effluents, log debris, stormwater, and pollutants from septic fields, livestock or agricultural/horticulture products used within the watersheds. It is a challenge to identify pollution sources and to develop appropriate management strategies, especially for non-point source pollutants."

The following elements that could potentially affect the water quality have been identified:

- Septic fields: Until recently, none of Electoral Area A was serviced by a sanitary sewer system. Therefore, the likelihood of having failing or poorly maintained septic systems affecting the groundwater quality is high, especially during the winter months, when the shallow soils are saturated and the water tables higher. This situation will improve locally along the corridor where properties are going to be connected to a sanitary sewer system. This corridor includes the Cedar High School and a limited number of properties along MacMillan and Cedar Road, between MacMillan and Hemer Road. There is no additional capacity in the Duke Point treatment plant to accommodate additional connections until more capacity is added at the plant.

- Abandoned coal mines: Numerous mine shafts are present in Area A (**Figure 45**). They act as preferential pathways for groundwater between shallow and deeper zones and may allow faster movement of poor quality groundwater (low pH, containing metals).

- Solid waste landfills (active and abandoned).

- Agricultural land and golf courses: The use of fertilizers, herbicides and pesticides can be a source of water contamination.

- Industrial land: Industrial activities have been identified that can be associated with the release of various contaminants (see Section 7).
- Fluoride and boron have been associated with some bedrock formations in Area A, resulting in higher concentrations of fluoride and boron in the groundwater. This was studied and presented in a technical publication (S. Earle and E. Krogh).
- Salt water intrusion: Area A borders the Georgia Strait along its eastern boundary. All the wells along the foreshore are completed in bedrock. There, groundwater will flow in networks of fractures, and any significant drop of the water table due to overpumping of wells presents the risk of inland migration of the freshwater/salt water front.

The potential sources of degradation of the water quality are further described and illustrated in Section 7.

6.2. Water Quantity Issues

There are issues with access to water in Area A. The conceptual water budgets presented in Section 4 indicate that there is a water deficit in the summer and fall in all parts of Area A.

In Zone 1, the water deficit will translate into a drop of the water table in both the overburden and bedrock aquifers and low flows of the Nanaimo River and its tributaries. The following consequences are expected:

- Reduced capacity and increased cost of extracting water from production wells for water system operators;
- Reduced or lost production of residential wells;
- Reduced flow in the Nanaimo River and its tributaries: This has an impact on fish species and ecosystems, due mainly to a change of conditions (from wet to dry), a change of temperature, and resulting physical and geochemical conditions (less dissolved oxygen, etc.);
- Stress on the vegetation and modification of the landscape: Low water tables during long periods of time will reduce soil moisture available to the root system of the vegetation. The species vulnerable to these modifications will disappear.

In Zone 2, except for the small area corresponding to the overburden Aquifer 163, the main water supply is Aquifer 162, a bedrock aquifer. Wells completed in this aquifer typically have a small yield (less than 25 m^3/day or 5 USgpm). They will be adequate to meet the water demand of a residence during approximately half of the year, when the water table is high enough to saturate the more fractured upper portion of the bedrock aquifer. As soon as the water table drops to a depth where the effective porosity of the bedrock is much less (due to less fractured rock), the yield of the wells decreases and, for many properties, the wells cannot meet their water demand. Residents currently rely on two private water delivery companies serving the area. Island H_2O Services and Stan Wood Trucking Ltd., which fill their trucks with water supplied by the City of Nanaimo.

Figure 32 shows areas where water is delivered by truck, according to information provided by the water delivery companies. It shows that many areas in Zone 2 suffer from water shortages. It provides general information and is not specific to any particular lot in the circled area. This map does not take into account property owners that would import or truck in their own water.

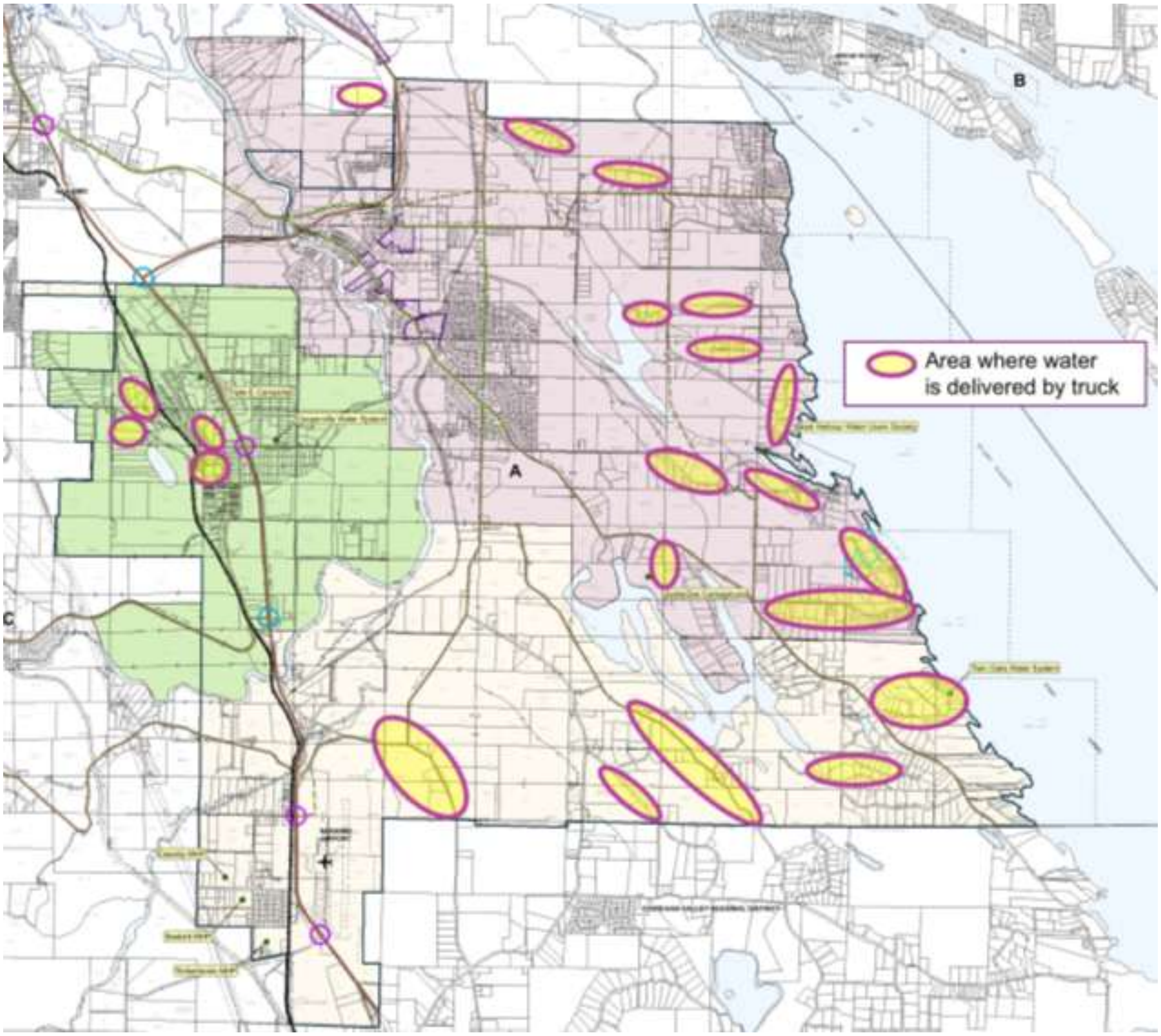


Figure 32: Areas where water is delivered by truck

7. HAZARDS AND THREATS

This section describes hazards and threats to the quality of the water source in Area A. We have identified areas and type of threats in various parts of Area A (**Figure 33**). The limitations of the scope of the project did not allow us to define in detail the hazards and threats. Instead, we are showing the various areas (yellow circles in **Figure 33**) where human activities could affect the water quality. A zoom on each circle is provided in **Figure 34** through Figure 45 and the legends of the figures provide information on the type of activities and associated potential contaminants.

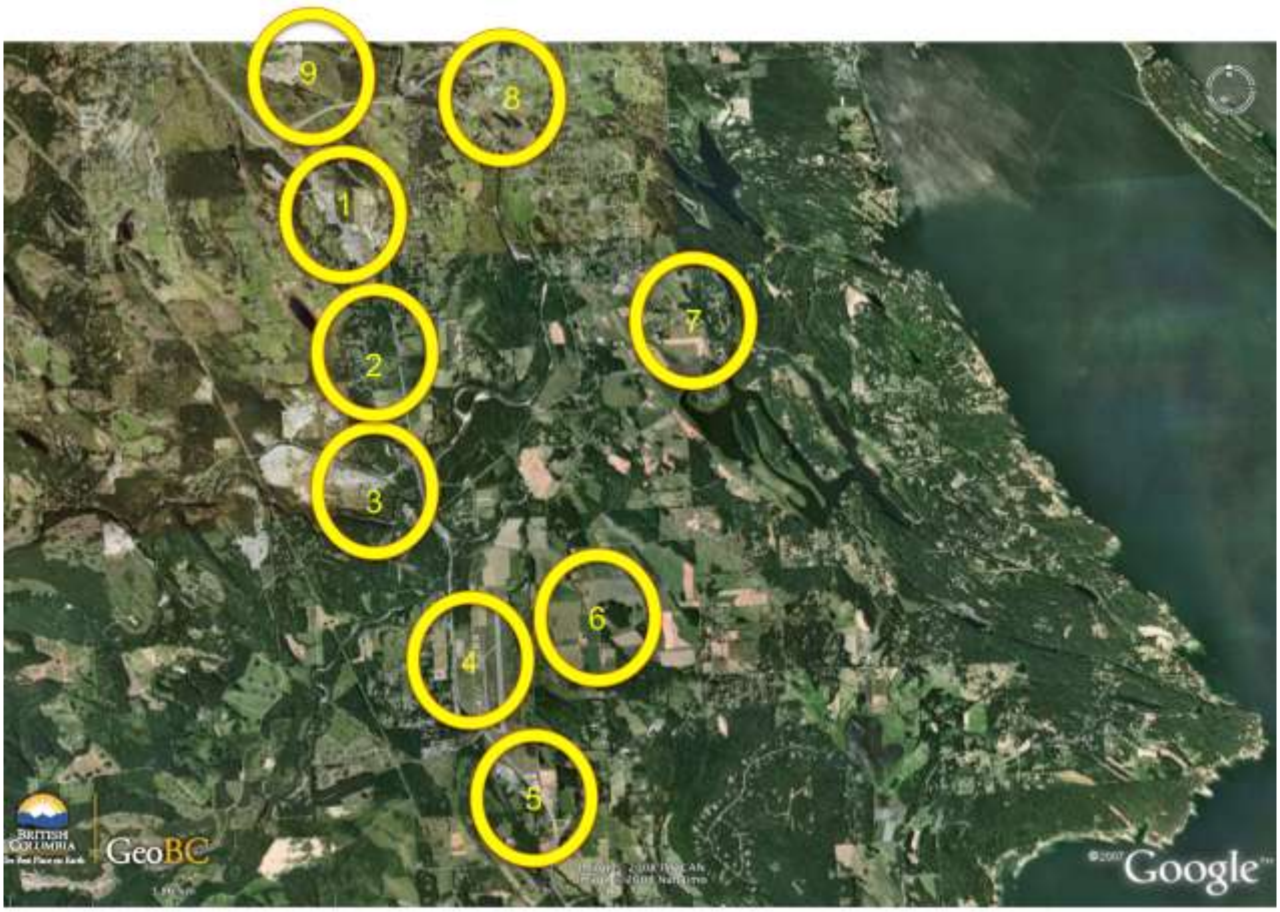


Figure 33: Areas associated with potential hazards and threats to water quality

Figure 34: Circle 1 - Area with numerous auto wrecking and salvage yards in South Wellington.

Figure 35: Detail of Circle 1. Potential contaminants associated with auto wrecking and salvage yards will include hydrocarbons, cooling fluids, and metals.

Figure 36: Circle 2 shows the Eagle Crest Golf Center. The maintenance of the land typically requires the use of fertilizers, herbicides and pesticides.

Figure 37: Circle 3 shows gravel pits. In such areas, the dry overburden is removed, thus reducing the filtering effect of the soils above the aquifer(s). Other activities such as asphalt production may take place in gravel pits; potential contaminants include hydrocarbons.

Figure 38: Circle 4 includes Nanaimo Airport and the Cottonwood Golf Course. Potential contaminants associated with the operation of an airport include hydrocarbons, de-icing salts and de-icing fluids. The maintenance of the golf course typically requires the use of fertilizers, herbicides and pesticides. A gas station is also located on the highway in this area and poses the risk of release of hydrocarbons to the subsurface.

Figure 39: Circle 5 shows the southern tip of Area A (triangular lot). The site immediately adjacent to the east is in the CVRD and is a reported contaminated site. Its contamination may affect the quality of the groundwater in Area A.

Figure 40: Circle 6 shows agricultural use of the land. Potential contaminants include fertilizers (natural and artificial), herbicide and pesticides.

Figure 41: Circle 7 shows a forestry research center. Potential contaminants include fertilizers, herbicide and pesticides.

Figure 42: Circle 8 shows a high school and residential lots. The school is now connected to a sanitary sewer however the other properties still discharge their liquid effluents to the ground. Potential contaminants associated with the discharge of liquid waste include bacteriological contaminants (viruses and bacteria), pharmaceutical products and endocrine disruptors (now referred to as Pharmaceutical and Personal Care Products – PPCP)

Figure 43: Circle 9 shows the RDN solid waste facility (landfill) in the City of Nanaimo, bordering Area A. Although controlled by a leachate collection system, part of the leachate created by the landfill discharges into a drainage at the southeast corner of the landfill. This drainage flows east, southeast into Area A. Water quality parameters mainly indicate low pH, and the presence of metals (iron, manganese) mostly associated with organic degradation (Morrow 2001).

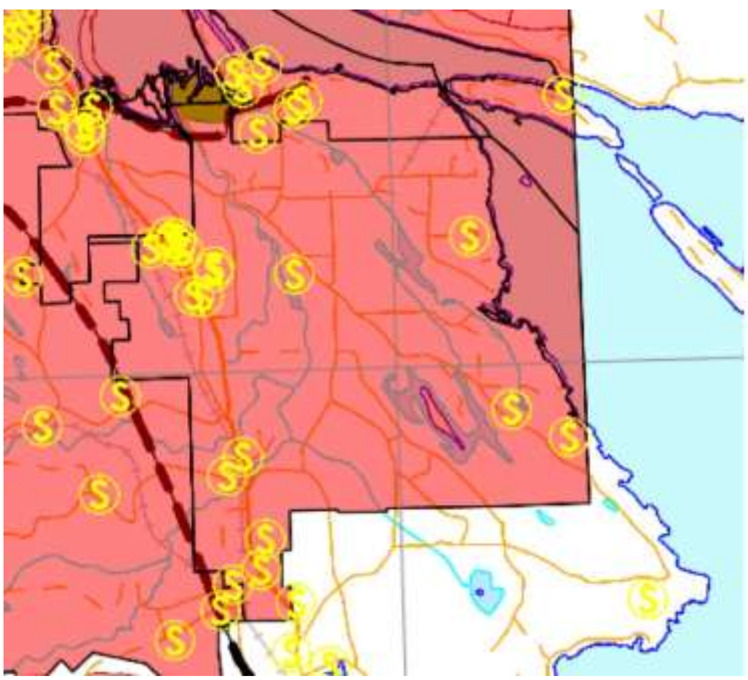


Figure 44: Listed contaminated sites, according to BC Ministry of Environment database. This map shows 17 contaminated sites in Area A. Details on these sites were not readily accessible.

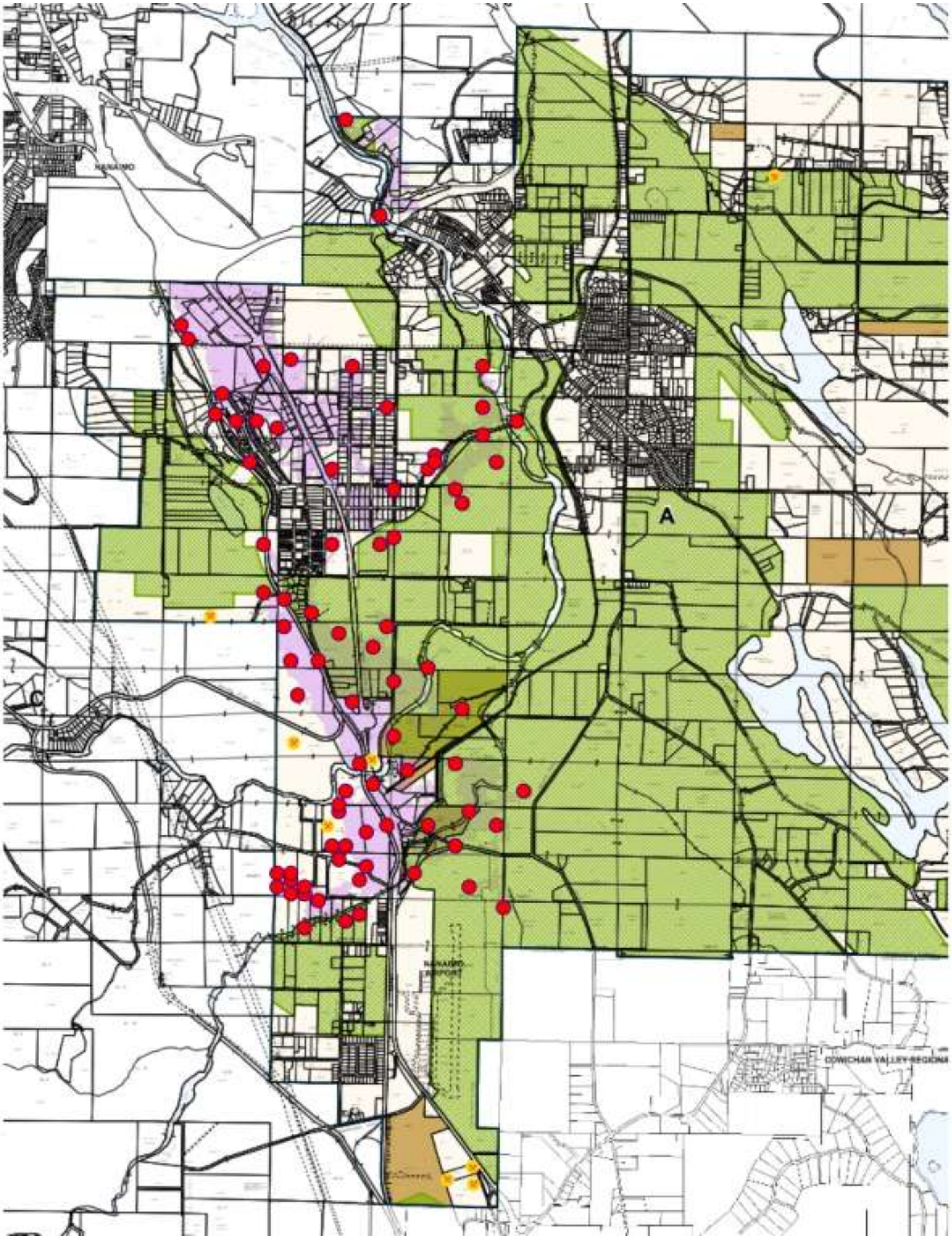


Figure 45: Old coal mine shafts (based on RDN Map No. 8 - Natural Resources). This map shows there are numerous mine shafts acting as conduits between coal seams and potentially affecting the groundwater quality (lowering pH and mobilizing metals).

Most of the properties located along the coast rely on bedrock wells for water supply. If the pumping rates, pumping levels, and water quality are not monitored, there is a likelihood that pumping may create lateral or vertical migration of the fresh water/salt water interface, also referred to as sea water intrusion.

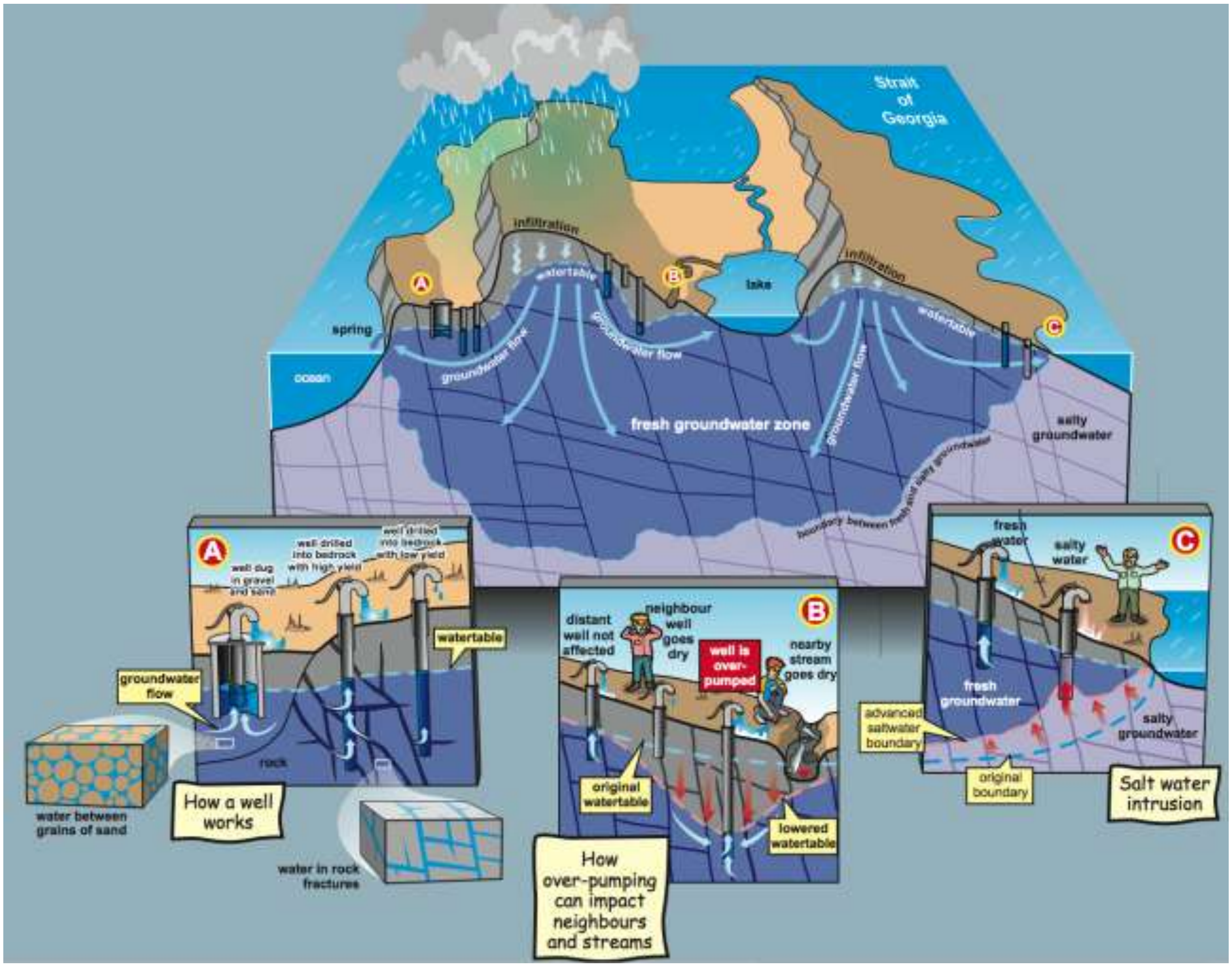


Figure 46: Illustration of salt-water intrusion in bedrock aquifers created by overpumping of wells in a coastal setting (NRCan Geoscape)

Figure 34 through **Figure 46** show the regional distribution and variety of activities that can affect the quality of the water source. It appears that most of the activities in Area A will have a more diffuse impact because of their occurrence over a large area (use of fertilizer, herbicide and pesticide over agricultural land), or due to numerous point sources having effects over a large area (discharge from a large number of septic fields, large number of abandoned coal mine shafts, numerous adjacent lots with car wrecking and salvage yards), series of bedrock wells potentially promoting sea water intrusion by overpumping, etc.

8. VULNERABILITY ASSESSMENT

Area A includes large, shallow and unconfined aquifers in coarse permeable materials (see red colored areas on Figure 47, and Figure 8). These aquifers are very productive but also very vulnerable. The release of contaminants at the surface would reach the water table quickly and could rapidly pollute a large volume of the aquifers.

The aquifer vulnerability assessment in Area A is part of a larger study, the Vancouver Island Water Resources Vulnerability Mapping Project (VIWRVMP or VMP for short) that was completed in two phases in the spring of 2010. The first phase (or pilot study) specifically analyzed the Cowichan Valley Regional District (CVRD) and the Regional District of Nanaimo (RDN) and the technical methods used and description of the mapping process is provided in detail by Liggett and Gilchrist (2010). Subsequently in phase 2 the assessment was expanded to cover all Regional Districts on Vancouver Island, which is documented by Newton and Gilchrist (2010). Because of newly available data and some changes in the methods of analysis, the assessment of vulnerability for the CVRD and RDN was re-assessed during phase 2 and is similar, but is not identical, to the pilot study. The results of phase 2 (Newton and Gilchrist, 2010) are presented here (Figure 47), and more information about the differences with the pilot study are given in section 10 of this report.

Aquifer vulnerability in BC has previously been assessed with the BC Aquifer Classification System, which is explained in section 2.3 in Liggett and Gilchrist (2010), and is reproduced below in italics.

"Developed aquifers in BC have been mapped with the BC Aquifer Classification System (Kreye et al. 1994). Aquifer boundaries have been defined based on bedrock and surficial geology mapping, well lithology records, and hydrogeological reports. The system classifies aquifers based on their level of development and intrinsic vulnerability to contamination (Berardinucci and Ronneseth 2002). The vulnerability to contamination classification is derived from the depth to water and permeability and thickness of overlying sediments. These parameters are evaluated over the mapped aquifer as a whole, and assigned one of three vulnerability categories (A - High, B - Medium, C - Low).

There are over 200 mapped aquifers on Vancouver Island (BC MoE, WELLS application). These aquifers consist of either fractured bedrock or unconsolidated (surficial) sediments. The most productive aquifers are within thick sand and gravel glacial outwash and post-glacial fluvial deposits. Wells completed in major faults or fractures in bedrock can also yield very high quantities of water (Yorath et al. 2002). Unconfined sand and gravel aquifers are most vulnerable to contamination since many have a shallow depth to water table, high vadose zone, and high aquifer permeability (Denny et al. 2007). Additionally, an often high level of development may create a hazard threat in these areas of unconfined aquifers."

The vulnerability map (Figure 47) has been derived using the DRASTIC methodology, which is explained in section 3.0 in Liggett and Gilchrist (2010), which is reproduced on page 56 in italics.

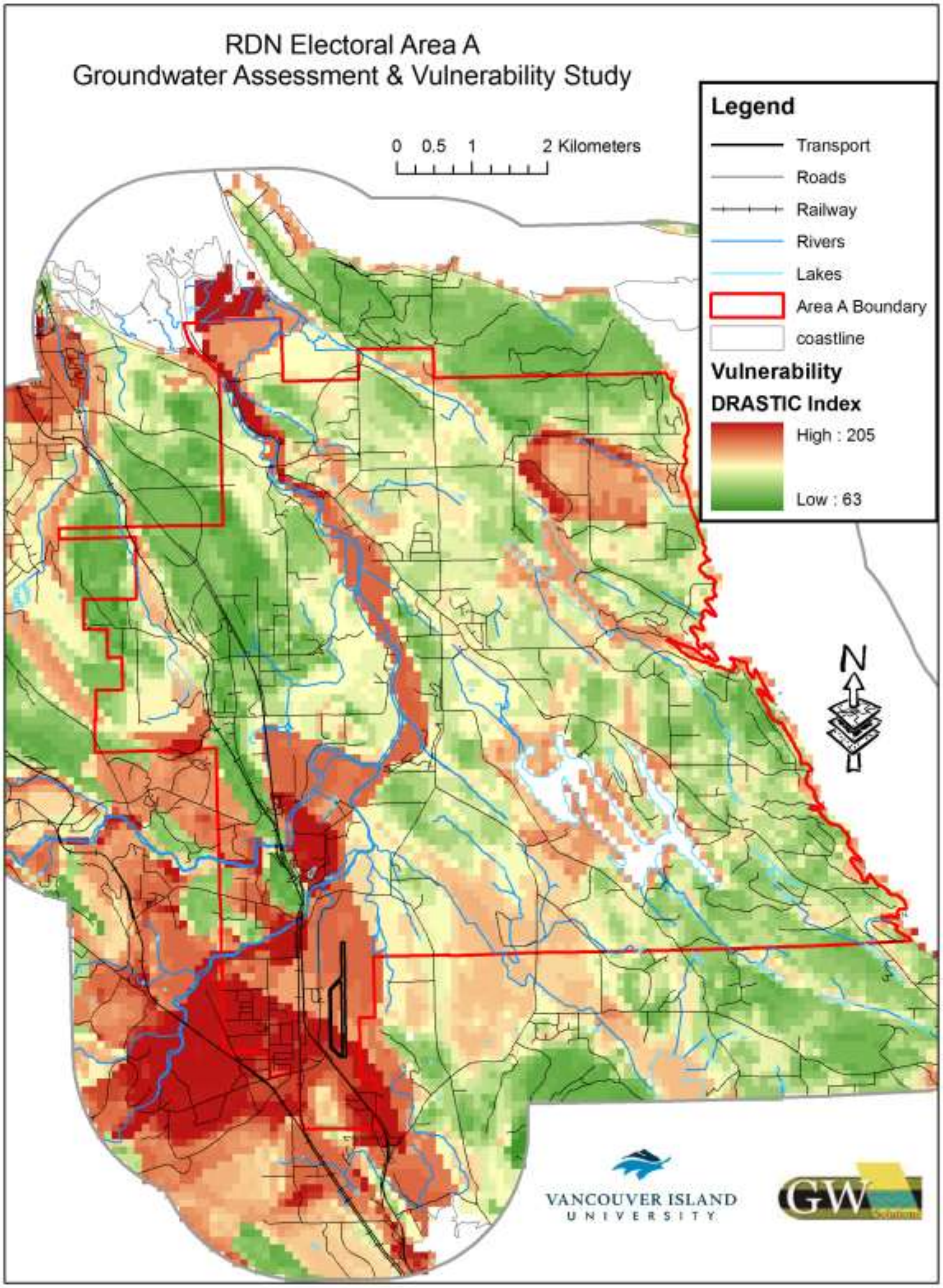


Figure 47: Aquifer Vulnerability Map – DRASTIC

"The DRASTIC method (Aller et al. 1987) has been used to map the regional intrinsic aquifer vulnerability of the RDN and CVRD study area. This indexing method provides a relative, qualitative assessment of the intrinsic vulnerability of an aquifer to contamination. The assumptions in this method are that a) the contaminant is introduced at the surface, b) that it is driven vertically through the vadose zone (between the soil and the water table) by precipitation at the same rate as water, and c) that the mapping extent is 100 acres (40.4 hectares) or larger. This minimum mapping extent is to emphasize the regional nature of this vulnerability mapping method.

*DRASTIC stands for each of the seven input parameters: **D**epth to water, net **R**echarge, **A**quifer medium, **S**oil medium, **T**opography, **I**mpact of the vadose zone, and hydraulic **C**onductivity (Table 3.1). Each parameter is mapped and attributes are assigned a rating from 1 to 10 (lowest to highest vulnerability) based on a set of rating tables. The final vulnerability is calculated by summing the product of each parameter's rating and a relative fixed weight (Equation 3.1 – DRASTIC parameter weights).*

$$5D + 4R + 3A + 2S + 1T + 5I + 3C = \textit{intrinsic vulnerability} \qquad (3.1)$$

The final vulnerability is represented by a value ranging between 23 and 230. Different parameter weights are assigned if the vulnerability map is completed in an area where pesticides are a concern (Aller et al. 1987)."

DRASTIC parameter summary (Modified from Table 3.1, Liggett and Gilchrist (2010)

	Parameter	Impact on intrinsic vulnerability	Weight
D	Depth to water	As water depth decreases, vulnerability increases, due to shorter transport time between the surface and the aquifer, and less time for natural attenuation	5
R	Recharge	Greater recharge promotes faster downward contaminant movement; therefore, the higher the vulnerability.	4
A	Aquifer media	In general, larger grain sizes and more intense fracturing lead to a higher vulnerability, because of increased permeability and decreased natural attenuation	3
S	Soil media	Areas with thin coarse textured soils will have a higher vulnerability than thick fine grained materials, such as silts, which have slower infiltration and a higher natural attenuation capacity	2
T	Topography	The lower the surface, the higher the vulnerability due to less runoff and a higher potential for infiltration of contaminants into the subsurface.	1
I	Impact of vadose zone	A higher permeability of the vadose zone material leads to a higher vulnerability, due to decreased time for natural attenuation of any contaminants	5
C	(hydraulic) Conductivity	The faster water and contaminants can move through an aquifer unit, the greater the likelihood of the contaminant spreading throughout the aquifer; therefore, the higher the hydraulic conductivity of an aquifer the higher the vulnerability	3

The DRASTIC vulnerability map (Figure 47) derived by the VMP indicates that Area A is composed of aquifers that vary greatly in their vulnerability to surface contamination, and augments the BC MoE aquifer maps (Figure 8). An important factor determining the vulnerability is the depth to water, which is shown in Figure 48.

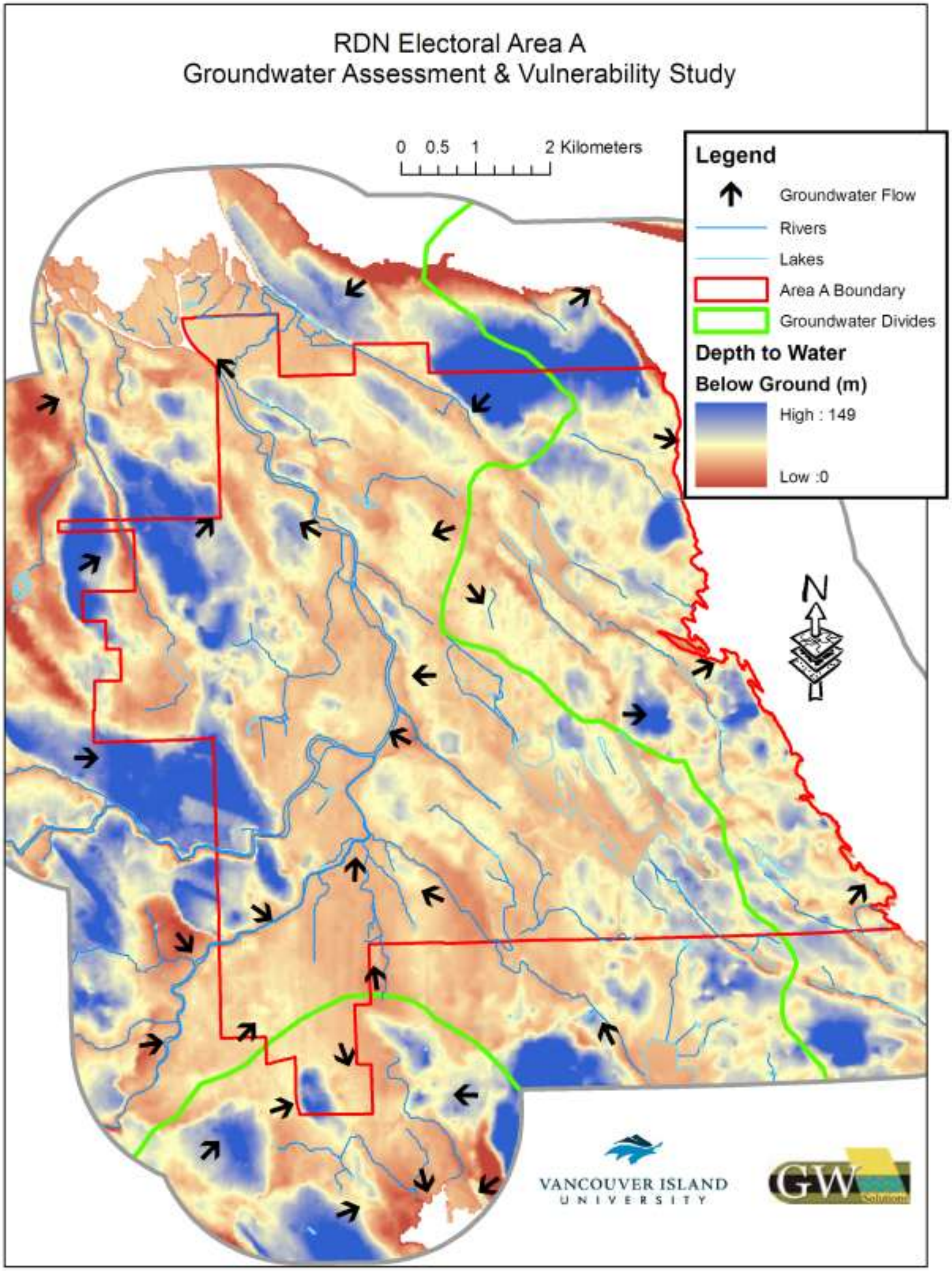


Figure 48: Depth to Water

Where groundwater is shallow, close to the land surface, then vulnerability is high as the vertical distance that pollution has to travel to enter an aquifer is less than for a deeper aquifer.

Furthermore, from section 3.0 on DRASTIC in Liggett and Gilchrist (2010), which is reproduced below in italics.

"The DRASTIC methodology differs from the vulnerability rating of the BC Aquifer Classification System in a number of ways. DRASTIC includes more parameters (e.g. aquifer medium, recharge), and more spatial variability of parameters within mapped aquifers. Rather than assigning a single vulnerability value to an entire aquifer polygon, DRASTIC may show variation in the vulnerability as parameters such as depth to water, topography, soil medium, and impact of the vadose zone vary over a single aquifer. Another difference is that DRASTIC only shows the vulnerability to the uppermost aquifer, whereas the BC aquifer Classification system can show the vulnerability of a number of aquifers that are stacked on top of each other. In this case the lower aquifers are less vulnerable since contaminants have further to travel and are protected by the overlying sediment. For these reasons, the vulnerability produced from the DRASTIC methodology may be different from the vulnerability classification assigned to previously mapped aquifers in BC."

Some of the aquifers in Area A consist of surficial sand and gravel (e.g. aquifer polygons 160, 161 & 163, Figure 8) which are highly vulnerable due to the porous nature of the aquifer material, while others are composed of fractured bedrock (e.g. aquifer polygon 162), and tend to be less vulnerable. An additional factor that DRASTIC does not take into account is that in some areas there are manmade conduits, such as the old mine shafts present in Area A (**Figure 45**), that directly connect the land surface with deeper aquifers. These can potentially allow contaminants to quickly enter a deeper aquifer and effectively increase vulnerability.

The DRASTIC vulnerability map for Area A (Figure 47) shows that the index varies from 63 to 205 across the region, which depends upon the local parameter values. Although this large range is informative, it makes interpreting the map difficult when applying it to an issue such as making decisions regarding land use. In this case the map needs to be simplified to be useful and this is explored further in Section 10.

9. DATA GAP ASSESSMENT

Identified data gaps are summarized in Table 8.

Table 8: Data Gaps

Domain	Field	Reason	How to
	What	**Why**	**How**
Water Demand	Demand from various drinking water users	Need to better define global water demand, especially during most critical time of year	• Largest water users need to measure and keep at least monthly records of their water use • Compile and review groundwater extraction data
	Demand for Agriculture	Assess volume of water used for irrigation and livestock	• Inventory of agricultural land, crops, and livestock
	Surface water licenses	Assess volume of surface water used	• Compare licensed volumes to actual surface water use
Water Supply	Nanaimo River Flow at estuary	Understand water flow at outlet of watershed	• Install gauging station near Nanaimo River Estuary
	Groundwater flow through boundaries	Understand groundwater transfer through Area A	• Define Aquifer dynamic (section, conductivity, gradients) at boundaries. • Hydrogeological modeling of aquifers
	Groundwater available in bedrock aquifer	Refine yield of bedrock aquifer	• Installation of Monitoring wells in bedrock aquifer. • Hydrogeological modeling of bedrock aquifer
Interaction Surface Water-Groundwater	River levels and groundwater levels	Assess 'gaining river' and 'giving river' sections, and their variations with time.	• Installation of monitoring wells and river gauges • Comparison of groundwater levels and surface water levels • Collecting information on surface water temperature
Aquifers	Water levels	Assessing fluctuations of water levels at various locations in the aquifers Assessing vertical gradients between aquifers	• Installation of monitoring wells and monitoring of groundwater levels

Domain	Field	Reason	How to
	What	Why	How
Water quality	Groundwater Quality	Assessing variation of water quality versus time and potential impact from land activities	• Sampling and analyzing selected monitoring wells
	Surface water quality	Assessing quality of surface water	• Sampling and analyzing surface water bodies at selected locations
	Groundwater impact of contaminated sites	Assessing impact of contaminated sites	• Compile MOE records
	Non-point source contamination	Assess impact of non-point source contamination	• Sampling and analyzing selected surface water and groundwater samples
	Salt water intrusion	Minimize risk of salt water intrusion	• Monitor water levels in bedrock aquifer and water quality in monitoring wells along foreshore (near clusters of production wells)
Sustainability	Sensitive ecosystems	Assess presence and sensitivity of most vulnerable ecosystems	• Biological assessments and mapping • Assess ranges of stress they can support

10. VIWRVMP AND THE RDN

The development of the VIWRVMP and the relationship with the RDN and other regional districts is summarized in section 1.0 of the phase 2 report (Newton and Gilchrist, 2010), which is reproduced below in italics:

"In 2006, the Vancouver Island Region Watershed Protection Steering Committee initiated the Vancouver Island Water Resources Vulnerability Mapping Project (hereafter referred to as the 'VMP'). The goal of the VMP was to develop a GIS-based mapping tool to aid in the improvement of land-use decision-making, with specific interest in protecting groundwater quality. Initially, the VMP focused on a pilot study area to characterize the vulnerability of groundwater to contamination (Liggett and Gilchrist, 2010). Using the DRASTIC method, the VMP developed intrinsic vulnerability maps for the Regional District of Nanaimo (RDN) and the Cowichan Valley Regional District (CVRD).

DRASTIC is an established aquifer vulnerability mapping methodology, developed by the U.S. Environmental Protection Agency (EPA) (Aller et. al, 1987). This method defines seven parameters that contribute to intrinsic aquifer vulnerability, each is represented by a letter in the DRASTIC acronym; D – Depth to water, R – net Recharge, A – Aquifer medium, S – Soil medium, T – Topography, I – Impact of the vadose zone, and C – hydraulic Conductivity. These seven parameters are then combined using a weighted sum equation to determine the overall intrinsic vulnerability.

The primary objective of phase 2 of the VMP is to expand the work of the pilot study to complete intrinsic vulnerability mapping for the remaining five regional districts of Vancouver Island. These include the Capital Regional District (CRD), the Alberni-Clayoquot Regional District (ACRD), the Comox Valley Regional District (CxVRD), the Strathcona Regional District (SRD), and the Regional District of Mount Waddington (RDMW), in addition to the RDN and CVRD. The second objective of phase 2 is the automation of the manual mapping processes used to complete the pilot study. Because phase 2 is based on the methodology developed during the pilot study, the information in this report is supplemental to the "Technical Summary of Intrinsic Vulnerability Mapping Methods in the Regional Districts of Nanaimo and Cowichan Valley" (Liggett and Gilchrist, 2010) and focuses specifically on differences in both the methodology used and results obtained between the pilot study and phase 2.

Automation of processes in the phase 2 analysis was important for a number of datasets, including preparation of the BC WELLS database and the terrain maps. Automation greatly reduced the amount of time required to complete error checking of the BC WELLS database and data extraction from the terrain map. It also enabled more data to be extracted from the terrain map for use in the A, S, I, and C parameters. The work of the pilot study was used to confirm the accuracy of automating the work during phase 2.

Additional changes in the phase 2 analysis included using the terrain mapping in place of soil surveys to rate soil medium due to the lack of digital soil mapping for northern Vancouver Island, and the incorporation of hydrogeological parameter data extracted from hydrogeological reports from regional districts in the phase 2 study area. Furthermore, it was assumed in this analysis that all surficial aquifers are unconfined.

Like the pilot study, the vulnerability maps are completed at a regional scale, with the objective of providing communities, planners, and policy makers with a tool to aid in the process of decision-

making for various land-use issues that have the potential to affect groundwater quality. Although we are not attempting to address causes of aquifer pollution or suggest land-use recommendations at this time, the vulnerability maps will aid in numerous groundwater management issues, including "sustainable development planning, identification of sensitive areas, planning of monitoring strategies, and focusing remediation efforts" (Liggett and Gilchrist, 2010). There is potential for future interaction between the VMP and local planners, to identify specific pollution risks and develop land-use recommendations at a more local scale."

The vulnerability maps are an important tool, developed with planners in mind, to help determine where, and how, development should occur taking aquifer vulnerability into account. However, the DRASTIC map from the phase 2 study (Figure 47) shows a large amount of variability, and it is difficult to make rational decisions without simplifying the map. Therefore, a classification scheme, grouping ranges of values into a single class, allows the information to be simplified and make it usable in a planning context (Figure 49).

In this case a simple classification scheme, dividing the range into three intervals, has been used to provide a small number of decision-making possibilities with regard to intrinsic groundwater vulnerability. At the present time this classification scheme is speculative, as there is no provincial standard to adhere to, so it should be noted that changing the break points in the classification scheme will change the distribution of the three mapped classes. The breaks chosen have been used by another study in BC using DRASTIC (Wei, 1998).

Given that caveat, the map suggests that most of Area A has a moderate vulnerability, while the area around Cassidy, the Nanaimo Airport and along the Nanaimo River floodplain has a high vulnerability, together with more isolated areas around Quennell Lake and just north of Holden Lake. Smaller areas at generally higher elevations (see Figure 5) have been assigned a low vulnerability.

As noted previously, the VMP results from the pilot study and phase 2 are similar but are not identical due to differences in the data used and how the data was analyzed. In particular, during phase 2 it was assumed that all aquifers are unconfined. This assumption was used because only small areas of Vancouver Island have detailed aquifer maps that define the level of aquifer confinement, and this aquifer characteristic could not be accurately predicted from the available data in unmapped areas. Therefore, mapped confined aquifers in the pilot study are generally assigned a higher vulnerability by the phase 2 assessment, as is the case with aquifer 163 just north of Holden Lake (Figure 8). This is a more conservative approach to vulnerability mapping which fits with the role of a regional screening tool. More detailed hydrogeological studies can be undertaken to investigate aquifer confinement in a particular area, and modify the vulnerability rating if warranted.

The vulnerability maps (Figure 47 & 49) have a pixellated (or blocky) appearance as the maps have been generalized to a cell size of 100 meters (i.e. each map cell is a square of 100 x 100 meters giving an area of 10,000 square meters or 1 hectare). The choice of this resolution reflects the regional nature of the analysis, and also the generalization of the results for the purpose of land use planning. Again, the assigned vulnerability is a guide to help formulate plans for land use taking regional aquifer vulnerability into account. For a particular property parcel (or lot) a more detailed hydrogeological study can be used to provide a definitive assessment of aquifer vulnerability at a particular location which, due to specific local conditions, may vary from the results of the DRASTIC analysis presented here.

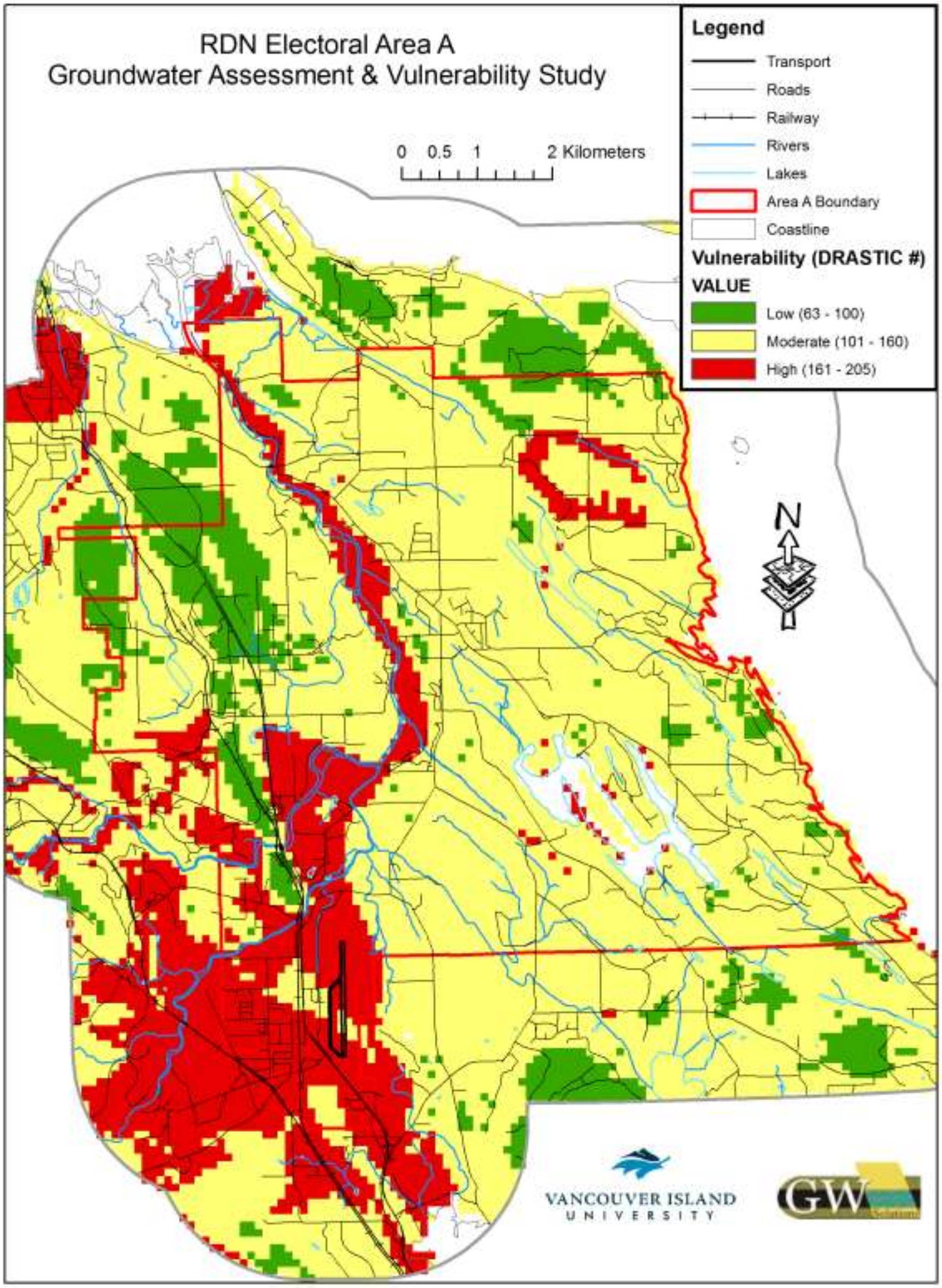


Figure 49: Aquifer Vulnerability – Classified with 3 classes

11. GROUNDWATER MANAGEMENT STRATEGY AND BMPS

The goal of this section is to provide planners, developers and stakeholders with recommendations to protect the water sources from contamination, using Best Management Practices (BMPs). This study and the proposed BMPs apply more to a regional district than to a municipality.

In this document, BMPs were generated from the framework of a double-entry table which takes into account on the one hand, aquifer vulnerability (DRASTIC index) and on the other hand, a specific human activity which can potentially represent a source of contamination. DRASTIC mapping consists of identifying on a map the vulnerability levels of aquifers. If such mapping is available for a given region, then it must be included in the project development process in order to limit the impact on groundwater quality and to prevent groundwater contamination.

This document identifies the different potential sources of groundwater contamination and proposes BMP recommendations based on the vulnerability level of aquifers expressed by the DRASTIC index.

11.1. DRASTIC index and classification of the vulnerability of aquifers

The DRASTIC index is a method of assessing the vulnerability of aquifers. It is usually represented by a map of an area, showing the existing aquifers and their level of vulnerability to contamination. The different levels are indicated by numbers.

A literature search on the existence of BMPs based on vulnerability levels of aquifers has revealed that, even though DRASTIC index mapping is generally very well documented and studied in the scientific literature, there is a general lack of recommendations which would normally be the result of this mapping. Thus, very few guidelines and BMPs have been generated to guide developers and stakeholders in regard to the protection of groundwater.

The DRASTIC index should become an important tool for sensible resource management and land use planning.

The present document uses available data on aquifer vulnerability, as determined by the DRASTIC model, as a starting point to achieve 2 objectives:

1. To identify the most common potential sources of contamination of aquifers; and
2. To propose some recommendations on solutions to manage and limit these sources.

The BMP recommendations proposed in this document have therefore been developed based on the limited available data combined with engineering knowledge, technical experience, and common sense. The DRASTIC index (DI) scale ranges from 23 to 230, indicating a lowest (23) to a highest (230) natural groundwater vulnerability. From the vulnerability map of a given municipality, region or surface area, three different zones have been identified:

- Low vulnerability for $23 < DI < 100$.
- Moderate vulnerability for $101 < DI < 160$.

- High vulnerability for 161 < DI < 230.

From the groundwater vulnerability map, areas of high, moderate, and low vulnerability have been identified. For each level of vulnerability, this document proposes the Best Management Practices which should be applied to each area of such a map, depending on the type of proposed development which will occur in that area. BMPs are designed to prevent or reduce the risk of groundwater contamination. The present document takes into account the most common known threats to groundwater. BMPs are proposed for each contamination source at each level of vulnerability according to the DRASTIC index map.

The principal sources and causes of groundwater contamination are classified as Regional District, Industrial, Agricultural, and Miscellaneous.

Table 9 summarizes the BMPs. Detailed explanations of the table are presented in Appendix 5.

Table 9: Best Management Practices (BMPs)

Sources of Contamination		Aquifer Vulnerability: Low	Aquifer Vulnerability: Moderate	Aquifer Vulnerability: High	Responsible Parties: Senior Governments	Responsible Parties: RDN & Municipalities	Responsible Parties: Individuals & Businesses
Industrial	***Liquid wastes***	Confined industrial wastewaters disposal allowed (use of impermeable liners)	Confined industrial wastewaters disposal allowed (use of impermeable liners)	No industrial wastewaters disposal is allowed	✓		✓
	Tank and pipeline leakage	Tanks and pipelines are allowed, with groundwater monitoring	Tanks and pipelines are allowed, with groundwater monitoring	No tanks or pipelines are allowed	✓		✓
	Mining activities	Mining activities are allowed with water management plans	Mining activities are allowed with water management plans	No mining activities	✓		✓
	Hazardous products handling and storing	Detailed list of hazardous products handled, stored and used. Use of highest industry standards for handling and storage (double/triple lining of containers, safe storage program, emergency plans) Auto – wreck yards: All vehicles coming to the yards have to be drained of all their fluids (fuels, oils – lubricating and hydraulic, cooling) and batteries be removed and recycled. The BC Vehicle Dismantling and Recycling Industry Environmental Planning Regulation (June 2007) applies. Design and implementation of staff education and training programs on toxicity and risks to the environment Reporting to reg. agencies every 3 years	Detailed list of hazardous products handled, stored and used. Use of highest industry standards for handling and storage (double/triple lining of containers, safe storage program, emergency plans) Auto – wreck yards: All vehicles coming to the yards have to be drained of all their fluids (fuels, oils – lubricating and hydraulic, cooling) and batteries be removed and recycled. The BC Vehicle Dismantling and Recycling Industry Environmental Planning Regulation (June 2007) applies. Design and implementation of staff education and training programs on toxicity and risks to the environment Reporting to reg. agencies every 2 years	Industrial activities in a high vulnerability zone are not recommended. Detailed list of type and quantity of hazardous products handled, stored and used. Use of highest industry standards for handling and storage (double/triple lining of containers, safe storage program, emergency plans) Auto – wreck yards: not allowed. Reporting to regulatory agencies every year.	✓	✓	✓
	Hazardous products use	Detailed reporting of products used (every 3 years)	Detailed reporting of products used (every 2 years)	Detailed reporting of products used (every year)	✓		✓
	Waste generation and disposal	Detailed description of waste generated (type and volume) and outcome of wastes	Detailed description of waste generated (type and volume) and outcome of wastes	Detailed description of waste (type and volume) and outcome of wastes	✓		✓

Sources of Contamination		Aquifer Vulnerability			Responsible Parties		
		Low	Moderate	High	Senior Governments	RDN & Municipalities	Individuals & Businesses
Regional District	***Sewer leakage***	6 year inspections	4 year inspections	2 year inspections	✓	✓	✓
	Liquid wastes	Irrigation, infiltration-percolation, and overland flow allowed	No irrigation or infiltration-percolation allowed, but overland flow is allowed	No irrigation, no infiltration-percolation, no overland flow	✓	✓	✓
	Solid wastes	Landfill permitted	No landfill	No landfill	✓	✓	
Agricultural	***Irrigation***	Irrigation is allowed- water management and conservation plan recommended	Irrigation is allowed - water management and conservation plan recommended	Irrigation is allowed - water management, monitoring, and conservation plan required	✓	✓	✓
	Animal wastes	Livestock raising is allowed	Livestock raising is allowed	Livestock raising is not allowed	✓	✓	✓
	Fertilizer application	Fertilization is allowed	Fertilization is allowed with groundwater monitoring	Fertilization is not allowed	✓	✓	✓
	Pesticide application	Pesticides are allowed	Pesticides are not allowed	Pesticides are not allowed	✓	✓	✓
Miscellaneous	***Spills***	Containment is required	Containment is required	Containment is required	✓	✓	✓
	Stockpiles	Containment is required	Containment is required	Containment is required	✓	✓	✓
	Septic tanks and disposal fields	Inspections every 2 years	Inspections every 2 years	Inspections every 2 years Monitoring well installed downgradient of field at property boundary and groundwater quality monitoring every 3 years	✓	✓	✓
	Roadway de-icing	Use of sand recommended. Road de-icing is allowed	Use of sand recommended. Road de-icing is not allowed	Use of sand recommended. Road de-icing is not allowed	✓		
	Cross-contamination of wells	Abandoned wells plugged and new wells properly sealed	Abandoned wells plugged and new wells properly sealed	Abandoned wells plugged and new wells properly sealed	✓		

Water Supply				Responsibility		
				Senior Government s	RDN & Municipalities	Individuals and Businesses
Aquifer Vulnerability	**Low**	**Moderate**	**High**			
Connection to water purveying system	Recommended	Highly recommended	Compulsory	✓	✓	
Water balance	Use integrated approach to water management with minimal net footprint	Use integrated approach to water management with minimal net footprint	Use integrated approach to water management with zero net footprint	✓	✓	✓
Land Development or Subdivision - Hydrogeological Assessment	Description of hydrogeological conditions within regional context	Assessment of local hydrogeological conditions and installation of 1 permanent monitoring well per 4 hectares (minimum one per site) Reporting of monitoring data every 2 years (piezometric levels)	Detailed assessment of local hydrogeological conditions and installation of 1 permanent monitoring well per hectare (minimum one per site) Annual reporting of monitoring data (piezometric levels and water quality)	✓	✓	✓
Water Use	Water consumption metered Reporting every 5 years	Water consumption metered Reporting every 3 years	Water consumption metered Reporting on a yearly basis	✓	✓	✓
Water conservation (Xeriscaping, water efficiency, water recycling)	Compulsory	Compulsory	Compulsory		✓	✓

Notes: Applicable legislations : BC Vehicle Dismantling and Recycling Industry Environmental Planning Regulation (June 2007); Environment Management Act (2004); Waste Discharge Regulation (2004); Minister's Codes of Practice; Groundwater Protection Regulations

12. CONCLUSIONS

Based on the work completed, GW Solutions and VIU draw the following conclusions:

1. Area A includes three main groundwatersheds, referred to as Zone 1, 2, and 3. Zone 1 includes the lower section of Haslam Creek and the Nanaimo River. These river systems are very dynamic, transporting large amounts of water. They occupy the western half of Area A and discharge to the Nanaimo River Delta. Much less water movement occurs in the eastern half of Area A (Zone 2) because it consists predominantly of a flatter region where most of the water flows through a bedrock aquifer towards the Strait of Georgia. The southern tip of Area A (Zone 3) discharges south to Ladysmith Inlet. The following paragraphs summarize the water dynamic in these zones and identify the critical conditions.

Water Dynamic

- **Zone 1**: Covering over 4500 ha, Zone 1 includes the Cassidy Aquifer (Aquifer 161, unconfined), and the Lower Cassidy confined aquifer (Aquifer 160). These two sand and gravel aquifers are collectively up to 30 m thick and are very productive. Zone 1 also includes the South Wellington bedrock aquifer, where residential wells of much lesser yield are located. The Cassidy Aquifer is closely connected to the Haslam Creek and the Nanaimo River. A gauge located just at the western boundary of Area A on the Nanaimo River reports flows ranging between 1 m^3/s and 1300 m^3/s. The water balance reflects the role played by the Nanaimo River**: it is estimated that the river flow corresponds to 95% of the water transferring through Zone 1**. Precipitation, with an approximate amount of 1 m per year, is the main water input. Groundwater will also reach zone 1 through its western boundary, but at a rate estimated to be 13% of the precipitation.
- **Zone 2**: Covering over 1700 ha, Zone 2 is predominantly composed of the Cedar, Yellow Point, North Oyster bedrock aquifer (Aquifer 162), and the Cedar, North Holden Lake confined overburden Aquifer (Aquifer 163). In the uplands, water will converge to local depressions. Otherwise, water will discharge to the Strait of Georgia, mostly as groundwater flowing through the bedrock fractures. Compared to Zone 1, water movement is much less dynamic. The volume of water transferring through Zone 2 is estimated to be only 1% to 2% of the water transferring through Zone 1.
- **Zone 3**: With over 1400 ha, it only covers 2% of Area A, south of the Nanaimo Airport. It corresponds to part of Area A where water drains south, predominantly as groundwater, through the Cassidy and Lower Cassidy Aquifers, towards Ladysmith Inlet.

Water Use and Water Balance

- **Zone 1**: The aquifers provide water for residential, agricultural, commercial, and industrial use. Harmac is the largest water user and extracts an estimated total of 136,500 m^3/day (82,000 m^3/day from a well field and 54,500m^3/day from a surface water intake in the Nanaimo River). This water is removed from the Nanaimo River watershed to supply Harmac facilities, located outside of this watershed. **The volume used by Harmac is equivalent to the total amount of the yearly precipitation over Zone 1**. The second largest water user is the NCID, which, with 1240 m^3/day, represents 0.03 % of the water output for Zone 1 and approximately 1% of the water extracted by Harmac. The total use from the remaining users (residential properties and small systems) is equivalent to the use of NCID.

- **Zone 2**: Water input is solely precipitation, with the exception of water import via water delivery (trucked water). Evapotranspiration represents the largest water output in Zone 2 (62% of water input), followed by discharge to the foreshore (47% of water input). Water use for residential purposes represents a small percentage of the water balance (1%).
- **Zone 3**: The main elements of the water budget in Zone 3 are natural inputs and outputs. Groundwater extraction attributed to human activities represents a small percentage of the output (less than 1%).

Critical conditions

- **Zone 1**: The critical conditions appear to take place during the late summer months when there is no precipitation, the evapotranspiration is high, and water use is high. **During the critical period of the year the water output is estimated to be four times the water input**. During the driest period of the year, Harmac water extraction is estimated to represent 37% of the total water output for Zone 1; it equals the estimated evapotranspiration over Zone 1, and, at approximately 1.6 m^3/s, is of the same order of magnitude as the lowest water discharge of the Nanaimo River (1.2 m^3/s). In Zone 1, the water deficit will translate into a drop of the water table in the overburden and bedrock aquifers and low flows of the Nanaimo River and its tributaries. The following consequences are expected:
    - Reduced capacity and increased cost of extracting water from production wells for water system operators;
    - Reduced or lost production of residential wells;
    - Reduced flow in the Nanaimo River and its tributaries: This has an impact on fish species and ecosystems, due mainly to a change of conditions (from wet to dry), a change of temperature, and resulting physical and geochemical conditions (less dissolved oxygen, etc.);
    - Stress on the vegetation and modification of the landscape: Low water tables during long periods of time will reduce soil moisture available to the root systems of the vegetation. The species vulnerable to these modifications will disappear.
- **Zone 2**: The summer and early fall will be the critical period of the year. The bedrock aquifer has very little storage, therefore the water table drops relatively quickly once recharge due to precipitation stops. After mid-summer, bedrock wells will often be unable to meet the demand of residents, requiring water to be trucked in. During this critical period, the risk of salt-water migration will increase because the water levels in the bedrock aquifer will be the lowest, and the needs of the population will be the greatest. With no water input, except small volumes being trucked in, the water output is approximately 75,000 m^3/day, (74% evapotranspiration, 25% flow to the foreshore, and 1% residential extraction).
- **Zone 3**: No major critical situation has been identified for Zone 3.

2. Both point sources and non-point sources of contamination have been identified in Area A. These cover a wide range of organic, inorganic, and bacteriological contaminants. Sampling, chemical analyses, and monitoring are recommended to assess the impact of the identified sources of contamination on both surface water and groundwater.
3. The management of the water resource in Area A in a sustainable way requires a better understanding of water use and water extraction during the summer and fall. This is a critical time of the year for water users as well as for sensitive ecosystems, such as the Nanaimo River Delta. Overpumping along the coast can produce seawater intrusion resulting in a deterioration of the residential water supply.
4. Aquifer vulnerability mapping shows that areas corresponding to the Cassidy Aquifer are rated highly vulnerable. Otherwise, mapping shows that the remaining area is predominantly rated moderately vulnerable.
5. Best Management Practices (BMPs) are recommended to minimize the risks of degradation of the water source and to promote its management in a sustainable manner.
6. Low flows are critically important to ensure the sustainability of ecosystems in the Nanaimo River, its tributaries, and the surface water network in Area A. A specific effort should be made to define the vulnerability of the most sensitive ecosystems, and to manage the surface and groundwater resources accordingly.

13. RECOMMENDATIONS

This study has shown that the surface water and groundwater regimes in Area A are very complex, and are still not well understood. An overview of the data gaps indicates that work is required to better define the water demand, the water supply, the interaction between surface water and groundwater, the aquifers, the water quality, and sensitive ecosystems. In particular, the team makes the following recommendations:

- Monitoring wells should be installed to characterize the dynamic of the aquifers and to monitor the interaction between the surface water and the groundwater. They should also be installed along the coast to better characterize the groundwater discharge to the foreshore and to monitor any deterioration of the groundwater quality due to sea-water intrusion.
- It is essential to install a surface water gauging station where the Nanaimo River discharges into its estuary. This will provide the information required to calibrate the water budget in Zone 1 and to better assess how the groundwater extraction affects the dynamic of the river flow, mainly during the period of low flows.
- Evapotranspiration is an important element in the water deficit during the driest period of the year. Land use and agricultural activities should adopt soil cover and crops with both low watering needs and small loss to evapotranspiration.
- For the large part of Area A (Zone 1 and 2) the conceptual models of the water balance reveal that there is a significant deficit in water during the critical period of the year. It is

therefore necessary to better define the level of stress and the sources of stress of the water sources. This requires a better characterization and quantification of the items identified in the water balance. This is based on the principal that we can only properly protect and manage a water source if we can quantify and monitor its inputs and outputs.

- The volume of water being used by the holders of surface water licenses and also being delivered by trucks needs to be quantified and monitored.

14. ACKNOWLEDGEMENTS

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15. CLOSURE

Conclusions and recommendations presented herein are based on information provided in part by others. The assessment has been carried out in accordance with generally accepted engineering and geoscience practice. No other warranty is made, either expressed or implied. Engineering and geoscience judgment has been applied in developing the recommendations in this report.

This report was prepared by personnel with professional experience in the fields covered. Reference should be made to the 'GW Solutions Inc. General Conditions and Limitations', attached in Appendix 6 that forms a part of this report.

GW Solutions and VIU were pleased to produce this document. If you have any questions, please do not hesitate to contact us.

Yours truly,

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