ASSESSING THE WATER BALANCE AND FUTURE CONSUMPTION SCENARIOS FOR DEMAND MANAGEMENT OF THE ALDERGROVE AQUIFER IN B.C.

by

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B.Sc., Lancaster University, 2004

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES
(Resource Management and Environmental Studies)

THE UNIVERSITY OF BRITISH COLUMBIA

December 2006

Abstract

Many municipalities in the Lower Fraser Valley rely on groundwater as their main source of water. With the rapid increase in population and land use intensification, excessive groundwater extraction is of growing concern. There is evidence that current extractions from the Aldergrove aquifer in Langley exceed sustainable rates but little quantitative information is available about water recharge and demand.

The aims of this research is to assess the current status of this aquifer in terms of recharge, storage and discharge, with the use of current and historical climatic, geological, land use and consumption data. Consumption between 1995 and 2005 was used to project demands in 2015 based on 3 different future scenarios, and some demand management strategies were also evaluated.

The results of the analysis suggests that the aquifer receives about 26 million m^3 of recharge each year, and has a storage capacity of up to 200 million m^3, with current water content less than 70% of capacity. Natural discharge is around 22 to 26 million m^3, while current consumption is 7 million m^3. Of all the land uses, agriculture occupies the largest area and also uses the most water, accounting for over half of total consumption. Since the climate over the past 10 years has remained largely constant while urbanization has increased, the reductions in water levels are due to increasing consumption. Projections based on the 'business as usual', 'greater growth', and 'conservation' scenarios suggest that consumption will range from 6 to 11 million m^3 by 2015. The evaluation of demand management strategies based on increasing efficiency of water use suggests that significant reductions can be achieved in the agricultural and residential sectors, which has a combined potential of reducing the current total annual consumption by at least 20%. However, these conservation efforts are insufficient by themselves to reduce consumption to 'sustainable' levels.

The analysis shows that current extraction is unsustainable and unless drastic measures are taken to reduce water use and/or increase supply, the aquifer will not be able to continue meeting demands in the near future.

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Acknowledgements

Firstly, I would like to thank my supervisor, Hans Schreier, for his incredible support and advice. Despite his numerous commitments, Hans always made time available to counsel me on my thesis woes, which was on a weekly basis. I owe much of my academic and personal development achievements to his guidance, and would never have got through the MSc program without him.

Secondly, I would like to thank my thesis committee, Ken Hall and Roger Beckie, for providing me with invaluable feedback and support throughout the process of completing the thesis. Roger in particular was my main advisor for the physical hydrogeology component of my thesis, and I am very grateful for his tolerance of my constant thesis requests.

The Township of Langley was also a pivotal partner for this project. A special thank you goes to Antigone Dixon-Warren for all the help that she has provided in the form of data and expertise on the Aldergrove area, without which we could never have started the project. And sincere gratitude goes to Wyatt Babcock and Ryan McDougall for their willingness to offer time and effort with consumption data collection.

Within IRES, numerous people assisted me on different aspects of the thesis. Jennifer MacDonald provided me with constant assistance on the GIS front, saving me months of trying to figure out GIS on my own. I also want to thank my fellow student colleagues Sheena Pappas, Trudy Naugler, Oh Iwata, and Ronnie Wahl for their contributions to my thesis and my social well-being. As well, I want to thank Cindy Starsyk at the Earth and Ocean Sciences Department, for her help with streamflow data.

And finally, I want to thank the Canadian Water Network for their funding and support of this project.

Chapter 1 – Introduction

1.1 Aquifers and Water Use

Water is fundamental to life and the availability of good quality yet easily accessible water is becoming increasingly an issue with the continued development of society and the growth of the population. For many communities, the only source of such water is from the ground. An aquifer is a body of saturated rock or sediment capable of transmitting useful quantities of water to wells or springs (Hudak, 2005). Such geological 'stores' are favourable as sources of water due their tendency to be able to provide a consistent supply with seemingly limited environmental impacts, as mirrored by the lack of legislation and restrictions governing extraction. This perception, coupled with that of the 'myth of abundance' engrained in the minds of many Canadians when it comes to water availability (Sprague, 2003), has led to the systematic overexploitation of groundwater resources, to the point where detrimental effects are now starting to become apparent. In many places across Canada, water utilities are facing a dilemma: how to ensure continued supply to the ever increasing demands of residents and businesses alike. To address this issue requires two main considerations: one is the current status of the supply and demand, and two is the methods by which imbalances between supply and demand can be remedied. The second component cannot be addressed without characterizing the first. Therefore, the initial step is to generate a better understanding of the aquifer system, and the typical method for assessing aquifers as a resource is to create a water balance.

1.2 Water Balance

A water balance can be defined by the written equation:

$$\text{Input} - \text{Output} = \text{Change of Storage}$$

Whereby the equation accounts for all the water moving into and out of the various domains along the hydrological cycle (Dingman, 2002; Schwartz and Zhang, 2004). When used to refer to the water balance of an aquifer, the term *Input* refers to recharge while *Output* refers to Discharge. Usually, when characterizing the supply versus demand from an aquifer, the element of most concern is discharge; how much discharge can be 'sustainably' extracted from the aquifer, and whether this amount is capable of meeting demands. This notion of sustainable extraction is thus linked to recharge. Ultimately, the amount of recharge is what determines the allowable extraction.

1.2.1 Recharge

Recharge can be defined as the process by which water is added to the zone of saturation to replenish an aquifer (Ward and Trimble, 2004). The main factors that govern the method and quantity of recharge to an aquifer are climate, land use, surface conditions and subsurface geology (including aquifer characteristics).

For all aquifers and surface water bodies, the ultimate source of recharge is precipitation. The duration and intensity of precipitation has a strong effect on how much water can enter the aquifer as recharge. Recharge from precipitation depends on how much water can infiltrate through to the aquifer, whereby the rate of infiltration governs the rate of recharge. When precipitation causes the ground to be saturated, excess precipitation flows overland and is not able to contribute to aquifer recharge. Actual 'Hortonian Overland Flow' caused by precipitation rates exceeding infiltration rates is seldom seen under natural conditions as soil infiltration rates tend to be greater than precipitation rates (Binley. *pers. comm.*, 2001). However, the soil water table can rise to the surface when the soil is saturated and drainage is poor (sometimes caused by the geological conditions beneath the soil horizon, such as a hardpan or an aquitard layer), leading to a loss of recharge via surface or subsurface flow of excess water to surface water bodies. For this reason, the duration and intensity of precipitation can be very important to aquifer recharge.

Temperature is another climatic factor that can influence recharge, due to its effect on the biosphere. Temperature governs the evapotranspiration activity of plants, such that high temperatures caused more evapotranspiration, which leads to more soil-water extraction. This can reduce the available water for recharge. Conversely, during periods of very low temperatures, evapotranspiration can drop drastically or even effectively cease altogether. Such changes in evapotranspiration rates can cause corresponding changes in water availability that can be important for estimating seasonal recharge.

On the land surface, land use can be important to recharge due to the way in which the land is disturbed. Different land uses will have an effect on the vegetation types and the structural properties of the soil, and this will indirectly affect recharge. Land use can also directly affect recharge by creating imperviousness via urban development. Since precipitation needs to infiltrate through the soil in order to replenish the aquifer, any effect on the soil such as an impermeable barrier or compaction of the soil can reduce the amount of water penetrating through to the aquifer. Urban development tends to herald an increase in impermeable surfaces that also redirect precipitation to storm drains, thereby further preventing recharge to the aquifer.

In addition to the extrinsic factors such as climate and land use, recharge also depends on intrinsic properties of the aquifer. The type of aquifer is important, as confined aquifers are not directly linked to surface processes (as opposed to unconfined aquifers) and thus recharge entails more uncertainties. Confined (or semi-confined) aquifers are those that are bounded by a natural upper layer that is less permeable than the aquifer itself (Ward and Trimble, 2004). Such aquifers can either receive recharge from an unconfined part of the aquifer (exposed to the surface due to geological processes), or from the geological deposits surrounding the aquifer. These deposits many not be able to store water, but can transmit small quantities, and are known as aquitards. In cases where recharge is primarily via aquitards, the properties of the aquitard will have more influence on the rate of recharge to the aquifer than climatic or land use factors. Due to the limited exposure to the surface and the slow rates of transfer from aquitards, recharge to confined aquifers tends to be slower than that for unconfined aquifers. An exception to this is when natural or man-made channels allow water to enter the aquifer irrespective of infiltration and percolation rates, such as macro-channels and open wells.

1.2.2 Storage

The volume of water that can be stored in an aquifer is known as the storage, and this is dependent on the composition of the aquifer as well as its physical dimensions. Water can only be stored in the pore spaces between grains of aquifer substrate, so absolute storage is simply the sum of the volume of all the void spaces divided by the total volume of the sample (Ward and Trimble, 2004). The types of materials that the aquifer is made of determines the porosity of the aquifer, but the effective porosity is more important since only hydraulically connected pore spaces can contribute to the effective storage in an aquifer. Effective porosity is defined as the volume of void spaces through which water can travel in a rock or sediment divided by the total volume of the rock or sediment (Ward and Trimble, 2004). Any water trapped in 'dead-end pores' cannot be extracted, so they do not affect the storage of an aquifer. Large, coarse material such as gravel and sand have more hydraulically connected pore spaces, thereby allowing a lot of water to be stored between the particles, but finer material tends to contain more dead-end pores and therefore reduces the amount of dynamic storage (Manning, 1987). Another factor essential to deriving total storage is the volume and dimensions of the aquifer. This can be a difficult aspect to accurately quantify, as aquifers tend to be heterogeneous and the transition from aquifer to aquitard is rarely clearly defined, thus determining the boundaries of the aquifer requires defining cut-off points in hydraulic conductivity.

The term 'storage' often implies a static situation but in reality, water is always moving through the system (Dingman, 2002). Hydrogeologists tend to think of aquifer storage in terms of changes in hydraulic head and the effect of pumping. In this way, they define the storage of an aquifer as storativity, which is the volume of water that is released from or taken into storage per unit surface area per unit change in head (Schwartz and Zhang, 2004). When discharge is greater than recharge, due to pumping for example, storage is 'lost' in the sense that there is a lowering of the water level until the aquifer reaches a new equilibrium state whereby the increased pumping from the aquifer is balanced by an increased recharge and/or a reduced discharge (such as to a surface stream). Conversely, if recharge was to increase, then the water level in the aquifer will rise and more water is 'stored' in the aquifer. This subsequently leads to more water being discharged naturally, until the new equilibrium is established. In this way, an aquifer naturally attempts to maintain some sort of equilibrium with its inputs and outputs. Problems arise when the equilibrium cannot be maintained, or when the new equilibrium causes deterioration to hydrological systems linked to the aquifer. An example of the first situation is when pumping from the aquifer causes a drawdown of the water level and equilibrium cannot be reached before the cone of depression caused by the well extraction reaches the base of the deepest well. In this situation, the well will effectively 'run dry'. In the other situation, the well may not dry up, but the reduced natural discharge caused by the pumping can result in reduced groundwater contribution to streamflow, which may then adversely impact aquatic life in the surrounding streams. Sophocleous, (2000) explains more about this, as well as the 'safe yield' concept, which has historically been misinterpreted to be equal to the rate of natural recharge. Instead, Dingman, (2002) offers another definition for safe yield, whereby it is the rate at which groundwater can be extracted without producing undesirable effects, but adds that there is no general formula for computing safe yield, as it depends on what is or isn't valued by the society extracting water from the aquifer. Nevertheless, storage is one of the basic components that need to be considered when trying to estimate the safe yield, as pumped water always causes a reduction in storage; therefore the amount of available storage in the aquifer partially determines the rate of 'sustainable' water extraction from the aquifer. This 'storage capacity' of the aquifer is also important for determining the current water content in the aquifer relative to the maximum volume that can be 'stored', which in turn allows inferences to be made of how current extraction is already impacting the aquifer and estimations of how long it may take before the extractable storage is depleted.

1.2.3 Discharge

Discharge in the context of an aquifer system refers to the removal or output of water from storage, either via natural flow mechanisms or due to artificial withdrawal. In an undisturbed aquifer system, water in the aquifer exists in a state of dynamic equilibrium with its surroundings, whereby water moves to and from hydraulically connected 'units', such as lakes, rivers or other aquifers. In this way, the mode of discharge from the aquifer, such as seepage to surface waters, can also be a mode of recharge when the conditions are right. The main 'condition' that determines the flow of water is the hydraulic head. Since water flows from high head to low head, any hydraulic unit that has the lowest head will receive flow from the other units. A second parameter that affects groundwater flow is hydraulic conductivity. This is defined as the ability of a porous medium to transmit a fluid under a unit hydraulic gradient (Ward and Trimble, 2004). Groundwater always tries to follow the path of least resistance, so this can affect the direction of groundwater movement along with differences in hydraulic head. In a natural system, discharge is balanced by recharge and will seldom be an environmental concern, but the dynamics of the water balance changes when artificial extraction is incorporated. When a pumping well is added to the system, it represents an additional point of discharge, and the water removed from the aquifer via this unit must somehow be offset by equivalent changes in the natural hydraulic system. For aquifers that are tapped extensively for water supply, hundreds and maybe thousands of such wells will be extracting water from the aquifer at different locations, and even though it is relatively easy to calculate the volume of water extracted, it is immensely difficult to determine how the water balance of the aquifer will change as a result of this, other than that of a declining availability for ecological services. As storage depletes due to extraction, the shallower wells will be the first to start experiencing short term to permanent well drying, and unless the demand for water is reduced, the problems of water depletion will continue to escalate to the point where the damages to the aquifer system may be irreversible. For this reason, it is imperative that a greater effort is placed on understanding water demands and tackling the issue from this demand side, with the aim of finding a solution to the imbalance between recharge and discharge.

1.3 Demand-Side Management

Canadians are wasteful water consumers, ranking second only to the United States, with the average Canadian served by a municipal supply using on average 335 litres per person per day in 2001 (EC, 2004). This is more than twice the amount used in many European countries (Brandes and Ferguson, 2003) that have the same quality of life. Traditionally, water supply has increased to cope with demands, but as demand continues to climb, more and more municipalities are faced with shortage problems. Between 1994-1999, 26% of municipalities in Canada reported water shortages, citing increased consumption, infrastructure problems and drought to be the major causes (SOE, 2001). While some municipalities deal with supply issues, others deal with disposal issues, as the high volumes of consumption equates to an almost equally high volume of wastewater that needs to be treated and disposed (Maas, 2003). With the rising costs of infrastructure maintenance, upgrades and expansion, and the continued low price charged for water supply, municipalities are starting to feel the financial burdens of water wastage. In addition, depletion of water reserves, contamination of existing supplies and climate change all call for increased sustainability of water use.

1.3.1 Introduction to DSM

For the reason highlighted above and many others, researchers have been trying to draw attention away from supply-side management, SSM, (providing for increasing needs by increasing supply) to demand-side management, DSM, (managing demand in order to prevent the need for increasing supply). More specifically, DSM was defined by (Brocks and Peters, 1988) as *'any measure which reduces or reschedules average or peak withdrawals from surface or groundwater sources while maintaining or mitigating the extent to which return flows are degraded'*. This definition suggests that DSM is a two-pronged approach to water management: aiming to better manage water supply and how it is used as well as how the wastewater is disposed of. DSM is not meant to completely replace physical engineering solutions. Instead, it is meant to work with supply-side options to direct the focus to existing infrastructure and to reorient the scale of physical solutions to smaller, more decentralised projects (Maas, 2003). Overall, the idea of DSM is to make water use more sustainable, by integrating all aspects that influence water use from policy instruments and economic tools to physical technology and public perception in order to create the most efficient and 'eco-friendly' solution to current needs as well as be flexible and adaptable to future water needs.

DSM is not a new concept. Indeed, the application and the positive results have been demonstrated worldwide for a huge variety of water-related issues. Examples include water markets and other economic instruments in California, China and Australia (Cantin, Shrubsole and Ait-Ouyahia, 2005; Howitt and Hanak, 2005; Renzetti, 2005); wastewater reclamation for agriculture in Saudi Arabia, Tunisia, Egypt, Israel and the Okanagan, to name but a few (Gleick, 2000; Maas, 2003); wastewater reclamation for potable use in Namibia and dual system distribution in St. Petersburg, Florida (Gleick, 2000); mandatory efficient fixtures in Ontario (De Loe, Moraru and Kreutzwiser, *et al.*, 2001); the adoption of the ambitious Water Framework Directive in Europe which mandates full-cost recovery of water services (Renzetti, 2005); and even things like fog-water harvesting in Chile (Gleick, 2000). The list is practically in-exhaustive, as almost every country has and is currently implementing some sort of DSM strategy into their water practices. However, DSM has yet to become the dominant method of water management, as currently, its adoption has been more local scale and based on short term shortage problems as opposed to a solution for long term water management planning. Many countries still look towards SSM to meet their long term needs, as evident from the continued construction of mega-structures such as the Three Gorges Dam in China. In order to take full advantage of the benefits that DSM can offer, its combinations of policy, economic, physical and social tools must be fully integrated into current management practice, and this will require country-scale commitments that currently are not in place.

1.3.2 Water Use and DSM Opportunities in Canada

Compared to other OECD countries, Canada lags well behind in implementation of DSM (Cantin, Shrubsole and Ait-Ouyahia, 2005). This is not surprising given their historical perspective that water is plentiful and widely available, but this large and mostly unregulated withdrawal also presents a major opportunity for experimenting with various DSM tools, especially in the industrial, agricultural and residential sectors. Overall, industry is the largest use sector in Canada, with thermal power generation and manufacturing taking a combined total of 78% of total water withdrawals (Cantin, Shrubsole and Ait-Ouyahia, 2005). Municipal use, which includes commercial, institutional, light industrial and residential, account for about 12% of total withdrawals (Brandes and Ferguson, 2003). Agriculture, though being a minor player in terms of withdrawal at 9%, is the largest consumer in Canada, the difference being between withdrawal (how much is diverted from surface water or taken up from groundwater) and consumption (how much is actually 'removed' from the renewable water cycle, e.g. via products such as crops), as very little of the water taken for agriculture is returned to the environment (Cantin, Shrubsole and Ait-Ouyahia, 2005). Industries on the other hand, withdraw vast amounts of water but much of this will be returned to the environment, albeit in a more degraded state. Manufacturing industries already tend to have some form of water recirculation in place, however, large industries in general tends to be self-supplied, thus there is no real limit to how much water they can use (Renzetti, 2005). Municipal water use is highly diverse, from drinking, cooking and cleaning to landscaping, fire fighting and sewerage. Residential represents more than half of the total volumes used in this category (EC, 2004), and with the intensive nature of urban water provisions; system leakages in the sector of up to 30% and ever expanding urbanisation, this sector represents a fundamental area for implementing DSM strategies (Brandes and Ferguson, 2003).

1.3.3 Implementing DSM

(Brandes and Ferguson, 2003) categorized DSM tools into three main categories: socio-political; economic; and structural-operational. Socio-political methods are based on efforts to change public perception about water, and involve such things as public education, legislation, building and plumbing codes, restrictions and permits. Economic tools use monetary incentives to encourage desired behaviour, achieved through pricing structures and options such as water markets. Lastly, structural-operational methods involve more physical ways to increase water use efficiency, via efficient fixtures, water reuse and recycling, rainwater harvesting, xeriscaping and systems upgrades and repairs.

To achieve optimum effectiveness, a combination of DSM tools is needed, but this requires detailed understanding of how different tools affect each other. Choosing the right combination of DSM tools can be even more complicated by indirect relationships between water needs and non-water needs. In some cases, issues such as energy availability or farming subsidies can have an even larger impact on water use than DSM tools. Similarly, other sustainability strategies such as energy conservation and a reduction in meat consumption can also affect water needs, as a 1% reduction in water intake by thermal power plants would have approximately the same effect as retrofitting every toilet in Canada (Renzetti, 2005). Such indirect effects on water needs are difficult to control, and attempts have been made to try to model the effectiveness of different combinations of DSM tools. Environment Canada's 'Water Use Analysis Model' and US Army Corps of Engineers' 'IWR-MAIN Water Demand Analysis Software' are two such models that can simulate the impacts on water use from implementation of various combinations of DSM tools (Kassem and Tate, 1994). Although unable to account for all variables, particularly those indirectly related to water use, these models help to allow comparison between DSM combinations and thus facilitate decisions on how best to achieve certain goals.

1.3.4 Post-DSM and the 'Soft Path'

Once a particular set of DSM tools have been implemented, a comprehensive monitoring and evaluation program is needed to record the effectiveness of this measure. The findings from previous and current DSM strategies are important for future decisions on DSM use. Predicting future water needs is just as important for achieving sustainability as meeting current needs with sustainable practices. Unfortunately, past attempts to forecast future water needs have been largely inaccurate and often highly over-estimating, as there is difficulty with assessing how much impact DSM, changes in behaviour and economy will affect future needs. A new way of approaching the problem of future needs is to use the soft path method known as 'backcasting'.

The idea of the soft path approach is to first determine the service that the water is used for, and then come up with alternative ways of providing that service such that the minimum or even no water would be required. In this way, it is one step more advanced than simply implementing DSM. According to (Brocks, 2005), there are 3 key concepts to the soft path: 1) to resolve the supply-demand gaps as much as possible from the demand side; 2) to match the quality supplied to the quality required by the end use; 3) to start from the idea of some water efficient future (the goal) and work backwards (backcasting) to determine how to attain this goal from the present. To be effective, the soft path method requires good knowledge of current direct and indirect water uses, DSM tools as well as knowledge of how other non-water resources might affect water use, such as energy and meat consumption (Brocks, 2005). In practice, this method will not be easier to work with; however, it encourages decision makers to aim for a desirable goal, thus helping to guide them on the best route to achieving a sustainable future.

1.4 Goals and Objectives

In all the studies that have been commissioned by the Township of Langley on the Aldergrove aquifer in the past, all have suggested at some point that water demands from the aquifer is increasing, and consequently, water levels are decreasing. However, actual knowledge of the capacity of the aquifer and how increasing demands may be affecting the aquifer is limited. As a result, there is little guidance on what can be done to prevent a potentially serious water shortage issue in the coming future. Given this situation, there is a strong need for a more specific study to be done on this aquifer.

This study will address the following research questions:

1) What is the current state of the Aldergrove aquifer?
2) How might demands change in the near future?
3) What can be done to better manage this aquifer?

Consequently, this study was conducted with the goals to:

1) Determine the current status of the Aldergrove aquifer by assessing its water balance. This involves:
    a) Analyzing recharge parameters and modeling the effects of these parameters on annual recharge.
    b) Using well data to determine storage and water levels in the aquifer.
    c) Compiling metered water use data to estimate demands and their subsequent effects on total discharge from the aquifer.

2) Analyze trends in climate and land use to assess impacts on the aquifer.

3) Use the results of the water balance and land use trends to develop scenarios of future water demands.

4) Focus on structural-operational DSM tools and their effectiveness in reducing demand from the aquifer.

1.5 Study Site Background

1.5.1 Location

Aldergrove is a small community within the Township of Langley in the Lower Fraser Valley, B.C. (See Figure 1.1). It had an estimated population of 11,600 in 2004 (ToL, 2005). The land use near the centre of the community is mostly comprised of residential, commercial and institutional properties. Light industrial properties are concentrated in the northern outskirts of the community, and the rest of the land is made up of agricultural and hobby farms (See Appendix I – Figure 1.A-D).

1.5.2 Water Supply

The community of Aldergrove is completely reliant on groundwater sources for their water supply. Most of the commercial, institutional and industrial properties in this area are supplied by municipal wells owned and operated by the Township of Langley, thus their water consumption is metered. There are currently 7 municipal production wells in the area, one of which was newly installed in 2005 (Piteau, 2005). Conversely, practically all the agricultural properties and some residential properties are supplied by their own private wells, while those residential properties that are on the municipal supply are not metered, thus water withdrawal is largely unlimited and unregulated. While water quality has generally not been a major issue for this aquifer (Piteau, 1997), the continued growth and development of the community is putting an increasing pressure on the supply potential of this aquifer. Monitoring of the water levels at certain points on this aquifer has shown that the water levels have been declining since 1986, and more rapidly since 1999 (Piteau, 2004).

1.5.3 Background on the Aldergrove Aquifer

The majority of the groundwater that supplies the community of Aldergrove originates from the Aldergrove aquifer. This is a largely confined aquifer spanning approximately 47 square kilometres (ToL, 2006a) and underlies most of the community of Aldergrove as well as extending into parts of the neighbouring municipality of Abbotsford. Much of the previous characterization of this aquifer was done by Piteau Associates Ltd., as part of their testing and installation of new municipal production wells, however they also conducted two hydrogeologic assessment of the Aldergrove aquifer in 1991 and 1997. In these reports, they determined that the aquifer consists of permeable sand and gravel units 'sandwiched' between silty clay units, with a thickness of up to 30 metres. They also looked at recharge, the impact of the municipal production wells on water levels, the hydrological connection of this aquifer to surface water and other aquifers, and water quality. Details of their reports can be obtained from the Township of Langley. More recently, Golder Associates Ltd. produced a comprehensive groundwater modeling report for the whole Township of Langley, and in their study, they deduced that the Aldergrove aquifer is fairly complex in structure, containing discontinuities as well as hydrological links to other aquifers. They also confirmed analysis by Piteau, stating that the aquifer is mostly bounded by aquitards, but is unconfined in some locales, and recharge is mostly via leakage from surrounding aquitards and an unconfined area just east of Aldergrove. In addition to this, Golder used the groundwater modeling software *ModFlow* to provide analysis of municipal production well capture zones and a water balance for the aquifer which includes a scenario for the future based on OCP buildout. The findings from this report and the analysis done by Piteau Associates provide most of the background analysis on which this thesis project will be based.

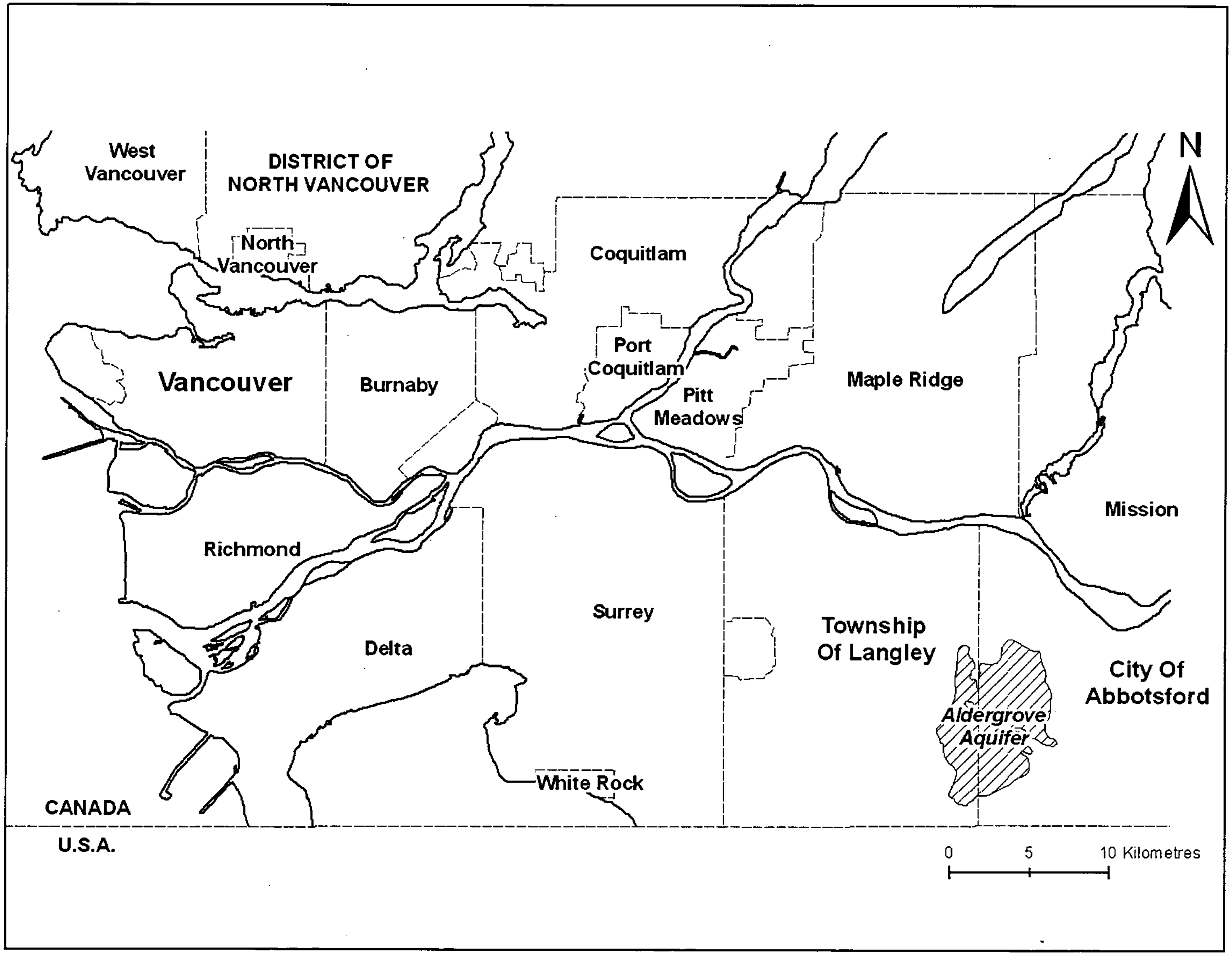


Figure 1.1 Regional map of the Lower Fraser Valley and the Aldergrove aquifer.

Chapter 2 – Recharge

2.1 Soil-Water Budget Method

2.1.1 Theory and Components of the Soil-Water Budgeting Method

Soil water budgets are typically a method used to determine the water balance at the surface, often for crop irrigation scheduling. At any point in time, this method can be used to estimate the water content of a unit area of land via a mass balance between water input mechanisms and water output mechanisms. For the purpose of determining the aquifer recharge, this method is capable of giving a more detailed analysis of how surface conditions affect recharge, but will not be able to properly account for the effect of below-soil zone geology and the presence of macro-geological features such as faults.

The basic components needed to determine aquifer recharge using the soil water budgeting method are:

- **Precipitation** – the sole input of water to the system for this model.
- **Evapotranspiration** – water loss from evaporation and transpiration.
- **Soil-water holding capacity** – the maximum volume of water that can be stored in the soil.
- **Impermeability** – the surface area that does not allow water to infiltrate for recharge.
- **Surface/subsurface runoff losses** – water that is drained to surface waters and not available for recharge.

The simplest method to determine recharge is to assume that all the precipitation infiltrates the ground, and so R = P * A. This grossly overestimates recharge, as not all the precipitation will infiltrate.

In order to get a more realistic estimate of recharge to the aquifer, parameters such as evapotranspiration, runoff and the water holding capacity of the soil will also be required, such that:

$R_{aquifer} = [P - (ET + WHC + RL)]*A$

R = recharge (volume of water transferred to the aquifer) from the surface per year

P = total precipitation per unit area of aquifer

ET = evapotranspiration loss per unit area of aquifer

WHC = amount of precipitation needed to saturate soil per unit area of aquifer

RL = surface/subsurface runoff per unit area of aquifer

A = area of land over the aquifer that is permeable

This equation assumes that once evapotranspiration and runoff loss is removed and the amount of water needed to saturate the soil (i.e. remove the soil moisture deficit) is full, then all the remaining water from precipitation will infiltrate into and recharge the aquifer.

2.1.2 Methodology

Determining Individual Parameters

Precipitation

Precipitation patterns and volumes are very important in determining how much water has the potential to contribute to recharge. Not all precipitation events will contribute the same ratio of recharge, as many factors need to be considered when calculating the 'effective' precipitation. These include consideration of antecedent conditions, and the magnitudes of precipitation events. Precipitation data for Aldergrove was obtained using the records provided by Environment Canada at Abbotsford Airport, which is within 10 kilometres of the aquifer. The daily total rainfalls recorded since September 2003 was used in the model to generate annual calculations which run from September to September each year.

Evapotranspiration

Evapotranspiration (ET) estimates were taken from *Farmwest* (Farmwest, 2006), which gives daily ET values based on climatic data at different meteorological stations. These daily ET values were averaged to give one mean ET per season. The land cover was split into 2 types: forested and pasture, as the ET for forests are different to those from pastures. Previous literature has suggested that forests in the Pacific Northwest tend to evapotranspire less water than pasture land, and a study by (Black, Spittlehouse and Novak, *et al.*, 1989) determined the mean ET of forests in the Fraser Valley to be 83% of that for pasture, thus the Farmwest pasture ET data was multiplied by 0.83 to give a corresponding ET for forests each season. A separate data set of lake evaporation taken from the UBC meteorological station was also used to compare calculated recharge values (EC, 1990). This lake evaporation data is based on more than 20 years of averaged daily means between 1971 and 1990, and since both lake evaporation and ET involve the same basic process, it is easy to assume that evaporation data which takes into account humidity and wind effects can be a reasonable estimate of ET (Burman and Pochop, 1994). The report by Golder (Golder, 2005) also produced an estimate of ET for the wet and dry seasons (which was calculated based on Environment Canada's climatic data for Langley). All three ETs will be compared.

Water Holding Capacity

The water holding capacity (WHC) for the soil was determined based on estimates of porosity for different soil types and the depth of soil zone requiring saturation before recharge can occur. The porosity values were obtained from percentage field moisture determined from soil profile analysis. These values have been recorded in a technical data bulletin for the Langley – Vancouver area by the Ministry of Environment (Luttmerding, 1981). To simplify the calculations, all the soil types found over the Aldergrove aquifer were grouped into 6 categories based on composition, drainage, and the porosity of different soil types within each of the 6 categories, which were averaged to give one mean porosity value per category. Since porosity is a highly variable parameter even within a soil type, the effect of averaging the soil types per category is not expected to make a significant difference to the accuracy of the recharge results. Since none of the soils within category 5 had any previous literature pertaining to porosity, the porosity value for this category was assumed to be the same as that of category 6 soils. The effect of this is also not considered to be very important for accuracy, as category 5 soils make up less than 6% of soils over the Aldergrove study area. To obtain the WHC, all the soils were assumed to require a saturated depth of 50 cm before recharge can occur, and the percentage porosity was rearranged to give WHC in m^3 per m^2.

Impermeability

Impermeability was manually determined via the use of aerial photos and GIS software. The total impermeability for the aquifer surface was divided into the 6 soil categories to give the impermeable surface area over each soil category. This value was then deducted from the total surface area at each category to give the corrected surface area at each soil type that is available for recharge to occur. Since the ET calculations require a segregation of pasture lands from forested lands, these soil-category based surface areas were further sub-divided into pasture area and forested area. The impermeability of the land itself is not necessary for the unit recharge calculation, but becomes important when the unit recharge value is scaled up to the size of the aquifer.

Runoff Losses

Runoff losses (RL) via surface or subsurface flow to streams is a big component of the balance which acts to reduce the amount of water available for recharge, however, it is also a fairly complex parameter to estimate accurately. For this water balance, runoff was estimated by assuming that all the areas over a watershed contribute the same amount of water to the stream that drains the watershed, i.e. uniform RL. The watershed that covers the largest area over the aquifer is the Bertrand Creek watershed, shown in Figure 2.1. Flow data from a stream gauging station just outside the aquifer boundary (at 264th street) was obtained from the Township of Langley for this watershed, and GIS was used to determine the area of watershed that is considered to contribute flow to the stream above the gauging station. This is the 'effective' watershed area. The assumption of uniform RL means that the percentage area of effective watershed that lies over the aquifer is equal to the percentage of flow contribution from that area. Since 75% of the effective watershed overlaps the aquifer, the total volume of water estimated to be lost to surface flow over the Bertrand watershed-covered part of the aquifer is 75% of the total flow measured in one year at the gauging station. This 75% determined volume can be divided by the total area of aquifer overlapped by this effective watershed to give a unit RL per unit area of aquifer. Since runoff to Bertrand Creek is taken as the representative of all RL over parts of the aquifer covered by other watersheds, this unit RL can be multiplied by the total surface area of the aquifer to derive an estimate of total RL out of the aquifer.

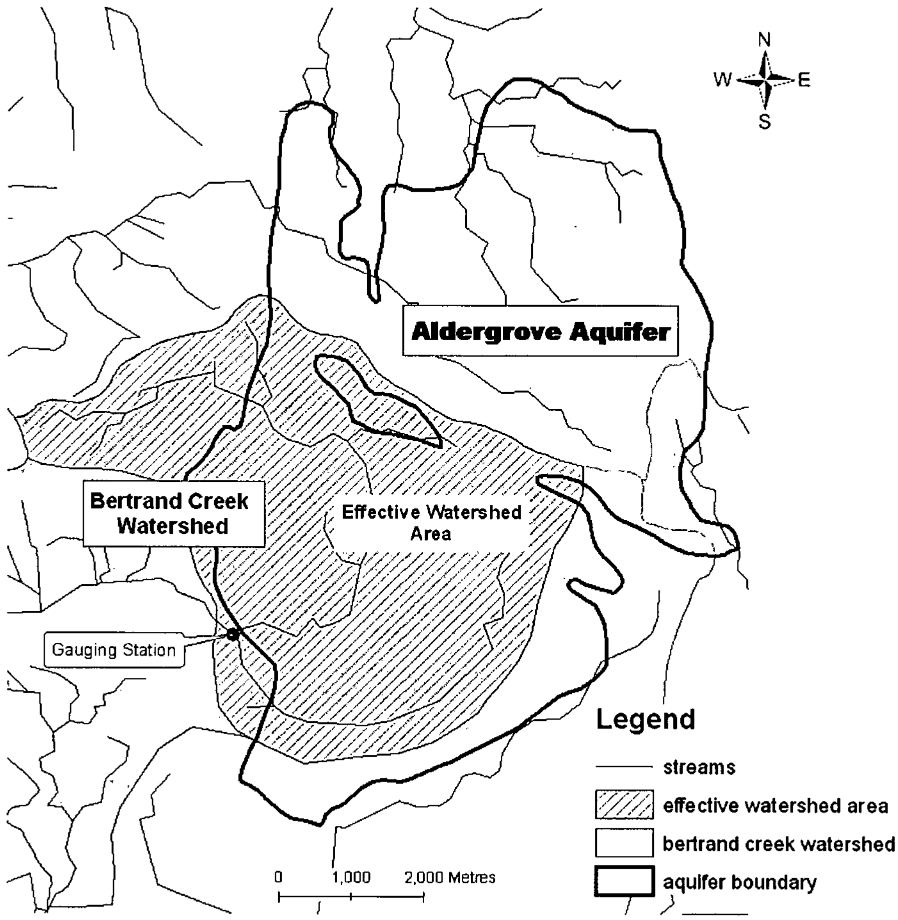


Figure 2.1 Map of the 'effective watershed area' in relation to the boundaries of the aquifer and the whole Bertrand Creek watershed. Aquifer boundaries defined by Golder (2005).

Calculating Recharge Using the Soil Water Budget Method

Calculations for recharge were generally split into two parts. The first part is the 'real-time' recalculation of values depending on changes in precipitation, and basically incorporates ET and WHC. The second part involves taking the final result from the first part, and scaling up to the aquifer level, taking into account impermeability, then deducting RL from the total values to give the grand final recharge value for that year period.

<u>Calculation for Part I</u>

The way the calculations were made was by assuming that the soil started off with a maximum soil water deficit (determined by the WHC, herein known as SMD), so recharge is initially negative. For this reason, annual recharge is considered to start at the end of summer and conclude at the end of the following spring. Each day, a value for ET is deducted from the recharge depending on the season and the SMD, such that when the SMD is at its maximum, ET is not deducted, the justification being that there is no water available for ET to occur. Each day, if the WHC gets saturated, any volume of water received from rainfall that exceeds the saturated capacity gets 'banked' as recharge, and this banked water cannot be lost again as ET. The WHC then remains at exactly saturation, ready for the next day's precipitation event (if any). This calculation of water availability is cumulative, as each daily calculated value is dependent on the saturation from the previous day as well as precipitation volumes for that day. Figure 2.2 shows the process of this calculation. Since each soil type category has a different WHC, this cumulative calculation is done separately for each category. The calculation for forested land was also separated from that for pastures. Thus the final recharge volume for the year per unit area of aquifer is the sum of all the cumulative 'banked' water from each soil category for each land cover type.

Calculation for Part II

This part of the calculation starts off by scaling up the unit recharge volumes to that of the aquifer. Each of the calculated recharge volumes for each soil category was multiplied by the permeable area occupied by that category. The new value for recharge contribution by forested areas was then pooled with the value for pastures to give one value for recharge for the aquifer. The total runoff loss determined separately was then deducted from the total recharge value to give the final recharge estimate (via surface and soil processes) for the aquifer for that year.

Since Golder Associates also derived their own estimate of recharge to the aquifer using ModFlow, their value was used as an indicator to compare the soil water budget calculation results against.

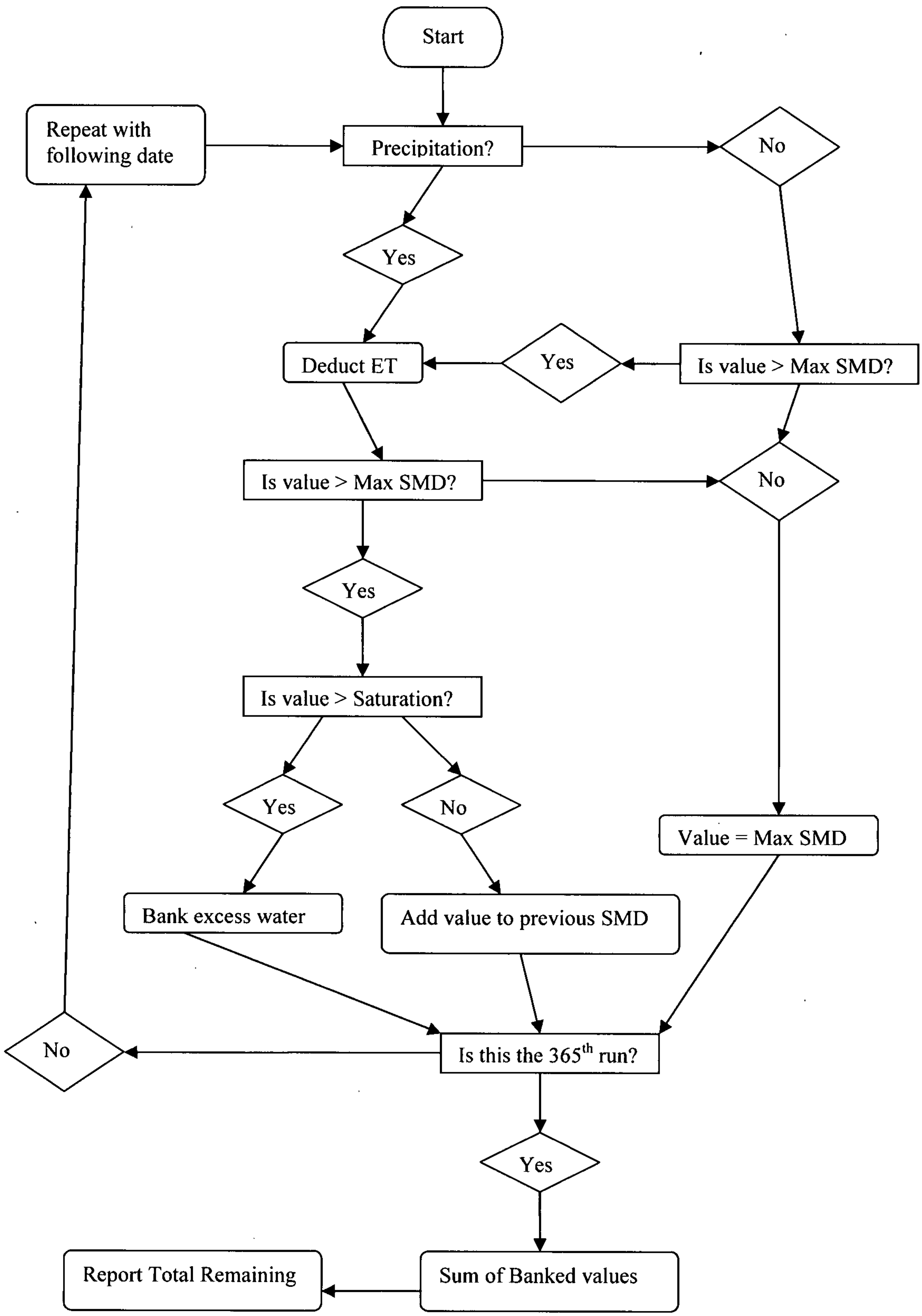


Figure 2.2 Process diagram for Part I of the soil-water budget calculation. The process is repeated until one annual cycle (365 days) has been completed.

2.1.3 Results

Climatic Data

The daily precipitation data was summed up to give seasonal totals during the analysis period.

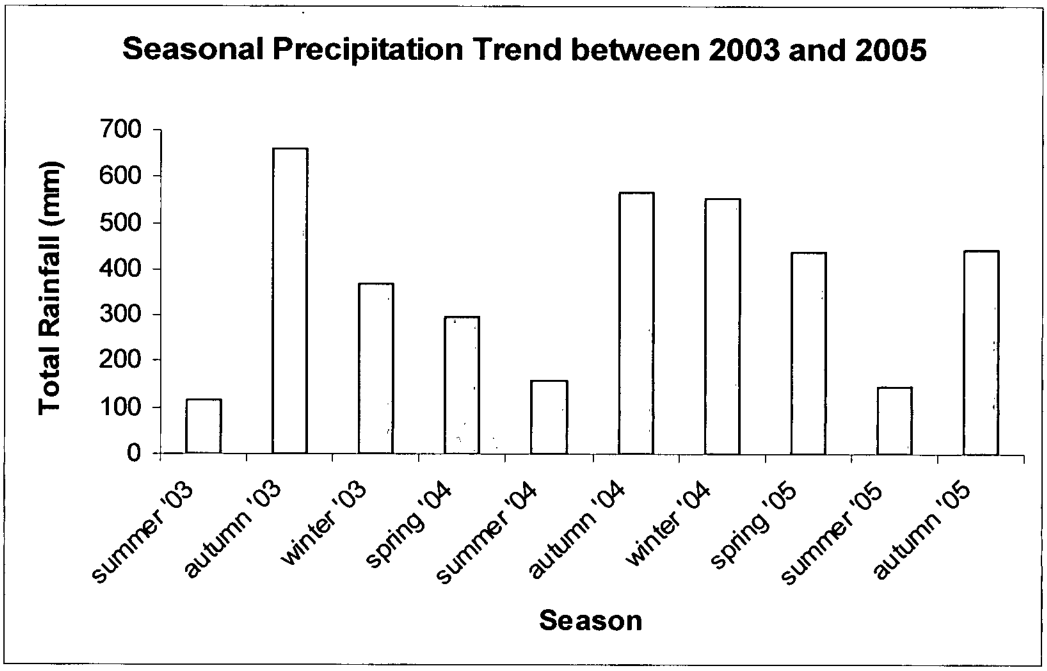
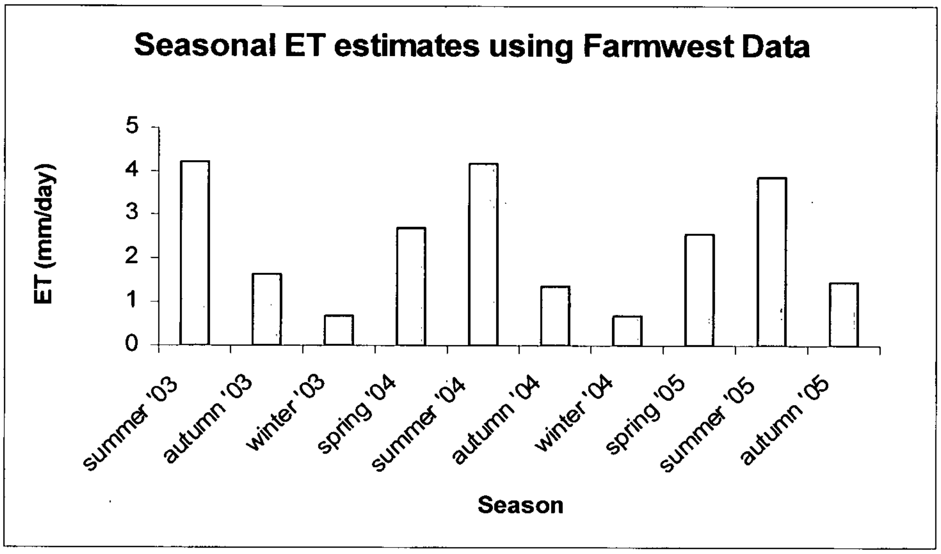


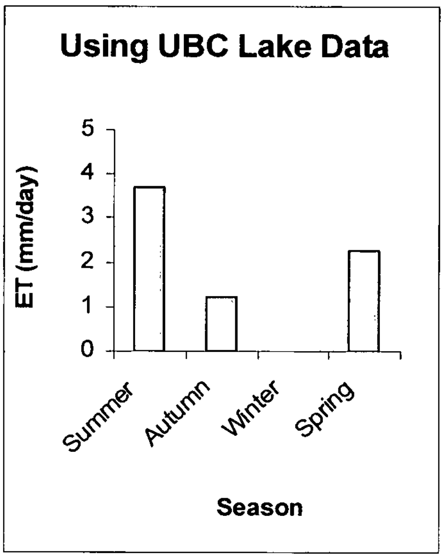
Figure 2.3 Average seasonal precipitation over Abbotsford airport from 2003 to 2005.

Figure 2.3 show that there is a clear oscillating trend whereby rainfall is lowest during the summer months and highest during the autumn and winter months. This is characteristic of climatic conditions in the coastal Pacific Northwest. From observing the graph, it is also possible to distinguish an overall greater total volume of rainfall occurring during the 2004-2005 annual period, compared to the 2003-2004 period.

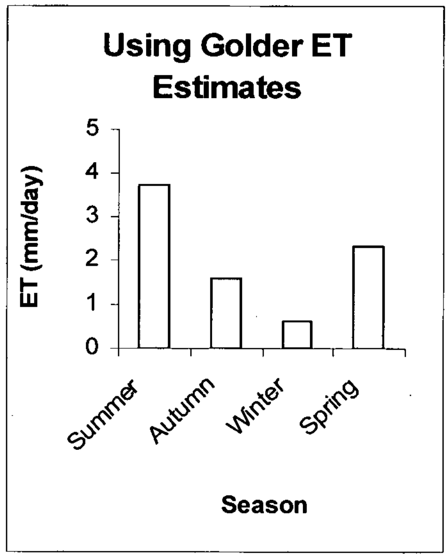
Three sets of evapotranspiration (ET) data were used in the recharge analysis; Farmwest data, Golder data and UBC Lake data. The Farmwest monthly ET estimates were pooled to give seasonal ET estimates. Figure 2.4a shows that ET for pastures is highest in the summer months, and is lowest in the winter months. The annual cycle appears to be fairly identical, though there seems to be a small decreasing trend in all the seasonal ET estimates with time, compared to the previous estimate for the same season. The ET estimates from the UBC Lake data (Figure 2.4b) show very similar estimates as the Farmwest data, though estimates for all seasons tend to be slightly lower and no estimate was available for winter.



(a)



(b)



(c)

Figure 2.4 Average seasonal evapotranspiration (a) obtained from Farmwest calculations, (b) obtained from historical measurements at UBC lake, (c) modified from the Golder Associates report.

The Golder report also derived monthly average ET, which was converted into seasonal averages for comparison with the Farmwest and UBC Lake data (Figure 2.4c). The seasonal values shown for Golder is very similar to that seen with the Farmwest data and almost identical to that of the UBC Lake data excluding winter, however, the Golder estimated ET took into account moisture deficit during the summer dry period, causing the summer average ET to be lower than that seen with the Farmwest data. Nevertheless, the same seasonal trend can be observed with all three data sources, with the order of decreasing ET being summer, spring, autumn and then winter.

ET for forested land was based on a set fraction of ET for pastures, thus the trends remain the same, though total ET losses from forests are slightly less than that for pastures. Forested land cover over the aquifer was manually delineated via aerial photos. The estimated total forest cover was found to be 15.3%. This means that the reduced ET loss will only affect approximately 2.6% of the total recharge calculation.

Land Use Data

One field moisture value was obtained for each soil category, based on an average of the field moisture values found for different specific soil types within each category (see Appendix II – Table 2.A).

Table 2.1 The dominant soil type, average field moisture value and the percentage of area over the aquifer covered by each soil category.

Soil Cat.	Texture & Drainage Class	Average % Field Moisture	% Aquifer Area
1	Well drained sand	16.92	17.7
2	Well drained silty loam	26.43	1.0
3	Fairly drained silty loam	18.30	62.8
4	Fairly drained silty clay	36.90	6.0
5	Poorly drained silty loam	same as cat. 6	5.9
6	Poorly drained silty clay	32.35	6.5

Table 2.1 show that there is a tendency for the finer textured and poorer drainage soils (categories 4-6) to have greater 'porosity' than the coarse textured and well drained soils (categories 1-3). The differences between the soil categories span more than a factor of 2. However, the two soil categories that occupy the largest area of aquifer (category 1 and 3) are also the two categories that have the lowest field moisture, thus these two categories have more influence on the total WHC of the aquifer as a whole.

Impermeability results for the Aldergrove aquifer area (Table 2.2) shows that soil categories 3 and 6 contain the most impervious area in relation to the total area occupied by that category. However, due to the large total area occupied by category 3 soils, the equivalent impermeable area is also large, constituting 70.8% of the total impermeable area over the aquifer. This means that impermeability will have a stronger influence on the Part II portion of the recharge calculation for category 3 soils than it would have for other category soils such as category 4 and 5. Altogether, impermeable areas occupy 9% of the total land surface area over the aquifer (See Appendix II - Table 2.B).

Table 2.2 The total impermeable area by category is given with the corresponding percentage of area that is impermeable for each category, and how that contributes to total impermeability over the aquifer.

Soil Cat.	Impermeable Area (m^2)	% of Category Area	% Total Impermeability
1	582,756	6.9	15.2
2	33,759	6.9	0.9
3	2,713,541	9.0	70.8
4	87,560	3.0	2.3
5	153,405	5.5	4.0
6	259,595	8.3	6.8
Total	3,830,615		100.0

Runoff Data

The results from the streamflow data used to estimate runoff loss is summarized below.

Bertrand Creek Watershed				
Total watershed area =	27,437,695	m^2		
Area outside Aldergrove Aquifer =	6,927,770	m^2		
Area inside Aldergrove Aquifer =	20,509,925	m^2		
% of Bertrand Creek watershed that covers Aldergrove aquifer =			75	%

Total Bertrand Creek Flow 2003-2004				
Total discharge from watershed =			13,440,955	m^3
Total volume water originating from Aldergrove aquifer =			10,047,235	m^3
Volume water per m^3 inside Aldergrove =			0.49	m^3 m^{-2} Aldergrove area
Total Aldergrove Area =	47,737,334	m^2		
Total runoff losses =	**23,385,177**	m^3		

Total Bertrand Creek Flow 2004-2005				
Total discharge from watershed =			12,629,184	m^3
Total volume water originating from Aldergrove aquifer =			9,440,429	m^3
Volume water per m^3 inside Aldergrove =			0.46	m^3 m^{-2} Aldergrove area
Total Aldergrove Area =	47,737,334	m^2		
Total runoff losses =	**21,972,822**	m^3		

The calculation based on assumptions of uniform runoff across the aquifer gave an estimate of runoff ranging from 0.46 to 0.49 m^3 per m^2 of surface area over the aquifer for the two consecutive years. When this is scaled up to the size of the aquifer, the total runoff loss is estimated to be between 22 to 23.4 million m^3/yr. This means that a large portion of the total recharge calculated after Part I will be removed in Part II via this runoff loss, making this loss mechanism a very significant one.

Recharge Calculation

Three sets of recharge calculations were done; one using the ET values from Farmwest, one using ET values from Golder, and the last one using UBC lake evaporation data as ET estimates. In each set, recharge was calculated for 2 annual periods; from the 1st September '03 to the 31st August '04, and from the 1st September '04 to the 31st August '05, giving a total of 6 annual recharge results (Table 2.3).

Table 2.3 Summary of the final recharge result for each annual period based on separate ET source data.

RECHARGE (million m^3)	2003-2004	2004-2005
Farmwest	12.2	26.5
UBC Lake	17.1	30.7
Golder	13.0	26.5

The results differed significantly between the three ET sources as well as between years. In general, recharge estimates from Farmwest data were smaller than those estimated by Golder or UBC lake data, though for the 2004-2005 period, both Farmwest and Golder had identical results. The recharge estimates from the UBC Lake data is consistently higher than the other two estimates for the same period. Between years, the recharge in the 2003-2004 period was also consistently smaller than that for the 2004-2005 period. The difference between subsequent years was found to be higher than differences between ET data sources. A comparison of precipitation and runoff losses between the two annual periods showed that the 2004-2005 year had 16% more precipitation, but also 6% less runoff than in 2003-2004. This combined effect of higher rainfall volumes plus lower ET in 2004-2005 resulted in more water available for recharge for that year.

2.1.4 Discussion

Performance of Input Data

The analysis of recharge for this soil-water budget method was based on climatic and land use data derived from many locations and varying widely in accuracy and representativeness of the actual conditions for this aquifer. Table 2.4 summarizes the performance of each parameter used in this analysis, and the importance of that parameter on the recharge outcome. Accuracy is based on the level of certainty that the values used are obtained in the most reliable and detailed method available, and representativeness is based on how likely the values obtained are true to the conditions found for that specific site. The total score is the sum of the scores for accuracy and representativeness, with 5 being the best and 1 being the worst. Thus the larger the total score, the better that parameter performed overall for this recharge model.

Table 2.4 Arbitrary performance ranking table.

Data Type	Accuracy	Representative	Total Score	Importance
Precipitation	5	4	9	5
Impermeability	4	5	9	2
Water-holding capacity	3	3	6	1
Evapotranspiration	2	1	3	3
Runoff	1	2	3	4

Table 2.4 shows that the best performing parameters were precipitation and impermeability, as both were determined more or less on site, and have a high level of detail associated with the data.

The WHC performed slightly less well, even though it too was obtained from data measured on site. One of the main reasons for this was due to the fact that this data was experimentally obtained from undisturbed soils, so it fails to account for the influence of surface compaction which is likely to be quite prevalent in that area due to the dominance of agricultural land use. In addition, all the soils were assumed to require the same depth of saturation for recharge to occur, which is highly simplistic given that the rooting depth of different vegetation varies greatly. The other factor that reduced the accuracy of the WHC was the need to average the estimates based on the 6 soil categories. Within each category, the difference between the WHC of different soil types varied significantly, an example being soil category 1, which had field moisture values ranging from 7% to 30%. This is not uncommon due to the very heterogeneous nature of soils. Thus there is less certainty that the sample averages obtained can really be considered representative of the 'population' average for the whole aquifer area.

With the ET parameter, the low score can be attributed to the difficulty with obtaining accurate and reliable estimates, since there are many factors that govern the daily variability of this parameter, most of which could not be accounted for in the estimates used. These include relative humidity, wind speed and vegetation types. The ET estimates provided by the Farmwest data were derived from a modified Penman-Monteith equation for a grass reference crop (Farmwest, 2006). This equation typically incorporates aspects of wind, temperature, vapour pressure and net radiation; however, not all of this data was actually available. In the case of the database from Abbotsford Airport, only temperature data were available, thus the ET estimates from Farmwest are further simplifications of the Penman-Monteith equation, meaning that the accuracy of the estimates will vary with wind and cloud conditions, among other factors. Indeed, it has been known for some time that ET estimates are particularly sensitive to marginal variations in albedo, radiation constants and wet-bulb temperature, and it has been suggested that ET is the most significant variable that affects soil-moisture balances (Howard and Lloyd, 1979). With the UBC Lake data, even though humidity and wind effects were considered, the fact that the data originates from pan evaporation measurements at UBC instead of Aldergrove, has no estimates during winter, and that it's a long term averaged mean rather than specific to the study period means that it is also likely to be less accurate as a result. The Golder data obtained their estimates from Abbotsford Airport, which where converted into ET values by Agriculture and Agri-Foods Canada (Golder, 2005). It is not known which method was used to convert the climatic data to ET values, but it would seem that this estimate should be the most accurate out of the 3. However, the fact that Golder already incorporated moisture deficit into the summer ET estimates without indicating what values were used means that it was not possible to separate the original ET from the modified (moisture deficit incorporated) ET. Since the recharge calculation already factors WHC of the soil, this means that the Golder data-based calculation will over-compensate for moisture deficit. This will likely lead to a slight overestimation of recharge, though the magnitude of effect on recharge is unknown. The lack of better accounting for the different vegetation cover over the study area also reduces the confidence of all the estimates, especially with the adjustment for forest ET, which is highly questionable with regards to its reliability since conflicting results have been observed depending on the region studied. For example, studies in the U.S., Siberia, Argentina and even the interior provinces of Canada have found that pasture ET is less than forest ET, with the pasture values ranging from 55 – 85% of forest ET (Hogg, 1997; Nosetto, Jobbagy and Paruelo, 2005; Twine, Kucharik and Foley, 2004; Yamazaki, Yabuki and Ishii, *et al.*, 2004). However, these study locations are all significantly different from the geoclimatic region of Aldergrove, and most of these studies were comparing grasslands to deciduous trees, while the (Black, Spittlehouse and Novak, *et al.*, 1989) study results from which this study's forest ET was based, obtained their values by comparing pastures to Douglas Fir trees. So depending on the dominant make-up of the forests in Aldergrove, it is likely that the difference between pasture and forest ET will also vary and require extensive research in order for the true ET difference to be determined.

Runoff was based on data from the actual watershed over the study area, and inherently, that data is accurate. The problem lies in the conversion of that data to a unit runoff loss over the aquifer, which is based on many assumptions including the representability of Bertrand creek streamflows in depicting runoff losses over the whole aquifer surface, the homogeneity of land surface (in terms of runoff generation), and no net interaction of the stream with other sources and sinks such as groundwater. The latter assumption may be the most crucial in reducing the accuracy of the runoff value used in the calculation. Another aspect completely unaccounted for by the soil-water budget method is the anthropogenic influence on stream flows, namely irrigation. On one hand, farmers that have obtained permits to extract surface water for irrigation can lead to reduced surface flows, but on the other hand, farmers that do not extract surface water for irrigation may contribute to surface flows via over-irrigation. Both situations are not likely to be particularly significant to the annual recharge budget, since few farmers in this area rely on surface water for irrigation (especially since streamflows are very low during the summer), and even fewer are likely to irrigate to the extent of causing runoff to streams.

Importance/Sensitivity of Individual Parameters

Attention must be paid not only to how well the input parameter performed, but also to the importance of that input parameter on the outcome of the recharge calculation, as a low performance parameter with a high importance is of more consequence than a high performing parameter with a low importance. For this reason, the importance of the input parameter to the outcome of the recharge calculation was also ranked and compared to the performance indicator. Importance rankings were based on the percentage effect that each parameter has on the final recharge result, given the presence or absence of that parameter in the recharge calculation. The results are shown in Table 2.5.

Table 2.5 Importance ranking for the parameters used in the recharge calculation.

Presence or Absence of:	% Effect (Difference) on Final Recharge Result	Ranking
Precipitation	100	5
Runoff	39-64	4
Evapotranspiration	18-45	3
Impermeability	10-15	2
Water-holding capacity	7-10	1

Ideally, it is preferable that the most important parameters are also the best performing ones. Unfortunately, Table 2.4 shows that this did not hold true in the case of ET and runoff. Both parameters are of relatively high importance because the calculation is more sensitive to changes in these compared to WHC and impermeability, but neither was able to meet expectations of performance, due mostly to difficulties with accuracy rather than representativeness. These two parameters are likely to cause the most uncertainty in the recharge result.

Comparison of Recharge Results Derived from the 3 Different ET Sources

The differences between the recharge results (Table 2.3) derived from the 3 ET sources highlights how important the ET estimates are for determining the final recharge result. The recharge results are entirely reflective of the difference in magnitudes between the ET estimates. The Farmwest data gave the highest amount of ET estimate for the aquifer, while the UBC Lake data gave the lowest estimates. This in turn resulted in the Farmwest recharge being proportionally smaller than that which was calculated for the UBC Lake. There is insufficient data to accurately determine the actual relationship between ET and recharge, but if the average ET for each source was used with the assumption of a linear relationship between ET and recharge, then a 1 mm reduction in average daily ET gives 5 million m^3 of additional recharge per year. Since the average ET estimate for Farmwest and UBC Lake differ by 0.9 mm, this obviously has a significant impact on the resulting recharge values, which correspondingly differs by over 4 million m^3.

It is difficult to say which ET estimate gave the most accurate recharge result for the aquifer. Since both the Farmwest and Golder ET estimates were derived from the meteorological station closest to Aldergrove, it would seem that they are likely to be more representative than the UBC Lake estimates. However, the likely over-compensation of moisture deficit from the Golder data suggests that the Farmwest data might be the overall victor in terms of accuracy of recharge estimate. If that is the case, then annual recharge is the lowest of the 3 estimates for both years, since Farmwest had the highest ET average. It is important to note that this arbitrary comparison of accuracy between ET estimates must not be misinterpreted as a measure of the best method to obtain ET values when calculating recharge, because as mentioned earlier, all three ET estimates explored here are very simply derived and hence are inaccurate by default. Morton, (1983) highlighted the limitations of conventional conceptual techniques for providing ET estimates more than 20 years ago, and despite many modifications to standard techniques and the increase in remote sensing methods since then, it would seem that there is still considerable debate and lack of consensus as to the best method with which to obtain accurate ET values.

Comparison of the Recharge Result between the Two Annual Periods

Perhaps more important than the difference between ET estimates is the difference between calculated recharge values for the two consecutive years. It is startling to find that in the space of just one year, the recharge to the aquifer can differ by more than 13 million m^3. The variability in the input data for precipitation and runoff are the main causes of the recharge variability. Naturally, precipitation will fluctuate for any given year, and it is a component of recharge that cannot really be predicted and most certainly cannot be controlled. Runoff, on the other hand, is highly amenable to anthropogenic interference, though the tendency has been to deliberately and inadvertently increase runoff as a result of increasing development. It is uncertain why runoff actually decreased in 2004-2005 while precipitation increased, as it would be expected that the two are positively correlated. This reversal of correlation implies that other, more significant factors were contributing to the reduction of runoff for that year. Possible explanations include anthropogenic abstraction or diversion of water at the upper part of Bertrand Creek, or conversely, a reduction of anthropogenic loading into the creek due to reduced irrigation and other outdoor water uses.

Assumptions in Calculating the Recharge Result

Based on the assumptions and accuracy of its input parameters, the recharge result is also highly variable. The difference in the recharge value determined with different ET estimates alone highlights how easily the final result can be altered due to discrepancies in certain input parameters. However, assumptions of the interaction between input parameters on the recharge calculation also play a role in the reliability of the outcome. The method for calculating recharge makes a number of assumptions which are listed below:

1. A maximum soil water deficit in the summer.
2. No snow or freezing of ground surface in the winter.
3. Recharge cannot occur over the area occupied by impermeable surfaces, so this area is deducted from the total area for recharge calculation, except when referring to runoff losses.
4. Linear ET loss rate up to the maximum SMD, then an abrupt stop of ET.
5. Saturation is required before recharge can occur.
6. Water 'banked' as recharge cannot be re-surfaced for deduction as ET losses.
7. Runoff can be pooled annually and subtracted from recharge as a bulk value rather than interactively with individual precipitation events.
8. No surface-groundwater or inter-geological unit transfer of water.
9. No anthropogenic factors that influence input parameter values.

The limitations in the recharge estimate as a result of these assumptions is immense, especially regarding the assumption 8 and 9, which are known to affect recharge quantities for all 'accessed' aquifers.

Effect of Individual Assumptions

Assumption 1

In the study area, assumption 1 can be justified since the summer period is renown for the lengthy dry weather, enough to bring the soil moisture content below the permanent wilting point for most short vegetation cover.

The starting month of the model (September) is somewhat contentious, since the time when soil moisture is completely depleted varies depending on the length of the dry season, but the lack of recharge in the summer generally means that the inclusion or exclusion of this season is unlikely to make much difference to the calculation since at the end of the summer season, the SMD is always near the maximum for that soil type. Thus the only difference to the results will probably arise from the inclusion or exclusion of runoff values for the summer months. Since groundwater most likely forms the bulk of streamflows in the summer, it would be worthwhile to see how exclusion of the summer runoff data affects the annual recharge estimate.

The effects of changing from a 12-month period to a 9-month period (counting only from September – May) was tested and the results showed that the recharge difference ranged from 4-7% greater recharge (with 9-month period) for 2003-2004 and less than 1% of the same change for 2004-2005. These small differences are indicative of the limited streamflow that occur in the summer, meaning that on the grand 'annual' scheme of things, the summer months contribute little to recharge and thus are not of great importance for deriving the recharge with this method.

For the more deeply rooted vegetation such as trees and most shrubs, assumption 1 does not apply either, but the effect of continued ET for these vegetation types cannot be accounted for since only one saturation soil depth was used to generate the WHC estimate. Given that the ET estimates are inherently inaccurate, it would be meaningless to make extra effort trying to account for ET losses with the less abundance trees and shrubs over the aquifer, though it is undeniable that the effect of this assumption could contribute to an overestimation of the recharge assuming that ET is underestimated.

Assumption 2

The magnitude of the effect of assumption 2 varies depending on the winter for that year, as it is possible for no snow or freezing of the ground to occur in milder winters. It is arguable that the effect of precipitation in the form of snow will not change the recharge result as the ground presumably is frozen, thus all the snowmelt will contribute to runoff into streams, and thus be accounted for via the surface flow component. The effect of snow cover and the frozen ground on ET loss is questionable though, as ET is unlikely to occur when vegetation is covered, but this in turn does not consider potential evaporation losses. In general, snow cover and ground freezing should result in less ET, and if the extra runoff of snowmelt is accounted for by the surface flows, then this assumption is likely to have the net effect of causing underestimation of recharge by overestimating ET during winter.

Assumption 3

Assumption 3 is based on the premise that other than runoff, all other parameters must exclude impermeable areas from the analysis as these areas cannot contribute to recharge of the aquifer. This is justifiable as there is an impermeable barrier between precipitation and the soil, then it is irrelevant whether ET or interception occur, since none of the precipitated water can infiltrate. The ambiguity occurs when there is a differentiation between total impervious areas and 'effective' impervious areas, the latter being only those impervious areas that provide a direct pathway for water to enter sewers and streams, thus bypassing the potential for infiltration. In areas that are not close to 100% impermeable, the difference between the two types of impervious areas can be significant, and this difference in surface area can be equivalent to the amount of recharge contribution from that of a pervious surface of the same size (Zandbergen, Houston and Schreier, 1999). Thus by excluding all impervious areas from potential infiltration recharge, it is likely that recharge will be underestimated since not all the precipitation that falls on this surface is lost to the atmosphere and surface runoff.

Assumption 4

Assumption 4 is a simplification of the ET loss process, in that instead of allowing for a slowing down of ET loss prior to reaching the maximum SMD, the ET loss is assumed to be linear up to the point of maximum SMD before abruptly ending. The effect of this is potentially to underestimate recharge since there is no slowing-down of ET losses, but the extent of rate reduction past a certain point of SMD is still a controversial issue. Alley, (1984) investigated the difference that would result between a linear approach versus a 'layered' approach, whereby the top soil layer has a different WHC than the lower soil layer, and his study showed that separating soil-moisture thresholds doesn't necessarily yield a statistically significant improvement over typical linear models. This suggests that the additional complexity of allowing for a non-linear change in ET loss does not necessarily improve the model, and since there is still no consensus regarding the drying curve for a vegetated soil, it would seem impractical to purposely fit one into the Aldergrove soil-water balance.

Assumption 5

Assumption 5 refers to the need for the soil to be fully saturated before recharge is expected to occur, herein termed saturation-excess recharge. This implies that at certain times of the year when the soil is never fully saturated, recharge will never occur, so in effect, recharge is limited just to winter months. It is clear why taking a saturation 'cut-off point' is preferable when modeling recharge as it gives a simple and clearly defined definition of when recharge can be expected, however, there is reason to question the validity of this assumption. Early analysis of the limitations of a soil-water budget model by Rushton and Ward, (1979) suggested a tendency for recharge to be underestimated due to assumptions like saturation-excess recharge and the masking of short periods of recharge when input parameters are averaged monthly or seasonally. For the soil-water budget modeled here, precipitation events were considered daily, so the method is still able to account for the 'one-off' recharge event, however, the seasonally average ET may be subject to the same errors of averaging. In the study by Rushton and Ward, (1979), a number of soil-water budget modifications were investigated which allowed recharge to occur despite a soil moisture deficit. The various scenarios they experimented with lead them to the conclusion that a conventional soil-water method was 'unacceptable' since it was inaccurate enough to result in a predicted recharge that was less than known outflows for their study aquifer in UK. There is no evidence to suggest that the same severe problem exists for the analysis with the Aldergrove aquifer, yet it is clear that there are limits to assuming saturation-excess recharge since the soil is not homogenous. With the presence of preferential flow paths (macropores) created by burrowing insects and worms, and the spaces left by decayed roots, a typical soil horizon usually has an abundant network of pathways by which water can rapidly descend, without needing the whole soil unit to be saturated. For this reason, a soil-water model should ideally be able to account for some recharge via this type of direct throughflow, but in order to account for this, a significant amount of additional experimental work needs to be done on each soil category in order to determine the best throughflow function to apply, and even then, the enormous variability within a soil category inevitably limits the accuracy of the derived function. Thus it is arguable that the benefits of increased thoroughness does not outweigh the 'costs' of time and effort for the purposes of this study, which is simply to estimate an annual recharge. Nevertheless, it is important to highlight this limitation to the study, and imply the potential recharge underestimation that this limitation causes.

Assumption 6

The soil-water balance used to calculate recharge stated that any water 'banked' as recharge cannot be depleted again when the SMD is at maximum, with the reasoning that water infiltrated past the arbitrary WHC 'cut-off' point (50 cm depth was used) is too far below the surface for plants or capillary rise to bring up the water again. For the confined parts of the aquifer, it is reasonable to assume this since it is unlikely that a significant amount of water already within the aquifer can migrate through the overlying aquitard. However, for the unconfined parts of the aquifer, upward re-migration of aquifer water to the surface could potentially occur if the water table is sufficiently close to the surface. Thus the model may overestimate recharge if there are sufficiently large areas of the aquifer with shallow water tables. The effect of allowing for re-migration of water up to the surface can be tested by removing the 'banking' function of the soil-water model, which will then lead to recharge being determined as the sum of the cumulated water after one annual cycle. In this cumulative method, water that is in the 'store' can be removed as ET loss on a daily basis, as there is no cap on the amount of water that can be drawn out again provided there were sufficient number of days without precipitation to cause excessive SMD beyond the maximum limit.

To test whether the difference between the 'cumulative' and the 'banking' method is great enough to cause concern, the soil-water budget model was re-formulated so that the WHC only had a minimum limit. The banking component was removed and daily recharge accumulation can be lost again whenever the SMD is at maximum. The summer period was excluded from the analysis to prevent all the cumulative recharge from being lost again in the summer season (which originally makes up the last quarter of the 'banking' annual recharge cycle), since allowing all the recharge to evapotranspire away in the summer dry season is not representative of real conditions either. When this modified approach was applied to all the ET sources, it was found that all the cumulatively-derived recharge was between 92% to 102% of the banking-derived recharge. From this we see that recharge did indeed change when the 'cumulative' method was used, compared to the 'banking' method, but the difference is not really significant in the sense that it completely alters recharge estimates. In actual fact, recharge estimates remain largely in the same range as previously deduced by this soil-water budget method, and this difference is even less significant when the full range of recharge estimates derived from various methods are compared (see section 2.3), making this limitation of the banking method inconsequential to recharge estimation. It must also be noted that the same type of limitations would have resulted if the cumulative method had been used for the whole aquifer, due to its reduced applicability for the confined regions of the aquifer, and to effectively use separate soil-water models for confined versus unconfined parts of the aquifer would require a superior knowledge of this dynamic water table, something that is currently not yet available.

<u>Assumption 7</u>

Assumption 7 states that it is possible to separate runoff from the interactive (Part I) part of the calculation, because it will not make any difference to the outcome. Since runoff losses are determined from stream flow, it is assumed that any interaction of the potential runoff water with the other loss/storage parameters have already been accounted for prior to stream entry, thus accordingly, it would be valid to just deduct the runoff loss as a bulk volume at the end of the calculation. This does not say anything about the inherent accuracy of the runoff volume itself, due to assumptions in the transformation of the streamflow data to runoff losses over the aquifer.

Assumption 8

Assumption 8 is perhaps the most controversial, as it is near impossible for a natural aquifer to have absolutely no connection to surface water bodies or other subsurface permeable units. For this study aquifer in particular, the report by Golder has already stated that flow from the surrounding geological units comprise the majority of recharge to the aquifer (Golder, 2005). It can be argued that the way in which annual recharge was derived using this method allows for some consideration of inter-geological unit transfer because recharge water has to pass through the overlying aquitard in order to reach the aquifer, and this can be simultaneously considered as inter-unit transfer as well as direct surface-infiltration recharge. Be that as it may, the soil-water budget method in its original form was made primarily for calculating water availability at the surface, i.e. for plant irrigation scheduling, and thus was never meant to incorporate below-soil geology into consideration. Indeed, the conventional soil-water method fathered by Penman and Grindley was primarily concerned with determining actual ET and soil-moisture deficit rather than attempting to balance water for recharge purposes (Rushton and Ward, 1979), making this method seem like a by-product of an agriculturally driven water cycle. Regardless of this limitation, it is still considered useful to get a recharge estimate via this method as it allows for analysis of how surface conditions affect recharge, which can supplement other hydro-geological recharge methods that would otherwise lack the detailed surface picture.

Assumption 9

Assumption 9 is another major gap in the recharge calculation, especially since the majority of land use above the aquifer is agriculture. The addition of irrigation water to fields during the summer can not only throw off Part I of the calculation via changing soil moisture deficit and subsequently ET levels, but also has the potential to contribute to runoff losses into streams, thereby impacting the final volume of stream flow used for runoff estimates, even though this is likely to be very rare. Overall, this double impact is likely to cause an overestimate of recharge to the aquifer, unless the water used for agriculture does not originate from wells tapping into the same aquifer, meaning that additional water is being supplied to the surface from an alternative source, thus potentially supplementing natural aquifer recharge. This unknown situation is undesirable, but is not easy to solve. The volume of water used for agricultural operations is something that many farmers are reluctant to disclose or simply do not know. For this reason, it is often difficult and inaccurate to try to estimate this parameter, meaning that there is no certainty of getting a better recharge result should attempts be made to quantify this irrigation component. Instead, it is hoped that irrigation is scheduled efficiently enough so that the net increase in water input is balanced more or less by the net increase in water loss via evapotranspiration of the crops, thus reducing the impact this component has on the recharge calculation.

2.1.5 Summary of the Soil-Water Budget Method

No models are perfect, and the soil-water budget method is certainly not an exception. It is a method that requires a large amount of comprehensive data for many different types of parameters in order to be precise, but as with all real world situations, this can rarely be met. The actual soil-water budget method used for this analysis is particularly simplistic compared to other studies, which have used this method not only for recharge estimation but also for estimation of runoff and things like soil-moisture accounting for agricultural purposes. However, since the aim of this analysis is to obtain a result for annual groundwater recharge, it is less critical to account for all the heterogeneity, non-linearity and daily fluctuations that occur with each measurement variable, since these are unlike to make much difference to the annual outcome. Alley, (1984) found this to be the case when comparing several variations of the soil-water budget method for simulating runoff to streams. Thus in spite of numerous limitations brought on by data availability, this model is capable of being optimized to make the best use of what is available, and the results generated were well within the limits of the accuracy range needed for this type of analysis.

The soil-water budget method demonstrates how a large number of variables all act in concert to determine the available water for recharge, illustrating how complex the system is. Analyzing the individual parameters that influence recharge has given more insight into the intrinsic properties that have a higher weighting in the calculations and are thus more important to consider when trying to optimize the model. These in turn reflect their order of importance to this aquifer, allowing a better understanding of how individual parameters affect the aquifer. Thus even if the reliability of the actual recharge values generated may be questionable, the additional understanding gained from the relationships between input parameters makes the analysis worthwhile. With this site specific information, predictions can be made for recharge in the coming years, and ideas and plans can start to be formulated for ways to manipulate certain parameters in order to achieve the desired future for this aquifer.

2.2 Flownet Method

2.2.1 Theory

Another way to estimate recharge to an aquifer is to calculate discharge using flow nets and hydraulic heads. For a simple aquifer system that is bound on all sides and the base by an impermeable boundary, any discharge out of this system must have originated from recharge directly above the system (Beckie. *pers. comm.*, 2006). Total recharge to the system can be inferred from calculating total discharge out of the system, assuming steady state conditions.

Calculating discharge Q requires knowledge of the Darcy's Law parameters, i.e. area A, hydraulic conductivity K, hydraulic heads h and the distance between heads l.

Darcy's Law:

$$Q(m^3/s) = A \times K \times \left(\frac{dh}{dl}\right) \times 1$$

This equation basically says that the volumetric flow of groundwater is dependent on the hydraulic head gradient, the cross-sectional area through which flow occurs, and the permeability of the material (Ward and Trimble, 2004). This is for an assumed uniform saturated thickness of 1 m. For an aquifer which has water level elevation data measured at specific points on the aquifer, flow nets can be drawn in order to visualize the flow vectors across the whole aquifer for a given time span.

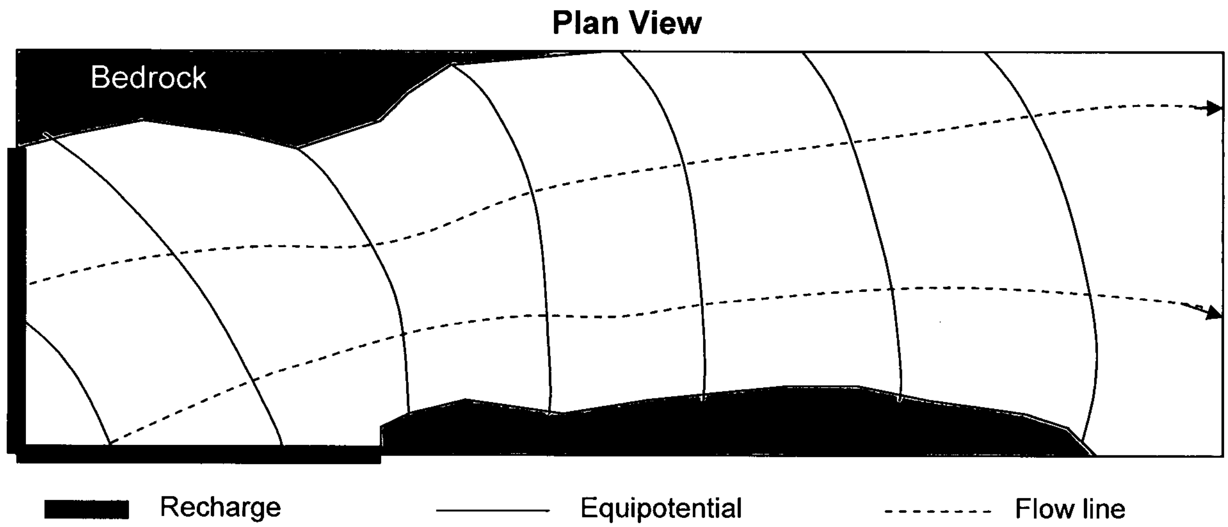


Figure 2.5 Example of a flow net system. Recharge occurs from the left and water flows from left to right.

Flow nets are composed of lines of equal potential (hydraulic head contours) intersected by lines of flow, as shown in Figure 2.5. Water traveling between two flow lines are part of the same streamtube. Provided that the flow nets are drawn correctly, then each square within the same streamtube has the same change in discharge.

For one streamtube:

$$dQ = K \times \left(\frac{dh}{dl} \right) \times dm \times depth$$

In an idealized streamtube, $dl = dm$ (as the distance between streamtubes and the distance between equipotentials should be the same), thus:

$$dQ = K \times dh \times depth$$

By calculating the discharge for one streamtube and multiplying by the number of streamtubes that crosses the aquifer area, these flow nets can effectively be used to provide a crude estimate of the discharge for the aquifer.

2.2.2 Methodology

For the Aldergrove aquifer, attempts were made to estimate discharge (and hence recharge) by constructing flow nets for several years where data was available. Water level data was available from 1972 to 1979 from the Ministry of Water, Land and Air Protection groundwater website, now known as the Ministry of Environment (MWLAP, 2005). These were entered into GIS and split into winter and summer periods. A winter period contains records from October – March, while the summer period contains records from April – September.

Recharge was determined using the following method:

1. ArcGIS was used to create contours of hydraulic heads using the Spline interpolation method, chosen because it ensures continuity of elevation, which is considered more suitable for water level mapping. This produced the lines of equipotential for the aquifer.
2. Flow lines were manually created based on the equipotential maps.
3. The change in head for one streamtube was multiplied by the hydraulic conductivity. An average value for hydraulic conductivity (estimated by Piteau, 2004) and the mean thickness of the aquifer was used.
4. The change in discharge calculated for one streamtube was multiplied by the number of streamtubes crossing the aquifer to give the total discharge, which was then multiplied by an averaged thickness to give the volumetric discharge across the aquifer.

Boundary Conditions

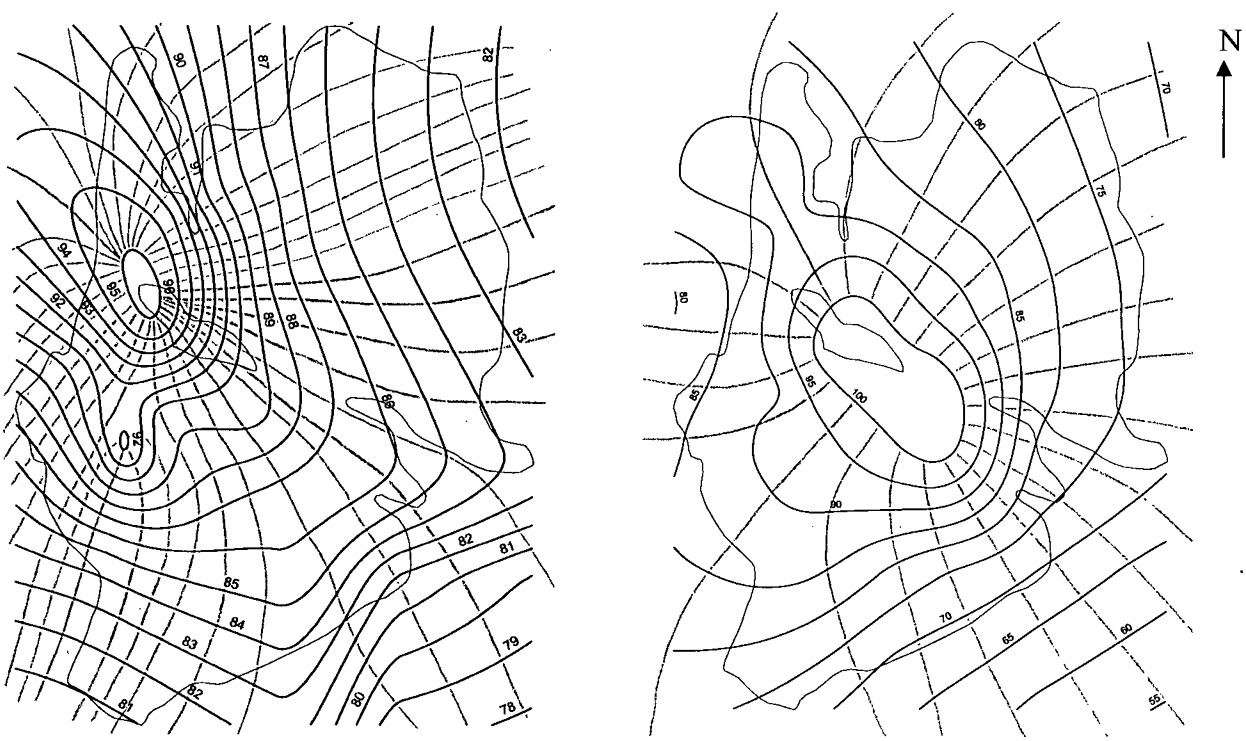
Conceptually, in order for discharge out of the aquifer to be equal to recharge from above, there must be no water flowing between the aquifer boundaries, i.e. the aquifer boundary must be effectively impermeable, either as a zone of groundwater divide, or a significant break in the permeability of the substrates, such as a clear transition from sand to clay.

For the Aldergrove aquifer, the boundary conditions were validated by analyzing the geological records for all wells located within 500 m of the perceived aquifer boundary. From the data provided by these logs, of which there were 119 wells; 74 showed sufficient evidence to suggest that there was either an absence of any aquifers, or that the aquifer being tapped is not part of the Aldergrove aquifer; 27 were right along the edge of the Aldergrove boundary and can be considered as transition points between inside the aquifer and outside the aquifer; and 18 were either unknown due to a lack of geological record, or uncertain as to the boundary of the aquifer. Since a large number of wells immediately outside the aquifer boundary can be shown to be unconnected to the aquifer, and also due to the fact that the horizontal extent of the aquifer is approximately 50 times that of the vertical extent of the aquifer, flow that does occur between the boundary can be considered insignificant and insufficient to affect the calculated discharge results.

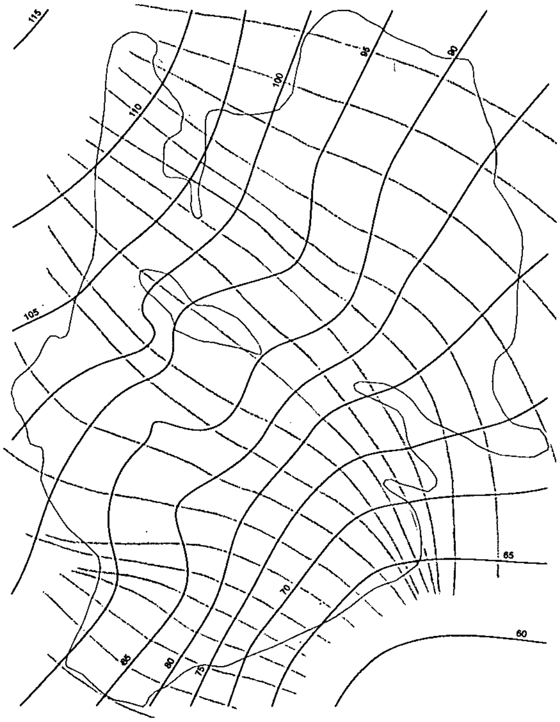
2.2.3 Results

Final Recharge Value

A total of 7 sets of water level contour maps were generated using the well data available. These are shown in Figure 2.6(a-g). These 7 maps are comprised of wells from the summer of '73 and '77 and the winter of '72, '74, '76, '77, and '79 (See Appendix II – Table 2.C).



(a) (b)


115
110
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100
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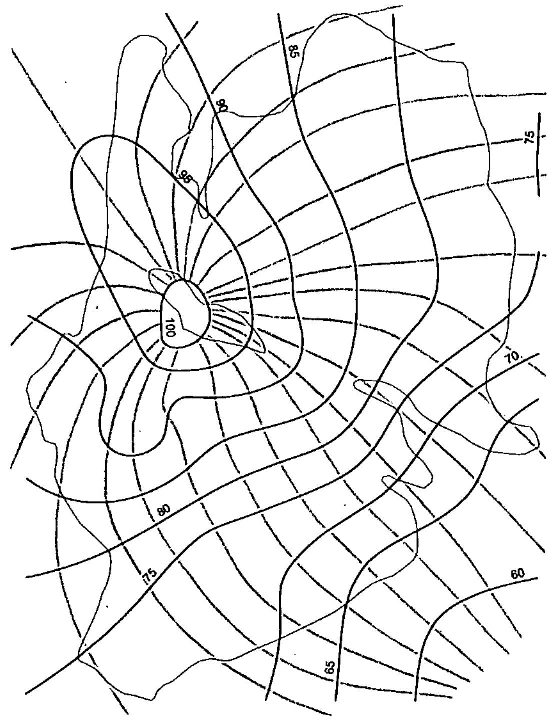
60

(c)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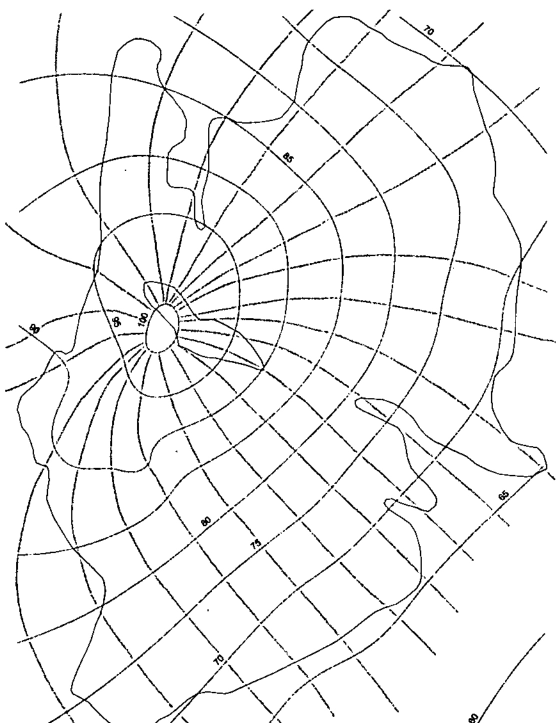
(d)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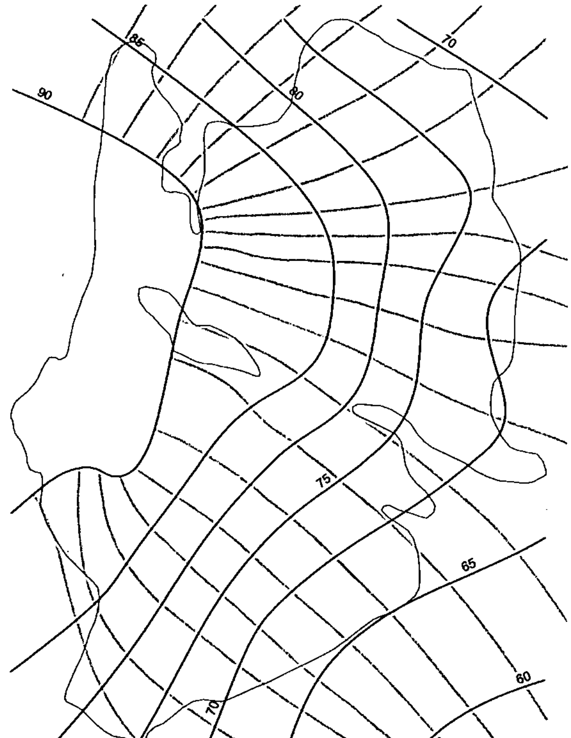
(d)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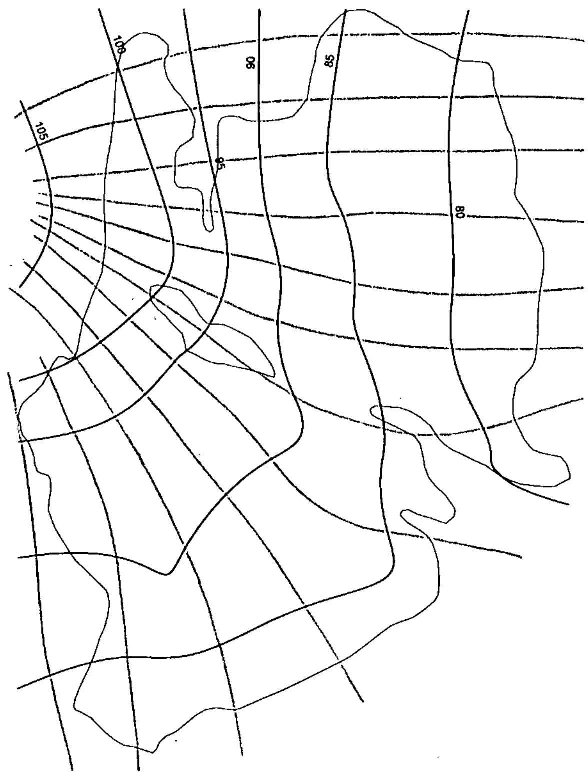
(f)



(g)

Figure 2.6 Maps of flownets drawn based on interpolated water level results for each biannual period (a) winter '72; (b) summer '73; (c) winter '74; (d) winter '76; (e) summer '77; (f) winter '77; (g) winter '79. The numbers on the maps represents height above datum for equipotentials.

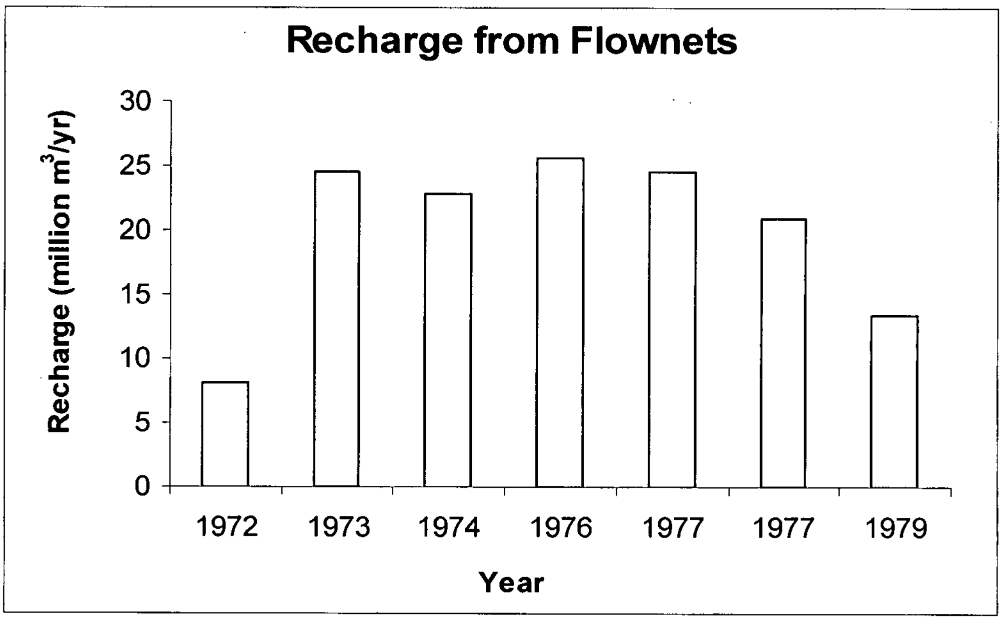


Figure 2.7 Summary of recharge values from each flownet analysis.

The results on Figure 2.7 show that recharge estimates range from 8.2 million m^3/yr to 25.7 million m^3/yr, a difference of more than a factor of 3 between estimates. However, out of the 7 estimates generated, 5 had recharge values greater than 20 million m^3/yr, which suggests that the actual recharge may be more towards the upper end of the range.

Patterns of Recharge

The water level contour maps generated in GIS showed several variations in zones of recharge as well as changes in water levels over the aquifer (Table 2.6).

Table 2.6 Summary of flownet recharge and water level patterns.

Period	Recharge Zone	Max. WL (m)	Min. WL (m)	WL Difference (m)
Winter '72	Mid-North West	96	81	15
Summer '73	Centre	100	70	30
Winter '74	North West	110	65	45
Winter '76	Mid-West	100	65	35
Summer '77	Mid-West	100	65	35
Winter '77	West	90	65	25
Winter '79	North West	107	75	32

Starting from the earliest record taken in winter '72 (Figure 2.6a), recharge appears to centre at the north western edge of the aquifer where the highest water levels were found, fanning out towards the east and southern parts, which had water levels down to 15 m lower than the recharge zone.

Figure 2.6b shows the flownet from the summer period (summer '73) immediately after the winter '72, where the recharge zone appears to have migrated and broadened around the centre of the aquifer. Water levels at the recharge area are higher than that for winter '72, but the gradient is also greater, with a minimum water level around 30 m lower than the maximum water level at the recharge zone.

Figure 2.6c shows the flow situation more than 1 year after the previous period, where recharge now seems to be occurring from the north westernmost tip of the aquifer edge. The height of water in the aquifer here seems to be greater than the previous period, but again, there is a bigger gradient also, with the water level difference now as big as 45 m between one part of the aquifer to the next.

Figure 2.6d shows the flownet 2 years after the preceding period, where the recharge has re-migrated back towards the mid-western part of the aquifer and the maximum height of water has dropped back down, though the minimum water level has not changed.

Following from the previous winter, the summer '77 (Figure 2.6e) shows that there has been no change in the recharge location or the heights of water levels, although contours are slightly smoother.

The winter period immediately following the summer '77 (Figure 2.6f) creates a rather big change in the flownet, with recharge suddenly expanded to encompass the whole western part of the aquifer. The height of recharge has dropped by 10 m from the average of half a year ago, but the gradient of water level change has also reduced since the minimum level has remained the same for the past 3 years.

The final period mapped (winter '79) shown in Figure 2.6g occurs 2 years after the previous period and the recharge zone does not appear to have changed much, still originating from the west to north west region. Water levels however, appears to have improved as both the maximum and minimum has increased, even though the difference between the levels remains quite large.

2.2.4 Discussion

Comparison of Water Levels between Flownets

The patterns from the flownets created gives a sense of the way flow generally occurs within the aquifer, and there appears to be some consistency in the general location of recharge, even though there have been noticeable shifts and changes in the recharge location and size during the 8 year span in the 1970s. A more detailed discussion of flow can be found in *Chapter 3*. This part of the discussion will focus more on how the water level has changed, and what this implies for recharge.

Throughout the study period, the height of water at the recharge point has stayed between 90-110 m above datum, while the discharge levels varied between 65-81 m above datum. Considering the size of the aquifer and the time span involved, this regional variability in water levels is very large, since the data suggests that this aquifer's water level regularly fluctuates by up to ±10 m between consecutive biannual periods. It is normal for shallow aquifers to have a seasonal and even monthly fluctuation in water levels, due to the strong influence of surface climatic conditions such as evapotranspiration and precipitation. In addition, the seasonal changes in consumption withdrawal from the aquifer and other discharge mechanisms also influence the net movement of the water level. However, it is difficult to justify such a large fluctuation in spite of these processes occurring, as typical annual water table fluctuations tend to be within ±2 m. Even the biannual variability of water levels in the municipal pumping wells does not show such high differences. Instead, the most likely explanation can be found in the limitations of the analysis, particularly with respect to the lack of continuous measurements from the same well. Even though attempts were made to minimize discrepancies by interpolating data from as short a timespan as possible, the lack of well data for identical time frames plus the irregular spatial representation made it impossible to ensure the accuracy of the resultant surface maps. Consequently, there was also little that could be done to minimize discrepancies when comparing interpolated surfaces for different years created from different wells. Since interpolation is already a method that averages the water levels between data points, the error within an interpolated surface coupled with the error between interpolated surfaces may be sufficiently large to generate a big difference between water levels for similar regions of the aquifer.

It is also interesting to note that the aquifer water levels differ by 15-45 m from the 'recharge' location to the 'discharge' location. Water levels are always lowest at the eastern part of the aquifer, where most of the aquifer is unconfined. Conversely, the western part of the aquifer is mostly confined, which supports the idea of flow from west to east, but does not explain why recharge comes from that part of the aquifer. It could be that instead of the western part having more recharge, the eastern part may be losing water faster due to greater withdrawal or natural discharge, thus maintaining a west-to-east gradient of flow as opposed to additional recharge occurring exclusively at the western end. This would imply that the eastern part of the aquifer is more vulnerable to water depletion, but unfortunately, the lack of data from the Abbotsford side means that it is currently not possible to verify this theory.

Comparison of Recharge

The recharge values shown in Figure 2.7 gives some idea of the volume of water entering the aquifer if each biannual period can be assumed representative of recharge conditions for that year. Values were originally determined in m^3 per day, so it is possible that scaling up to one year can exaggerate errors. However, the fact the all the values were well within a one order of magnitude difference is already a good sign that the results are not too implausible. The tendency for the recharge value to be greater than 20 million m^3/yr also compares favourably against the value determined by the Golder report, which quoted recharge in 2004 to be 23.4 million m^3/yr (Golder, 2005). This result suggests that recharge to the aquifer has not changed much in the past few decades, probably because climatic factors have remained relatively constant for just as long. The significantly lower recharge calculated for the winter '72 is somewhat an outlier compared to the subsequent values, but there are many possible explanations for this, most of which can be addressed as limitations of the input data and flownet method. The last two recharge values (winter '77 and winter '79) also suggest the beginnings of a trend towards less recharge, but chances are that this is part of the periodic water level fluctuation within the aquifer and so is not actually a real tendency towards less recharge. Unfortunately, the fact that only well data for the 1970s could be used to generate the flow nets means that there is no certainty of what recharge was like from 1980 onwards, nor can these estimates of recharge be sufficient for estimating current situations, as recharge volumes are likely to have changed over 30 years. Nevertheless, these historical flow nets can provide some insight into the way recharge occurred in the past.

Limitations and Assumptions

A number of crucial points underpin the reliability of the results obtained from this flownet analysis. The following is a summary of all the major contributing factors:

- Water level data exists only at the time of construction for each well, thus there are no consecutive water levels for the same location, and it is not possible to create an equipotential surface for timespans shorter than 5 months, as there are an insufficient number of wells constructed within this shorter time frame.
- Due to a combination of insufficient spatial distribution (whereby wells are too concentrated in just one location of the aquifer) and lack of records for wells completed within short time frames (less than 5 months), not all the available data could be used to create flow nets.
- Data prior to 1970 are not used due to suspicions that the true dates of well construction are not known (since the vast majority are dated only on January for each year prior to 1970).
- The use of flow nets to calculate discharge requires many simplifications to the aquifer, including assumptions of uniform saturated thickness and hydraulic conductivity, effectively impermeable boundaries (i.e. no flow into or out of the aquifer from the surrounding geology except for that which is directly above the aquifer), no areas of local absence within the greater aquifer bounding area and that the aquifer is in a steady state.
- Discharge values derived from flownets are highly dependent on the number of streamtubes that are constructed. This component of the analysis is highly subjective as it is very difficult to draw 'ideal' flow nets for a real system. Thus the discharge estimates from this method are subject to a lot of variability and error, and can only be used to provide a rough guess.
- For flownets to properly represent regional groundwater flow, the aquifer should ideally be in a natural state and not influenced by pumping (Scanlon, Healy and Cook, 2002), but it is known that this aquifer is extensively tapped for water supply, which will likely cause a biased mapping of the groundwater levels based around areas of strong extraction influence.

- The aquifer is not completely confined, such that the actual thickness of the aquifer is not equal to the saturated thickness of the aquifer. Since the mean thickness used in the discharge calculation is based on aquifer thickness, there is likely to be an overestimation of the saturated thickness of the aquifer.

2.2.5 Summary of Flownet Method

The flownet method provides a relatively simple and easy to derive estimate of recharge that is based more on the real conditions within the aquifer as opposed to theoretical input versus output methods. Relying mostly just on water level data, it eliminates the need for factoring many parameters into the calculation, and therefore is less vulnerable to the errors of multiple parameters. However, the results derived from this method is strongly dependent on the extensiveness and reliability of the water level records which, aside from the need for a good coverage over the aquifer in order to get dependable results, is also susceptible to misinterpreting local anomalies as regional patterns, thereby giving misleading conclusions. These two limiting aspects of this method are probably the reason why the use of this method has declined in favour of other, more comprehensive groundwater level-based recharge methods. A summary of groundwater level-based methods for determining recharge is discussed by Healy and Cook, (2002). Nonetheless, this type of method has a number of additional benefits beyond this particular application.

Aside from being a useful rough estimate of recharge, creating flownets can allow comparison of areas with greater hydraulic pressure (head) and hence water flow direction changes between years. The maps of water level also serve additional purposes, much of which is addressed in *Chapter 3*. For this reason, obtaining as much water level data as possible from wells over an aquifer is a fundamental component for assessing conditions within an aquifer.

2.3 Recharge Comparisons

2.3.1 Overview of Recharge Results

In the past, there have been two other studies completed on the recharge of this aquifer. One is the 2005 study by Golder Associates Ltd., and the other is a 1991 assessment of the aquifer by Piteau Associates Ltd. This section will attempt to compare the results derived from their methods against those that were derived using the soil-water budget and the flownet method. A summary of the recharge values is shown in Table 2.7.

Table 2.7 Summary of recharge values derived by different sources and methods.

Years Observed	Method Used	Recharge range (millions m^3/yr)	Source
2003 – 2005	Soil-water budget	12 – 31	This study
2004	ModFlow	24	Golder
1991	n/a	6	Piteau
1972 – 1979	Flownets	8 – 25	This study

Table 2.7 shows the span of recharge values obtained during the years that recharge was measured using different methods. Starting from 1972 up to 2005, recharge has seemingly fluctuated from a low of 6 million m^3/yr to a high of 31 million m^3/yr. This is apparently not uncommon. It has been suggested that a range of recharge within one order of magnitude is acceptable for groundwater, as a result of all the difficulties associated with determining this value (Beckie. *pers. comm.*, 2006). In real life, it is highly unlikely that recharge to the aquifer can fluctuate this much between years, particularly with the factor of 2+ difference experienced by the soil-water budget method between consecutive years (see Section 2.1.3.4). Even for a time span of 30+ years, there must have been extreme changes to climate and land use in order to cause a 5-fold increase in recharge. For this reason, it is largely without doubt that the bulk of the variation in recharge observed is due to the discrepancies and deficiencies between recharge calculation methods. The question then becomes, which method is more accurate at describing the recharge to this aquifer? At minimum, to correctly compare between methods, data from the same year should be analyzed. The table shows that except for a one year overlap between the

soil-water budget and Golder methods, all the other methods calculated recharge for different years. This makes it very difficult to compare methods without acknowledging the uncertainty in the conclusion brought on by the annual variability of nearly all recharge-affecting parameters.

2.3.2 Comparison of the Soil-Water Budget to the Golder Recharge

The Golder report published values for recharge in the Aldergrove aquifer in 2003. Their values were divided into 'surface' recharge and 'subsurface' recharge. The report stated that recharge was derived from precipitation, ET and storm runoff. The surface component consists of river/stream flow and precipitation, while the subsurface recharge component is made up of flow from surrounding aquitards and other permeable units, such as the Aldergrove C and D aquifers. These estimates were obtained via meteorological interpretations and with the use of the groundwater flow model *ModFlow*. A summary of their result is shown in Table 2.8.

Table 2.8 Summary of Golder recharge results.

Recharge Source	m^3/day	m^3/year
Surface	2,300	839,500
Subsurface	64,200	23,433,000
Total	66,500	24,272,500

If only the surface component of the Golder result was considered to be equivalent to the soil-water budget result, then we can see that there is a huge difference between the two results, as Golder determined surface recharge to be less than 1 million m^3, while the soil-water budget estimated recharge to be at least 12 million m^3. However, if the soil-water budget calculation encompasses some components relevant to subsurface recharge, such as recharge coming from the overlying aquitard, then we find that the Golder result is very similar to the range of recharge determined by the 2004-2005 soil-water budget. Since the bulk of the subsurface recharge reported by Golder originates from surrounding aquitards, it would seem that the results between the two methods correspond quite well, even though both methods account for and neglect different aspects of recharge.

The soil-water budget method is likely to provide more accurate estimates of how different surface parameters affect recharge, but cannot account for flow originating from areas outside of the aquifer boundaries. Conversely, the Golder method is better able to model subsurface recharge from other permeable units, though it is less precise with surface recharge parameters. Despite this difference, the similarity of the results suggests that neither method is overly deficient in the surface/subsurface aspect, as these two aspects are so intricately interlinked that an effect occurring with one ultimately affects the other as well. In this way, it would appear that neither method of determining recharge is superior to the other, though depending on what aspect of recharge is the target for better understanding, one might favour a method over the other.

2.4 Chapter Conclusion

The soil-water budget and flownet methods discussed here are just two of numerous recharge methodologies that exist in the world today. Healy and Cook, (2002); Sanford, (2002); and Scanlon, Healy and Cook, (2002) presents a range of recharge methodologies that can be applied for different aquifers, covering practically all situations under all conditions. Yet despite the enormous growth in available methods, all are still fundamentally dependent on the reliability and completeness of their respective input parameters. Models of aquifer recharge can only ever be as good as the data used to create it, and the lack of sufficient data is still the major limitation of models today. Nevertheless, current recharge methodologies have progressed a long way since their first introductions in the early 1900s, and the relative agreements between the recharge results derived from different methods highlights that depending on the application of the results, it is not always essential to have a thorough data set before useful information can be extracted from the process. The recharge methods used here have both provided not only an annual recharge quantity but also additional analysis of climatic, soil and hydrogeological processes that are undeniably relevant to a proper understanding of the recharge system for this aquifer as a whole. The information gained from the process may turn out to be more worthwhile than the actual recharge value itself, for the sustainable management of this aquifer.

Chapter 3 - Storage

3.1 Theory and Importance of Aquifer Storage

In theory, sustainable aquifer use does not require much knowledge of the aquifer's physical parameters, as it can idealistically be simplified into just the recharge and discharge components. If recharge is more than or equal to discharge, then the aquifer use is deemed sustainable as that there is no net reduction in the water content of the aquifer. However, this oversimplification has many limitations and flaws, as it neglects to account for many of the parameters that control how quickly water travels in the aquifer and how storage affects water content and availability in the aquifer. An example of this is an aquifer with a 50 year lag time between recharge and discharge. Is it certain that by matching recharge to discharge now, the sustainability of the aquifer is ensured? There is no guarantee that such an assumption will hold, since the water being withdrawn now is actually from recharge that occurred 50 years ago, and depending on the properties of the aquifer, water can be locally scarce in some parts of the aquifer and abundant in others. In addition, without knowing the capacity of the aquifer, simply matching recharge to discharge gives no indication of the water content in the aquifer, as it assumes that an aquifer with only ¼ of its capacity is just as sustainable as another aquifer with ¾ of its capacity, as long as recharge and discharge match. For this reason, determining factors associated with the storage of the aquifer is essential, as it provides an estimate of the capacity of the aquifer, its current water content status and its future ability to support water demands.

3.1.1 Components of Aquifer Storage

The term 'aquifer storage' refers to the quantity of water that can or does currently exist within the aquifer at any point in time. This should include all water within the specified boundaries of the aquifer, ranging from freely flowing water to non extractable water such as those that are trapped in 'dead-end' pore spaces as well as 'capillary' water – water that is associated with substrate surfaces. However, the focus of aquifer storage is mainly on the free-flowing (extractable) water.

Aspects of storage can be broken down into two components:

1. Actual Storage Capacity – the maximum volumetric capacity of the aquifer
2. Water Content – historical water levels and saturation within the aquifer

3.2 Methodology

3.2.1 Actual Storage Capacity

Parameters Needed to Model Aquifer Dimensions

As with all geological analysis, an understanding of the subsurface requires taking samples of the geological substrates and conducting experiments and interpretations from these samples. These borehole 'logs' provide the basis for the vast majority of geological maps available today. Given that logs cannot be obtained for every square meter of land surface mapped, information about the geology of a location between two or more logs are interpolated from the areas of known geology surrounding it. The same is done for mapping of aquifers. Aquifers are formed from the geology of the region, thus these same geologic logs can be used to give an idea of the location and bounding characteristics of subsurface water bodies.

For the Aldergrove aquifer, the boundaries of the aquifer was determined by Golder Associates in their 2005 groundwater modeling study for Langley (Golder, 2005), and this was used as the base for all the analysis involving 2-dimensional knowledge of the aquifer boundaries and extent, such as the impermeability analysis in *Chapter 2*. As with all the analysis on bounding characteristics, this aquifer boundary provided by Golder was also based on well and borehole core data.

For analysis on the 3-dimensional components of the aquifer, such as its volume and the shape of its upper and lower boundaries, additional information had to be collected. Data for the elevation of the aquifer's top and base layers were collected from well logs submitted to the Ministry of Environment (MWLAP, 2005). The Ministry keeps a web-based record of these well logs on its interactive BC Water Resources Atlas, and it was from this database that information from specific wells located above the Aldergrove aquifer were obtained. Note that this is the same data used to estimate recharge in *Chapter 2*. In total, the network of well records publicly available is extensive; however, for the purpose of determining the 3 dimensional components of the aquifer, it was necessary to obtain well logs that also recorded information on the geological stratigraphy from the logs. Unfortunately, many well logs did not record this information, especially those that were dug rather than drilled, and those from a period prior to the 1960s. Nevertheless, a total of 311 well logs covering the Aldergrove surface were found that contained information on well depths and geology sufficient to determine the aquifer top boundary. As for the aquifer's base boundary, many wells did not penetrate the aquifer sufficiently to provide details of the geology below the maximum depth of the aquifer, thus only 88 well locations could be used to model the aquifer's base.

Visualization of the 3D Aquifer

3D visualization of the aquifer geometry was done using ArcGIS (specifically ArcScene and the 3D Analyst tool), which allows surfaces to be mapped and viewed in 3-dimension, given a z-value (elevation). The elevation of the aquifer top/base (Aq_{el}) was calculated from the surface elevation (S_{el}) data from well logs, such that:

$$Aq_{el} = S_{el} - W_{depth}$$

Where W_{depth} is the depth of the well to the aquifer top/base. Since all well depths are taken at the surface elevation of that location, this basically corrects the depth of the aquifer to the surface elevation, thereby normalizing all elevations to a standardized datum. Using these elevation values, 2 dimensional map layers for surface elevation, aquifer top elevation, and aquifer base elevation were drawn, using the ArcScene default Kriging method of interpolation, which works well for irregularly spaced data. From these '3D' maps, a picture of how surface topography in the Aldergrove area varies can be visualized. The maps of aquifer top and base also gives a rough visualization of the shape of the aquifer boundaries, allowing inference of thick and thin regions in the aquifer. The volume of the aquifer could also be calculated from the volume of space between the top and base boundaries of the aquifer.

Calculating Aquifer Volume (Total Water Content Storable)

Due to certain software and data limitations, the volume of the aquifer had to be inferred from the volume of space below the aquifer top elevation, minus that below the aquifer base elevation relative to the datum. This calculated aquifer volume is the 'absolute' volume, in that it refers to the total volume of water that the aquifer could in theory contain if it was hollow. Given of course that this is not true in real aquifers, a separate calculation must be made of the volume of actual water storage available as determined by the pore spaces between aquifer substrate grains. This requires knowledge of the porosity of the aquifer substrates.

After deriving the 'hollow' volume of the aquifer from the GIS interpolation, the true volume of the aquifer was determined by the following steps:

1. Review all the well logs and making a note of the dominant aquifer substrate type for each well location.
2. Simplify records into 3 categories: gravel, sand, and a mixture of sand plus gravel.
3. Conduct a literature review of the common porosity values found for these 3 types of substrates.
4. Use the range of porosity for each substrate type to determine the maximum and minimum porosity ranges for each substrate.
5. Use GIS to create thiessen polygons around each well location to estimate boundaries between different substrate types found in each well.
6. Calculate the total area covered by each of the 3 types.
7. Use a mean thickness of the aquifer to derive the total volume of aquifer composed of each type of substrate.
8. Multiply by the max/min porosity factor for each substrate type to give the 'real' water content of the aquifer, in terms of the upper and lower bounds for porosity.

3.2.2 The Water Level and Aquifer 'Semi-confined' Status

Previous studies on Aldergrove have already indicated that the aquifer is not completely confined (Golder, 2005; Piteau, 2004; Piteau, 1997). What determines whether an aquifer is confined or not is the water level and the geology within any given point in the aquifer. If the aquifer is contained between two aquitards and the water level measured at one point in the aquifer is higher (in elevation) than the elevation of the top boundary of the aquifer, then the aquifer can be deemed confined. Conversely, if the water level drops below the top boundary of the aquifer, then the aquifer becomes unsaturated and thus is considered unconfined, even though there may be an aquitard overlying the aquifer (Hiscock, 2005). Since the properties of an aquifer can be different depending on its confining status, it is important to establish what the changes in water levels are and how this affects the aquifer's hydrogeological properties.

Modeling the Aquifer Water Levels

Using ArcScene, water levels recorded during well construction were sorted according to the year and month the record was made, and then grouped into summer and winter periods (consisting of 5-6 months, mostly between October to March for winter periods and between May to September for summer periods). From this grouping, a number of years and periods were identified (shown in Table 3.1) that contained enough water level records and were sufficiently widely spaced around the aquifer that enabled interpolations of water levels for the whole aquifer to be created.

Interpolations were made using the Spline interpolator, as it gives smoother contours of water levels and can thus help to iron out the discrepancies between months within each period. In total, 8 periods were interpolated, starting from the winter of 1972 (which basically starts in Oct '72 and ends in Mar '73) to the winter of 1979. Note that with the exception of summer 1979[1], all the other biannual periods and their associated well records used to interpolate water levels are the exact same ones used to create the flownets in *Chapter 2*. The water level surfaces created from these interpolations were also compared to the interpolation of the aquifer top in order to visualize how changes in water levels have affected the ratio of confined versus unconfined areas of the aquifer.

[1] The summer 1979 water level map was not used in the flownet analysis due to the difficulty creating and interpreting its irregular equipotentials for the purpose of recharge analysis.

Table 3.1 A summary of the time periods used to interpolate water levels and the associated number of well records available to base the interpolations on.

Year Period	# well records
Winter 72	13
Summer 73	16
Winter 74	17
Winter 76	14
Summer 77	10
Winter 77	13
Summer 79	10
Winter 79	11

Surfer Analysis of Water Content

A limitation of the ArcScene software was its inability to calculate volumes between two layers that have variations in elevation for both layers, thus an alternative surface modeling program (Surfer) had to be used. However, in order to calculate statistics between two varying surfaces, Surfer requires that both surfaces have exactly the same data point locations. For this reason, the surfaces created by ArcScene were needed in order to recreate the surfaces using arbitrary sample locations. A grid of sample points was created which covered a rectangular area of the aquifer, and by superimposing these sample points onto the 2 dimensional layers of aquifer and water level surfaces, it was possible to extract the elevations of the layers at each sample location. Adding the spatial coordinates of the sample points then gives a layer file which has elevation data for all surfaces at identical locations which can be plotted on Surfer. This allowed the surfaces to be recreated on Surfer, which then facilitated area/volume calculations to be made between layers.

The aquifer top, base and the water level surfaces were re-interpolated using Surfer's default Kriging algorithm, which is slightly different from that of the default for ArcScene as the Surfer one uses a linear semi-variogram as opposed to the spherical semi-variogram used by ArcScene. Since the surfaces generated were the rectangular extent of the aquifer and not its actual shape, the surface had to be 'masked'. This means that all the areas outside of the aquifer boundaries are excluded from the analysis, which ensures that all calculated results are actually based on the area and volume within the boundaries. Surfer was then asked to give the 3-dimensional statistics between two layers for 2 sets of surfaces: between the aquifer top and water level, and between the aquifer base and water level. The hollow volume of the aquifer was also recalculated and compared to that calculated by ArcScene to determine the discrepancy as a result of recreating the surfaces on Surfer.

3.3 Results

3.3.1 Storage Capacity

Visualizing the Aquifer in 3D

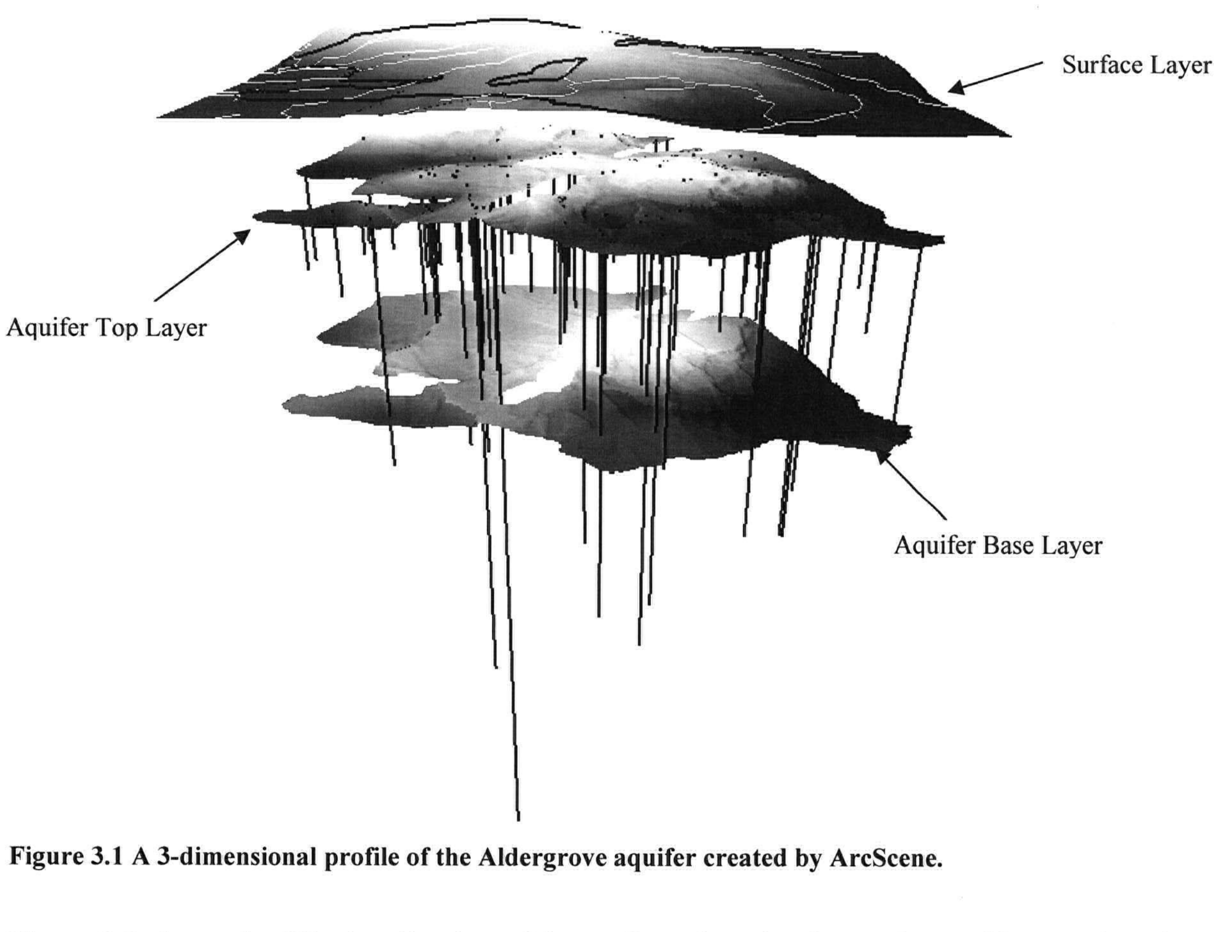


Figure 3.1 A 3-dimensional profile of the Aldergrove aquifer created by ArcScene.

Figure 3.1 shows the 3D visualization of the surface elevation layer, the aquifer top elevation layer and the aquifer base elevation layer. The black lines that puncture through the aquifer top and base layers are the wells used to generate the layers, with the length of the line corresponding to the depth of the well. This 3D visualization incorporates a vertical exaggeration of times 15 as well as an offset between the surface layer and the aquifer top layer of 100 m and between the aquifer top layer and aquifer base layer of 200 m. In reality, the aquifer is very thin relative to its (x,y) extent, with a maximum interpolated thickness of 23 metres. Overall, the aquifer is fairly flat, and its top and base elevation corresponds quite well to the surface topography for that area, though the aquifer appears to be more clinoformal, as found by (Golder, 2005).

Calculating the Storage Capacity

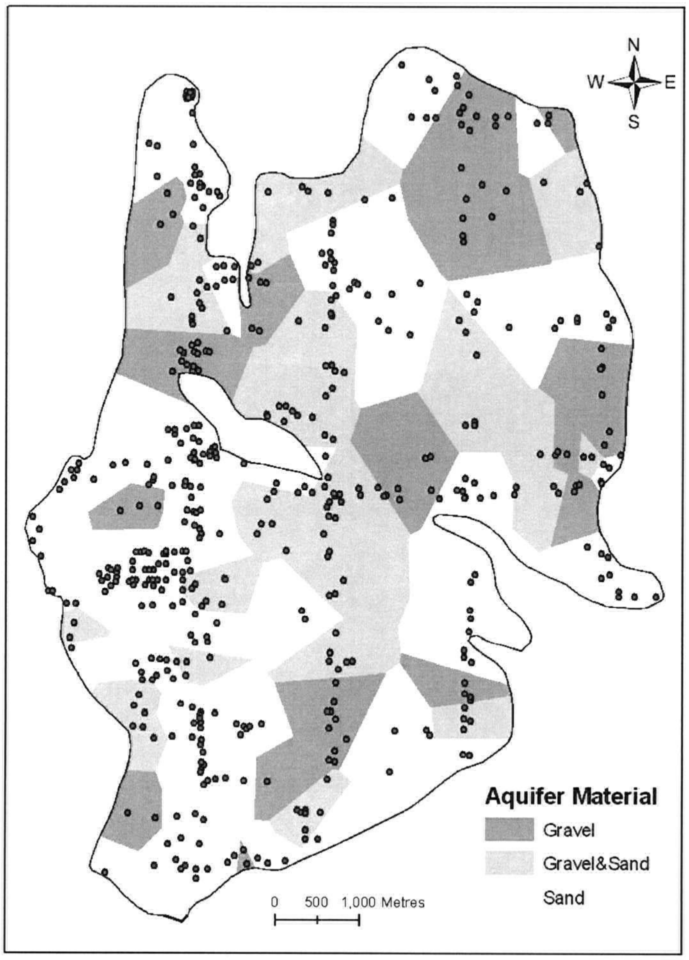


Figure 3.2 Map of aquifer substrates as deduced by thiessen polygons around wells of known substrate type

Table 3.2 Summary of substrate types, their coverage over the aquifer and the porosity ranges found in literature.

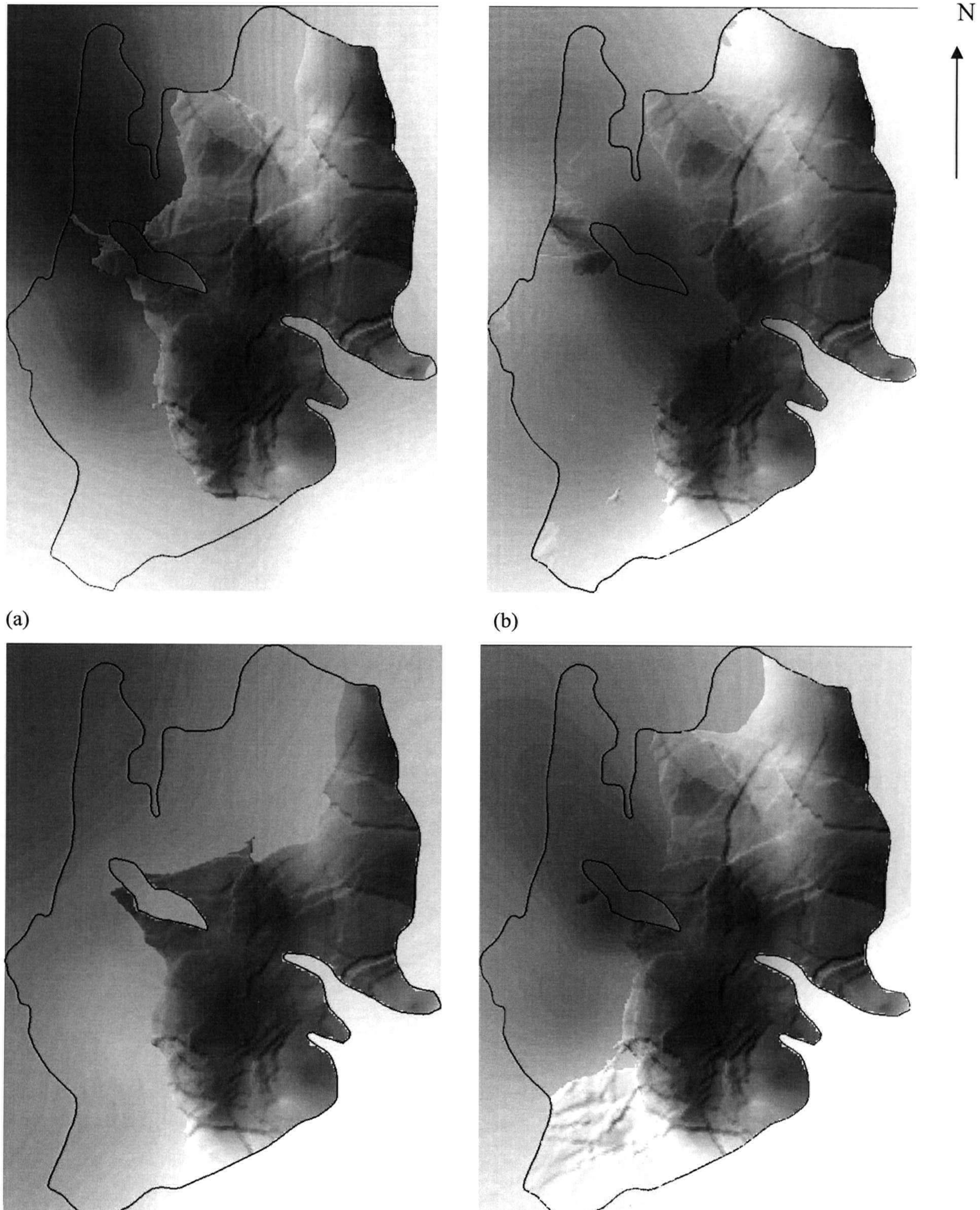
Substrate Type	% coverage	porosity range % min	porosity range % max
Gravel	16	20	40
Gravel and Sand Mix	39	15	35
Sand	45	35	53

From the polygons created to deduce the aquifer material, Figure 3.2 and Table 3.2 shows that the dominant substrate forming the aquifer is sand, followed by a mix of sand and gravel. A small but significant portion of the aquifer was comprised of gravel. The maximum and minimum porosity values found from literature (Chow, 1964; Domenico and Schwartz, 1998; Schwartz and Zhang, 2004; Walton, 1970; Weight and Sonderegger, 2001) are also shown in Table 3.2. Using the same ratio of substrate types determined by the polygons, the upper and lower boundaries of storage capacity was deduced from the total 'hollow' volume. The results show that the aquifer can store between 20% and 44% of its hollow volume equivalent of water, which amounts to a water storage capacity range of 97 million m^3 to 210 million m^3 (See Appendix Table 3.A-C).

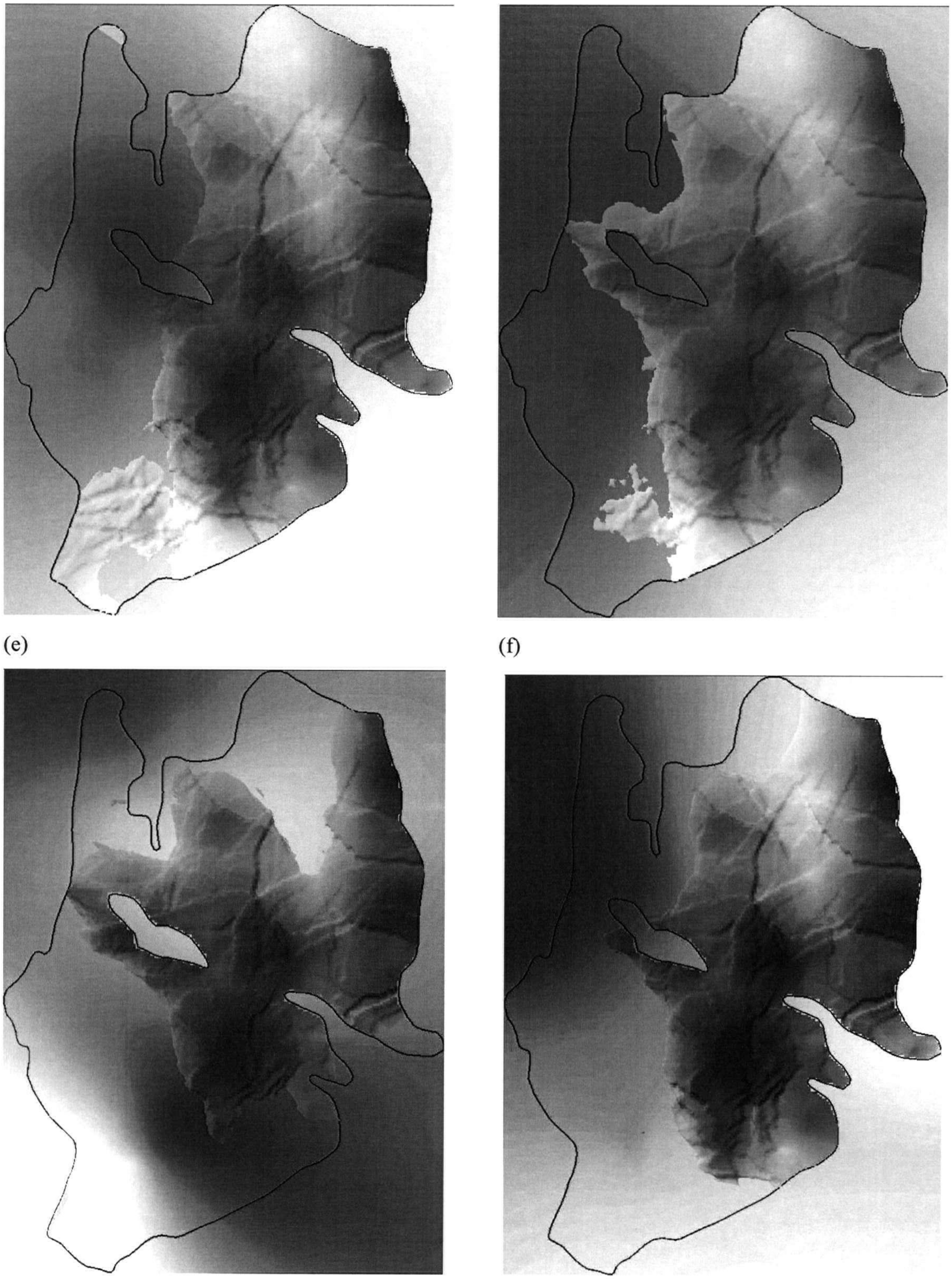
3.3.2 Water Content

Trends in Water Levels

Eight maps were produced (Figure 3.3) to show the difference between confined and unconfined areas in the aquifer. Aside from comparing changes in the aquifer's water level with time, these maps were also used to calculate the volume of water in the aquifer during those time periods.



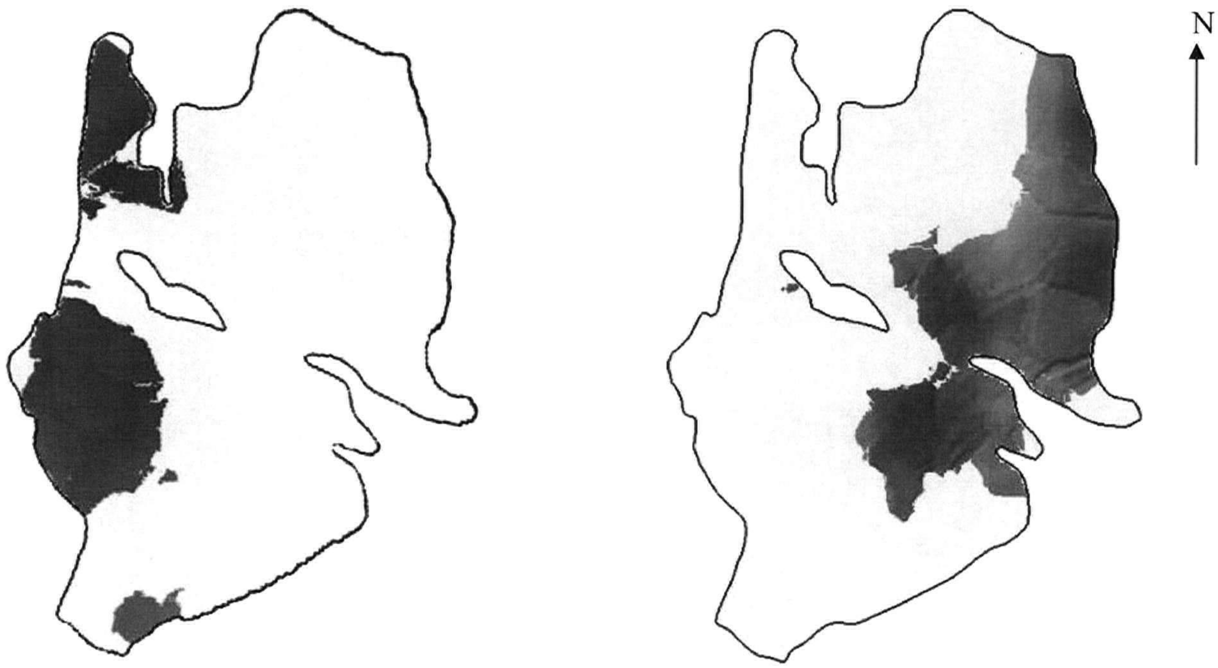
(a) (b) (c) (d)



(e) (f) (g) (h)

Figure 3.3 Water level maps showing the extent of confined versus unconfined areas within the aquifer during (a) winter '72; (b) summer '73; (c) winter '74; (d) winter '76; (e) summer '77; (f) winter '77; (g) summer '79; (h) winter '79. The smooth parts represent locations where the aquifer is confined while the rough textured areas represent the aquifer top layer where the aquifer is unconfined.

In the maps of water level versus aquifer top, there are certain areas in the aquifer where the water level is always lower than the aquifer top, suggesting that that region is permanently unconfined, namely most of the central to east region (Figure 3.4b). Similarly, most of the areas on the Langley side of the aquifer are permanently confined (Figure 3.4a), however, there are areas around the south; east to mid-north; and around the central region (where the aquifer is absent), that are intermittent in terms of their confining status. The summer period of 1979 appears to have been the time when the aquifer was most confined, while the summer and winter of 1977 was when the aquifer was most unconfined.



(a) (b)

Figure 3.4 Aquifer maps showing the permanently confined (a) and unconfined (b) areas, according to the water level maps. The darker areas represents the confined/unconfined area.

Water Content Analysis Using Surfer

Table 3.3 Summary of Surfer results.

Year Period	% aquifer saturation	% of aquifer that is confined	% of aquifer that is dry
Winter 72	56	38	28
Summer 73	57	43	30
Winter 74	58	50	29
Winter 76	46	31	40
Summer 77	44	28	47
Winter 77	40	27	49
Summer 79	71	47	8
Winter 79	56	41	33

The first analysis performed after transferring the GIS surfaces to Surfer was to check the discrepancy in the 'hollow' aquifer volume resulting from data transfer. The result showed that Surfer calculated the hollow aquifer volume to be 3.7% larger than that calculated by ArcGIS, and this is likely due to the slight differences in the kriging algorithm plus the raster grid sizes used to interpolate the surfaces, as area/volume calculations are highly dependent on the resolution of the raster grids. On the scale of the whole aquifer however, this discrepancy is not considered to be significant.

Table 3.3 shows that Surfer calculated water contents to be ranging from 40% to 71% of total aquifer volume during that period in the 1970s, with the majority of results indicating less than 60% saturation. The calculation of actual water volume seems to confirm the results of the GIS maps, with the summer of 1979 having the greatest volume while the winter of 1977 had the lowest water volume out of all the periods observed. There does not appear to be a long term trend in confining status with time, as the results show a somewhat oscillating pattern with the percentage of aquifer that is confined ranging from 27% to 50%. No major difference can be discerned between summer and winter periods, however, additional analysis of the surfaces show that in every time period mapped, there is an area where the water level is below the aquifer base elevation, and this ranges from 8% of the total area of the aquifer base layer to 49%, again corresponding with the summer of 1979 and the winter of 1977 as the respective minimum and maximum (See Appendix II – Table 3.D).

3.4 Discussion

3.4.1 Storage Capacity

Analysis of the 3D Aquifer Visualization

The 3D visualization of the aquifer is very useful in conceptualizing of the dimensions of the aquifer, giving better insight into how the aquifer behaves and allowing other inferences to be made with regards to water levels and flow directions. This model mostly supports previous analysis of the aquifer by Golder Associates and Piteau Associates, as the same basic well data was used.

The modeled dimensions of the aquifer are not untypical of what would be expected given the geology of the region. Previous literature (Golder, 2005; Ryder, 2006) has determined that the aquifer materials were laid down during the Pleistocene epoch between 2 million to 11,000 years ago, when the Lower Fraser Valley was subjected to several glaciations and interglaciations that facilitated the deposition of glaciomarine outwash sands and gravels. The reason why the aquifer is thin and absent locally within the greater aquifer boundaries is likely due to the constant reworking of the deposits during this period, resulting in erosion and thinning of the aquifer in some areas. Later, the rise in sea levels caused by the melting glaciers allowed glaciomarine silts and clays to settle, thus forming the confining unit above the aquifer.

One major flaw of the 3D visualization is depicting the boundaries of the aquifer. The visualizations show the edges of the aquifer to be just as thick as the interior, suggesting that somehow, the aquifer meets a vertical impermeable barrier at the edges. This is highly unrealistic in the absence of human interference such as construction of a vertical impermeable barrier. It is difficult to distinguish boundaries for aquifers is due to the tendency for a gradual transition from permeable to less permeable substrates (in the absence of geological faults), meaning that aquifers will get thinner towards the edges until it is no longer easy to distinguish between aquifer and non-aquifer material. As a result, the model should show a gradual 'meeting' of the aquifer top and base elevations, closing off the edges such that it is no longer possible to see the interior of the aquifer in the 3D visualization. This was not depicted in the model due to the interpolation of the surfaces. Interpolation uses known values of elevation in the nearest vicinity to estimate the surface elevation between data point locations. Because the elevations of the aquifer top and base are not known at the edge of the aquifer (due to lack of well data), the elevation of the aquifer top does not coincide with that of the aquifer base. Thus the program interpolates those areas based on the elevations of the nearest locations with data points. Thereby aquifer surfaces are created which do not properly account for edges. Nevertheless, the large horizontal size and limited thickness of the aquifer is such that this should not pose a major problem for calculations and interpretations using this 3D model.

Storage Capacity

The results in Figure 3.2 and Table 3.2 show there is uncertainty in estimating aquifer porosity. The polygon method used to estimate the spatial variability of aquifer material is originally a method meant for spatial rainfall estimation (Hiscock, 2005; Ward and Trimble, 2004), so it is likely that some of the assumptions inherent in the method are not applicable to subsurface geological variability. During the recording of aquifer substrates for the creation of polygons, it was difficult to decide which substrate dominated the composition of the aquifer at individual sites with geological information, as the aquifer often seems to consist of stratified layers of sand and gravel, which is typical of this sort mixture of glaciomarine and outwash deposit aquifer. Since the polygon method cannot take into account vertical variability, the resulting aquifer composition map is inevitably highly simplified.

In addition to the limitations with determining spatial distribution, it is very difficult to accurately determine the storage capacity of an aquifer because the porosity of different substrates within the aquifer can change radically from location to location, and the porosity values within a substrate type tends to span a large range, dependent on individual grain sizes as well as compactness of substrates. Since porosity values could not be measured directly in the aquifer, the reliance on general literature-based porosity – the large range of which reflects the uncertainties surrounding these values - makes the derived storage result questionable.

Despite accuracy issues surrounding the derivation of storage capacity, the estimates obtained allow additional inference of the state of the aquifer with respect to sustainability. The results suggest that if recharge is assumed to be 26 million m^3/yr (based on estimates derived in *Chapter 2*), then the aquifer is capable of storing up to 8 times that amount. Given that the rate of aquifer depletion is unlikely to be this large, it would seem that there is a buffer in the storage of the aquifer to accommodate unsustainable withdrawal; however this hypothetical situation is based on a number of assumptions.

Assumption 1 – Fully saturated aquifer.

Although storage capacity assumes that the aquifer can saturate to capacity, this is highly unlikely to be true. From aspects of the recharge section considered earlier, it is already known that some parts of the aquifer are unconfined, meaning that there are locations where the water level in the aquifer is below the top elevation of the aquifer, resulting in unsaturated regions within the aquifer. Even if anthropogenic discharge was negated and the aquifer was allowed to naturally replenish, it is unlikely that it will ever reach a state where the maximum capacity of the aquifer is completely saturated. This is because other factors also affect the ability of an aquifer to store water, including the geometry of the aquifer and its leakiness, as determined by the aquifer's transmissivity relative to that of the surrounding aquitards.

Assumption 2 – Accurate porosity values

The porosity literature from which the sand and gravel values were based shows a wide range of values, as porosity is highly dependent on specific site and deposit formation details, which will govern how loose or compact the sediments are. For this reason, a wide upper and lower porosity range had to be created, which makes it very difficult to accurately determine the storage capacity of the aquifer. Given this limiting input data, there will be uncertainties with the storage results.

Assumption 3 – Total porosity is equal to effective porosity

Total porosity refers to all pore spaces within a particular substrate, whereas effective porosity refers only to those pore spaces that are interconnected, such that water can flow through them. In this sense, the difference between total and effective porosity can have an impact on the storage results, as not all water is available for withdrawal. Since the calculation is an estimate of total porosity, any inference of sustainable yields and fossil water availability (water that was stored in the aquifer during the time of its formation and that cannot be replaced by natural recharge) can be overestimated if a large number of pores are not interconnected, leading to erroneous conclusions.

Assumption 4 – Uniform thickness of aquifer

Because of the difficulty with using GIS to calculate the volume between two varying surfaces, the storage capacity of the aquifer had to be determined using a uniform thickness for the whole aquifer. This has lead to discrepancies in the percentage cover of different substrate types, as sands occupying a thinner region of the aquifer will be assumed to contain the same volume as gravels occupying a thicker region with the same area size.

Assumption 5 – Fully continuous aquifer

Mapping of the aquifer done by Golder, (2005) showed that the aquifer is discontinuous, however, for simplicity, these gaps were ignored during modeling.

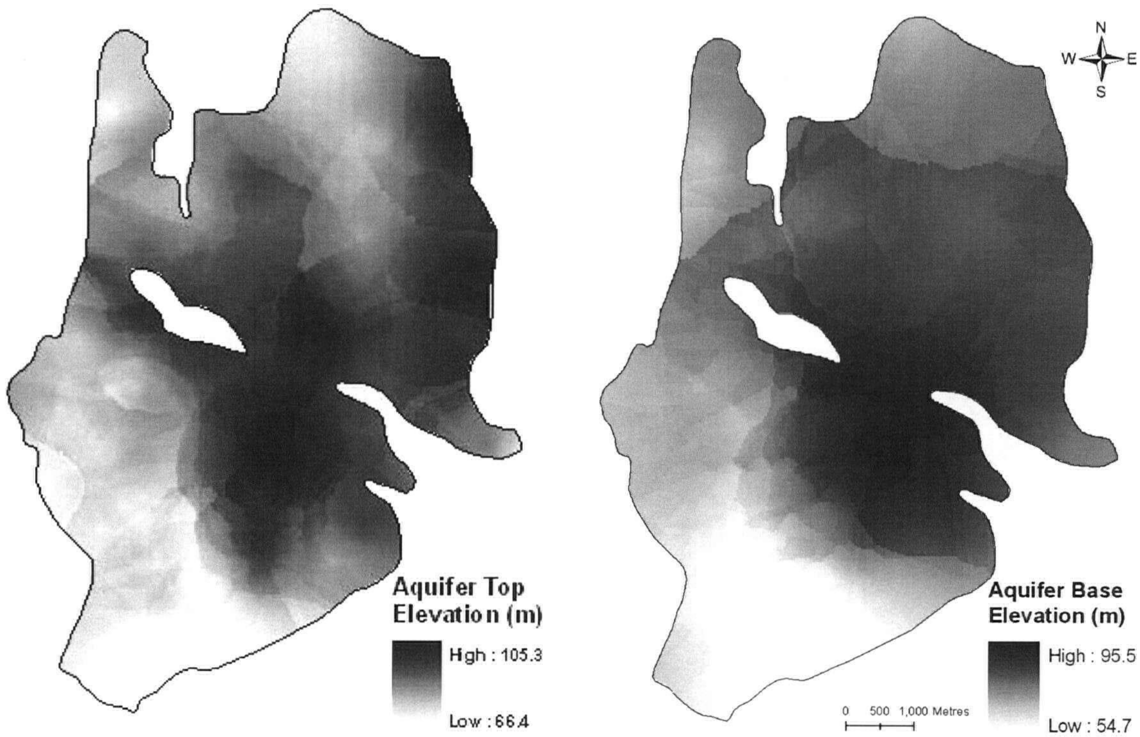
3.4.2 Water Content

Trends in Water Levels and their Inference for Depletion

The results from Figure 3.3 show that the aquifer water levels fluctuate annually, but there seems to be a trend in terms of which areas become unconfined first, and how this unconfined area spreads as water levels drop. A number of factors are likely to affect which areas deplete first. This includes:

- Elevation of the aquifer
- Thickness of the aquifer

- Rate of water withdrawal in that area
- Connections with other discharge locations



(a) (b)

Figure 3.5 Maps showing the variability in elevation for (a) the aquifer top and (b) the aquifer base. Elevation is in relation to an arbitrary datum below the aquifer.

Figure 3.5 shows the spatial variation of the aquifer top/base layers. From these maps, it is possible to infer that the aquifer is more highly elevated around the northeast to central regions, with the deepest parts of the aquifer occurring around the southwest. If flow in the aquifer was assumed to be entirely gravity-driven, then it would be expected that the higher parts of the aquifer would deplete first. This coincides with the regions in the aquifer that are mostly unconfined, as shown in Figure 3.4, suggesting that elevation plays a part in determining depletion locales for this aquifer.

The aquifer thickness was estimated using the difference between the aquifer top and base, with the additional modification that areas outside of the aquifer have zero thickness. This is to correct for the 'edge' effects as described in Section 3.4.1.

Figure 3.6 Map of aquifer thickness. Thickness increases with increasing darkness.

Figure 3.6 shows that the aquifer tends to be thickest in the north east corner and the southern end of the aquifer, and is thinnest in the mid-north portion. In terms of aquifer depletion, it can be surmised that the thicker parts of the aquifer will take longer to deplete than the thinner locales, so the areas most at risk of depletion are the northern and central regions. The distribution of thickness does not correspond with the unconfined areas from Figure 3.4; however, when considered in combination with Figure 3.5, the interpretation of the effect aquifer geometry has on areas most at risk of depletion starts to correlate, particularly for the southern region. In order to do a thorough analysis on depletion risk, anthropogenic influences cannot be discounted, but the lack of records pertaining to the presence and rate of extraction from private wells makes it difficult to assess how this parameter contributes to the spatial depletion trends observed in the aquifer. The limited understanding of the connections between the aquifer and other permeable units adjacent to and below the Aldergrove also complicates matters, as these connections can either act as induced recharge sources or locations for leakage, thereby potentially being a counteractive force against the spatial variability of water levels.

In terms of the lack of temporal trends in the water levels, it is most likely that climatic and/or changes in consumptive withdrawal are the primary causes of the seasonal differences, provided that the water level data can be assumed to be accurate.

Figure 3.7 shows a weak correlation between the saturation of the aquifer (based on water level data when available), and precipitation. This suggests that climatic factors are not the main causes of the water table fluctuation. It is difficult to compare precipitation trends with water level trends because the available data for calculating water content is not continuous, which hinders a full comparison of the two variables. In addition, recharge is not instantaneous, and the highly erratic precipitation is often much dampened by the time it starts affecting groundwater, thus interpretation of the relationship between these two variables can be very subjective.

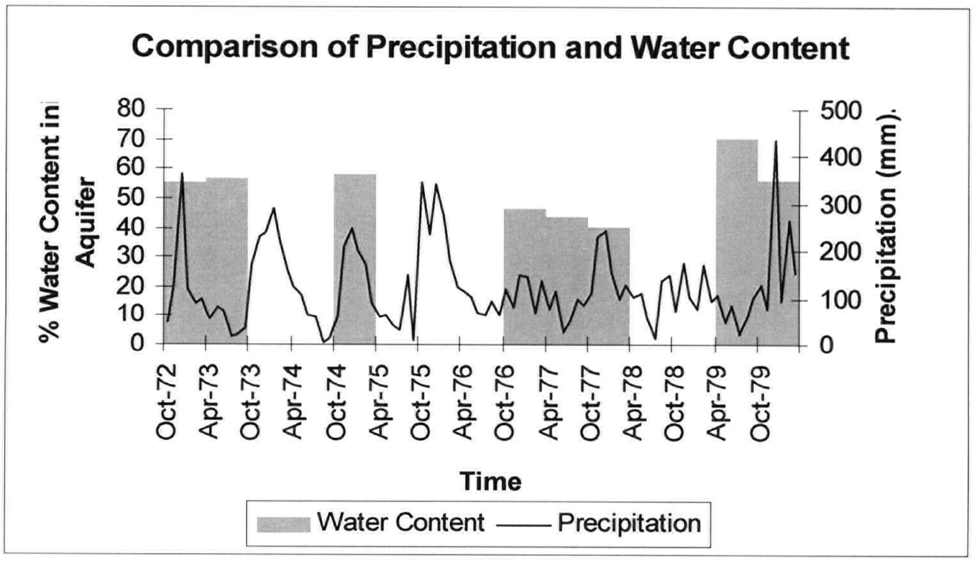


Figure 3.7 A comparison between the amount of precipitation and the saturation of the aquifer over time. Water level data was used to show aquifer water content where available.

If climate does not affect water level trends, then this implies that consumptive withdrawal is the main culprit, but this is difficult to confirm as there is no data on consumptive withdrawal for this period.

Water Content Analysis Using Surfer

The results from the Surfer analysis have demonstrated that the aquifer water content has historically been on average only 53% of theoretical capacity, and that a significant portion of the eastern side of the aquifer dries up completely on an intermittent basis, thereby many wells tapping into the east side of the aquifer are either withdrawing water from below the aquifer, (in another permeable unit), or are dry and abandoned. This result suggests that even without the advent of significant urban development, the aquifer's natural full capacity is already much less than the theoretical full capacity. Given this situation and the current consumption withdrawal rates, there is reason to be critically concerned about the sustainability of the aquifer. However, it would be premature to suggest that groundwater is depleting based on only this simple analysis. As previously mentioned, the water content of the aquifer is intricately linked to that of the adjacent aquifers and aquitards. With all 'leaky' aquifers, there is a certain amount of buffering that occurs whenever the saturation of one becomes significantly different from that of the others, similar to how osmosis regulates water/solute content between compartments separated by a semi-permeable membrane. The Aldergrove aquifer receives water from the surrounding geological units (other aquifers and aquitards), as water needs to pass through the overlying aquitard in order to get to the confined regions of the aquifer. Even though aquitards by definition are incapable of storing significant quantities of water, their ability to transmit water is essential to recharge, and likewise, the amount of water that they transmit is directly related to the amount of water that already exists within the aquifer, since groundwater flow is driven by hydraulic gradients. Thus the aquitards surrounding the Aldergrove aquifer have a vital role in maintaining the water content within the aquifer, and preventing it from depleting, as shown in historical saturation results. It is important to note that this buffering ability does not mean that the aquifer cannot be depleted. Induced recharge from aquitards to the aquifer can only occur at a rate determined by the hydraulic conductivity of the substrates, and this rate is unlikely to be great enough to match current rates of extraction. Likewise, the ability of the surrounding aquitards to replenish excessive withdrawal from the aquifer is in turn dependent on the ability of the aquitards to capture additional water from other sources, which can lead to negative repercussions for surface waters and other neighbouring aquifers. Thus though it is unlikely for the aquifer to dry up, the point at which extraction no longer yields required demands, or when extraction causes unacceptable deterioration of the surrounding environment (such as loss of summer baseflows in streams that support fish habitat), is very much an issue that could affect this aquifer very soon.

3.5 Flow Characteristics

The storage section has underlined some of the key physical properties of the aquifer and how the volume of water held by this aquifer has changed in the past, but a thorough understanding of the aquifer as a resource capable of supplying water needs to include an analysis of the way water moves within the aquifer. This is because an aquifer with a large storage capacity is of no use to the community if it cannot be extracted in sufficient quantities easily. For this reason, some analysis into the flow characteristics of this aquifer is a fundamental component of aquifer characterization.

3.5.1 Flow Parameters

As previously eluded in the recharge and storage analysis, there are several parameters within an aquifer that are important to characterize whenever groundwater flow needs to be considered. These parameters include:

Hydraulic Conductivity, K
Hydraulic Gradient, dh/dl
Storativity (storage coefficient), S

Hydraulic conductivity is a measure of the rate at which water is able to move through the aquifer, and together with the hydraulic gradient, they determine the discharge rate Q of the aquifer. Transmissivity T is the term that is used to relate hydraulic conductivity with the thickness of the aquifer. This parameter is important when trying to determine well yields and drawdown. The storage coefficient is defined as the volume of water released from storage per unit surface area of the aquifer per unit drop in hydraulic head (Hiscock, 2005). This parameter becomes important for determining the extent of the drawdown cone for a given pumping rate, and how quickly the aquifer will respond to changes in pumping.

Deriving the parameters *K*, *T*, and *S* often require on-site pumping tests to be conducted on the aquifer, or via laboratory tests on the samples obtained from the aquifer. For the purpose of this study, it is not possible to attempt either of these options, thus values for these parameters had to be collected from existing literature and previous studies on this aquifer.

Table 3.4 shows the variability of these parameters, not only between different locations but also within the same location, where the same well will yield different results depending on the type of pumping test used. This is a very typical scenario for aquifers, especially when they are highly heterogeneous with lots of interbedded layers of fine and coarse-grained sediments between the aquifer.

Table 3.4 Summary of flow parameters. Values are reported as averages with the standard deviation for those groups of wells tested.

Source	Transmissivity (m2/s)	Storativity	Hydraulic Conductivity (m/s)	Reported in:
Langley Municipal Wells	1.58E-02 ± 1.29E-02	0.018 ± 0.0086	6.76E-04 ± 4.96E-04	Piteau, 2004
Jackman Landfill Area	n/a	n/a	6.81E-04 ± 1E-03	Golder, 2005
Miscellaneous Wells	7E-03 ± 4.2E-03	n/a	1.54E-03 ± 2E-03	Golder, 2005

Considering that all the hydraulic conductivity values for this aquifer are in the 10^{-3}, 10^{-5} range, when the full range of values for these substrates (outwash sand and gravel) ranges from 10^{-3} to 10^{-7}, the hydraulic conductivity of this aquifer on the whole is relatively high, meaning that water is able to move through the aquifer relatively quickly. This makes the aquifer a productive water source for the community. The storativity values for this aquifer are also quite high, given that the typical storativity for a confined aquifer has been quoted as between 10^{-3} to 10^{-5} (Schwartz and Zhang, 2004). While it is known that this aquifer is not completely confined, the locations where these values were obtained are part of the confined portion of the aquifer, though it is possible that the wells exist in a region where there is some influence from the unconfined areas, which could help to explain the higher than average storativity.

3.5.2 Residence Time

The residence time is the estimated time that a 'parcel' of water takes from the moment it enters the aquifer as recharge to the moment it finally leaves the aquifer as discharge. This time period is dependent on the volume of the aquifer as well as recharge rates and flow rates through the aquifer. If the aquifer is assumed to be in steady state, and all the water in the aquifer flows at the same rate (i.e. there are no pockets of stagnant water), then the average or *mean* residence time can be estimated from volume and recharge such that:

Residence Time = Saturated Volume of Aquifer / Rate of Recharge

Residence times for the aquifer was calculated based on the maximum and minimum percentages of water content observed in the maps for the 1970s. The residence time for the hypothetical situation of a fully saturated aquifer (where the water content is 100% of aquifer capacity) was also calculated to allow comparison between results. It is important to note that the residence time is an average of all the flow times within the aquifer, because in reality, water will flow faster in some locations and slower in others.

Aquifer Residence Time Results

Given the results from the water content analysis on Surfer and using the recharge value determined from the soil-water budget calculation for *Farmwest* ET data, residence times were obtained for 3 volumes: the minimum of 40% saturation, the maximum of 70% saturation, plus a hypothetical 100% saturation of the storage capacity in the aquifer.

Table 3.5 Residence time results using aquifer volumes derived from GIS and Surfer.

Aquifer Saturation (%)	Residence Times (years) GIS	Surfer
40	7.5	7.8
70	13.1	13.6
100	18.7	19.4

Table 3.5 shows that if the aquifer is only 40% saturated, then the residence time of water in the aquifer is only up to 8 years, and this increases up to 14 years and 20 years given increases in saturation to 70% and 100% respectively. As with the conversion of GIS data to Surfer data, there is some discrepancy between residence times calculated with GIS and Surfer-derived 'hollow' aquifer volumes, resulting in residence time discrepancies that increase as the saturated volume of the aquifer increases (See Appendix III - Table 3.E).

Using Residence Time to Predict Future Water Content

Residence time is a parameter that is normally determined for water quality issues, whereby it gives an idea of how long it may take for the water body to flush out contaminants that have entered the system. Likewise, it is useful as an indicator of the solute potential of the aquifer, as the length of time that water has to travel through the aquifer is closely related to the concentration of dissolved compounds it contains (Hudak, 2005). By definition however, the residence time is an estimate of how long it takes for water entering the aquifer as recharge to leave again as discharge, thereby inferring the lag time between the two processes. In other words, if you know the residence time of the aquifer, then you can infer that water currently being discharged out of the aquifer originated from recharge *x* number of years ago. The results from the calculations suggest that the water in the aquifer could be up to 20 years old, though it is more likely to be less than 8 years old given the realistic saturation of the current aquifer. This assumes a no-mixing, 'first-in first-out' principle. If the residence time can be considered an indication of how long it takes for the water to travel through the subsurface before it reaches the aquifer, as opposed to how long the water stays in the aquifer itself, then knowing this lag time can allow a prediction of future water content in the aquifer, assuming discharge remains a constant. This is because under such assumptions, the water content in the aquifer is directly dependent on the amount of recharge from x years ago, so if you know the current water content, the lag time, and recharge volume each year, then it is possible to develop a relationship where a prediction of future water content can be made based on previous annual recharge volumes.

The idea of using residence times to predict future water availability in the aquifer has potential as a simple estimate, but it suffers from many flaws that limit its reliability. These include not only the unrealistic assumptions of this residence time method itself but also the inaccuracies of the input parameters that the calculations are based. Usually, when trying to determine the age of groundwater, more sophisticated methods such as isotope dating using tritium (^3H) are used, which can accurately date the age of the groundwater based on the decay of the isotope (Hiscock, 2005). This method has the ability to date different samples of groundwater, allowing determination of spatial variability and zones of local discharge within the aquifer. Thus this isotope dating method would be the ideal way to determine residence time, but unfortunately, this was beyond the capacity of the current study to conduct.

3.5.3 Groundwater Flow Patterns

In both *Chapter 2* and the previous sections, there has been reference to groundwater flow for the purpose of inferring recharge and depletion trends respectively. In this section, the actual patterns of flow itself will be analyzed, with special attention to the relationship between factors that influence flow directions.

The Effect of Surface Hydrology

Since groundwater and surface water are inevitably connected in each system, the surface conditions should also be considered when determining groundwater flow.

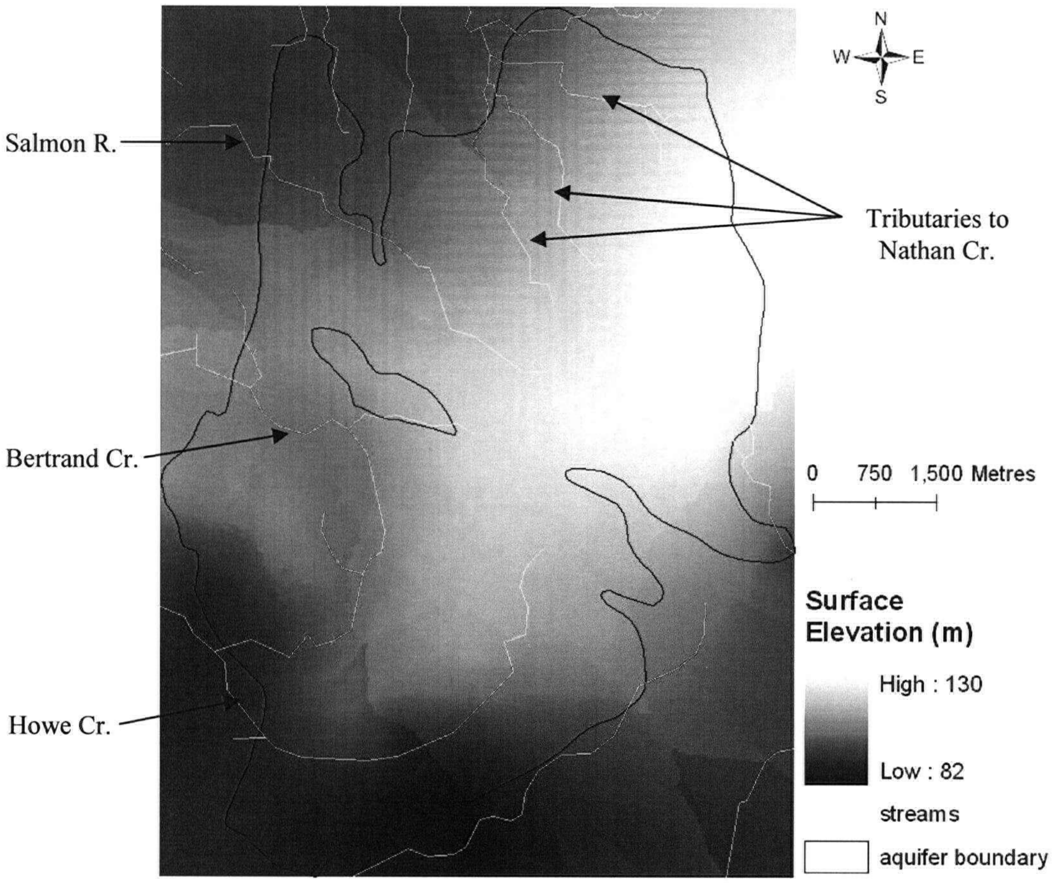


Figure 3.8 Map of surface topography over the Aldergrove aquifer based on well data.

In general, Figure 3.8 shows that the area surrounding the aquifer is relatively smooth, with a maximum range in elevation of 47 m. The topographically highest point is along the mid-east to north-east region of the aquifer, with the lowest points towards the south and south-west. Slightly more than half of the aquifer is covered by the Bertrand/Howes Creek watershed which flows south and then westwards from the aquifer area. The tip of the Salmon River and Nathan Creek make up the bulk of the rest of the aquifer surface, flowing north-westward and northwards respectively, with small contributions from other watersheds. This surface topography does not conform to the shape of the aquifer, which is more clinoformal (highest elevations around the centre of the aquifer with a decreasing trend towards the boundaries) as deduced by Golder, (2005) and supported by the results shown in Figure 3.5. Hydraulic head contours shown in *Chapter 2*, Figure 2.6 also do not conform with that of the surface contours, as flow tends to either radiate from a central location near the western part of the aquifer, or flow primarily from northwest to southeast.

Flow Patterns from Contour Maps

Contour maps (Figure 2.6) were generated for the flownet recharge analysis in *Chapter 2*, and aside from their use in estimating recharge, they are also important for displaying regional flow patterns. Contour maps generated for each time set show that the highest water levels tend to occur mostly in the northwest region of the aquifer, sometimes spreading further to the centre of the aquifer. Both the dominant location of highest water level and the pattern of groundwater flow seen from these flow nets are difficult to justify, especially since most of the contour maps conforms with neither the surface topography nor the shape of the aquifer itself. In fact, groundwater seems to flow in an opposite direction to that of surface water, and the shape of the aquifer does not entirely support this dominant flow direction either, except possibly for the case with the summer of '73, which found the recharge zone to be fairly similar to the point of highest aquifer elevation. A potential explanation of this contrasting groundwater flow is the possibility of anthropogenic influence caused by groundwater extraction. It is probable that wells not recorded were already operating near the vicinity of the recorded wells prior to their construction and water level measurement, thus new wells may fall under the cone of depression of existing pumping wells. This would make the water level lower than it would be in the absence of a pumping well. Unfortunately, it is not possible to verify the extent of pumping-induced head effects, as the regions of low water levels are mostly over the Abbotsford part of the Aldergrove aquifer, and there is no accessible data for extractions by private wells. Alternatively, a possible explanation for the high water levels around the northwest is the hydraulic connection between the aquifer and surface water bodies, such as the Salmon River and the upper part of Bertrand Creek. These streams can be responsible for providing additional water to the aquifer during times of high flows, thus helping to accelerate recharge in this area. Similarly, the streams near the eastern side of the aquifer may be ephemeral, such that they rely more heavily on groundwater inflow as a means of maintaining existing surface flow (baseflow). The fact that many of the streams which overlay the aquifer have their headwaters in the eastern part of the aquifer means that this is a reasonable likelihood, though verification would require extensive surface-ground water interaction studies. A final likely contributor to the somewhat unexpected groundwater flow patterns generated is the limitations of the data itself. Since most of the maps are generated with non-uniformly spaced well data spanning a period of 4-6 months, the chances of inaccuracy with the generated maps is quite high, especially since areas without data are interpolated from areas with data, leading to potential magnification of existing errors.

3.6 Summary of Storage Chapter

Storage is a rather ambiguous term when trying to characterize the physical and hydrological properties of an aquifer, because there are many aspects of an aquifer that are related to its ability to store and affect the movement of water. As a result, many separate topics were covered, from the actual storage capacity to water level trends and flow patterns. This chapter has been marked by a large amount of analysis on essentially the same set of limited data, which not only speaks of the importance of this well data, but also the difficulties that can be encountered when this data is insufficient. Modeling software proved to be an essential tool for analysis of surfaces, however, a combination was needed in order to obtain all the desired outputs from the analysis, providing the advantage of additional verification yet also causing disadvantages from data transfer discrepancies. Given the issues with such analysis, the results tended to contain wide ranges, reducing their worth in terms of the end result, but allowing valuable inferences to be made from the process nevertheless. It has been suggested that the concept of 'safe yield', where discharge can equal to recharge, is flawed and in reality, discharge must be sufficiently less than recharge in order for an ecological balance to be maintained (Sophocleous, 2000). The challenge will be to try and determine what is 'sufficiently less than recharge', which requires a good understanding of the interactive processes between the aquifer and its surroundings.

Chapter 4 – Discharge

For the Aldergrove aquifer, there are two main processes by which water is removed. One is via natural discharge mechanisms, and the other is due to consumptive withdrawal (water that is pumped out of the aquifer for human use purposes). The focus of this chapter will be to define consumptive withdrawal, hence the four components that will be analyzed are as follows:

1. Preliminary analysis of consumption trends in Aldergrove.
2. Estimate of total annual consumption over the aquifer.
3. Analysis of seasonal trends from the sub-sampled properties.
4. Estimate of natural discharge.

4.1 Preliminary Consumption Analysis

4.1.1 Introduction

The Township of Langley has progressively incorporated a metering programme for non-residential properties that obtain water from the Township's wells since 1995, and has been recording the consumption of each of these properties biannually – once in March and once in September of each year. Since agricultural properties have their own wells, they are not metered, and residential properties on the municipal supply are not metered due to the lack of consumption-based pricing for residential properties in Langley. In spite of this, all the other major categories of land use have been extensively metered, thus this data provides a good base for general analysis of consumption trends.

4.1.2 Method

Since consumption data is collected for properties throughout Langley and not just the Aldergrove area above the aquifer, it was considered worthwhile to compare consumption patterns in Aldergrove from those of the entire Township. Note that outside of Aldergrove, municipal water supply consists of a mix of local groundwater plus water from the GVRD (see Appendix IV – Figure 4.A). GVRD water accounts for 60% of the supply to the western system (ToL, 2006b).

Biannual Totals

Using the complete database of consumption recorded by the metered properties, the totals for each biannual period were added up and compared to the number of properties metered during that biannual period in order to give an average consumption value per metered property. This was done in order to correct for the changing number of properties metered each year.

From the entire Township's metered properties database, properties that extract water from the Aldergrove aquifer were isolated by using the municipality's route numbers, which corresponds to the origin of the water supply. With this extracted list of properties, the same analysis was done in order to compare Aldergrove within Langley.

Category Distribution

To make comparisons between groups with similar properties, several primary categories were devised. These consist of 'agricultural', 'commercial', 'industrial', 'institutional' and 'others'. Residential properties are not metered and therefore are not included. The breakdown of the types of properties included within each category is listed in Table 4.1.

Table 4.1 List of land uses that are housed under each major land use category.

Agricultural	Commercial	Industrial	Institutional	Others
Livestock farms	Public services	Food processing	Schools	Recreational
Fruits and crops	Retail	Products and services	Governmental	Municipal Residential
Horticultural	Food services	Materials, construction and manufacturing	Health and safety facilities	First Nations land
Hobby farms	Multiple units	Offices and storage	Cultural and tourist locations	Mineral extraction
	Other businesses		Churches	Unused land

The proportion of each category in Langley and Aldergrove were determined by dividing the number of metered properties in each category by the total number of metered properties in Langley/Aldergrove. Calculations were based on data from March 2005.

For Aldergrove, the number of metered properties was also compared with the total number of properties within each category that is over the aquifer area. This was done using the aquifer boundary map and land use (parcel) maps in GIS.

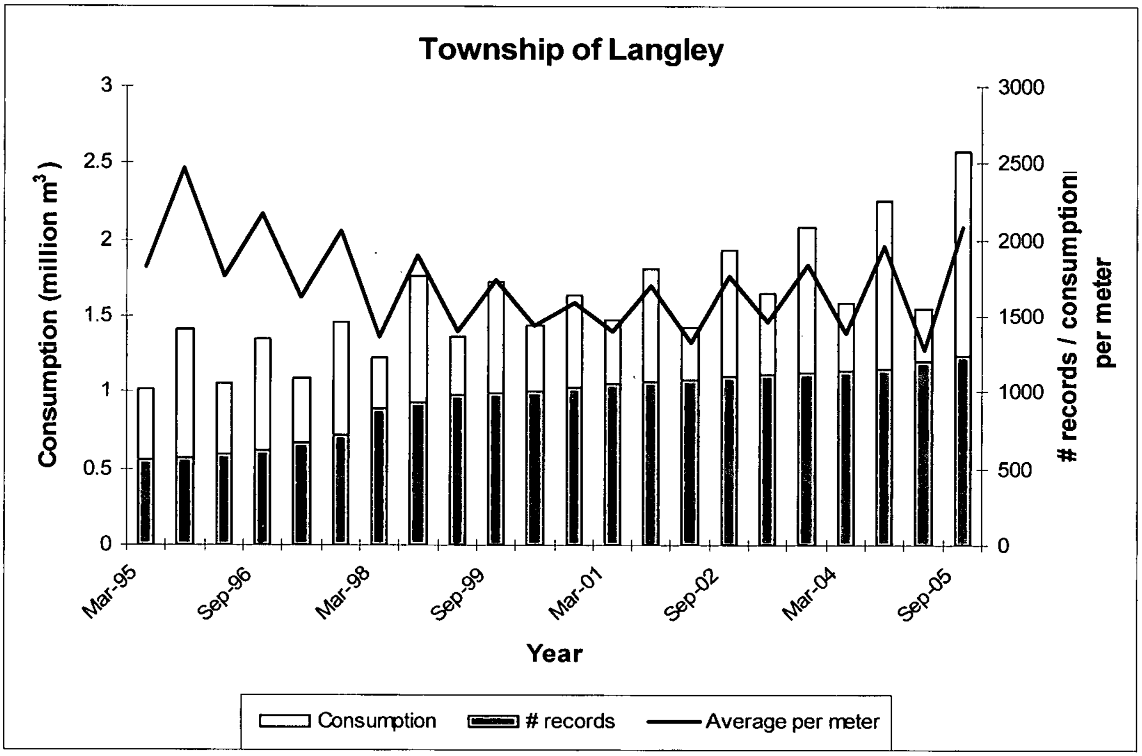
Category Trends

For this analysis, the biannual averages for each year were pooled to give just one consumption total per year. This value was then divided by the number of meters recorded in that year to give the average consumption per metered property within each category.

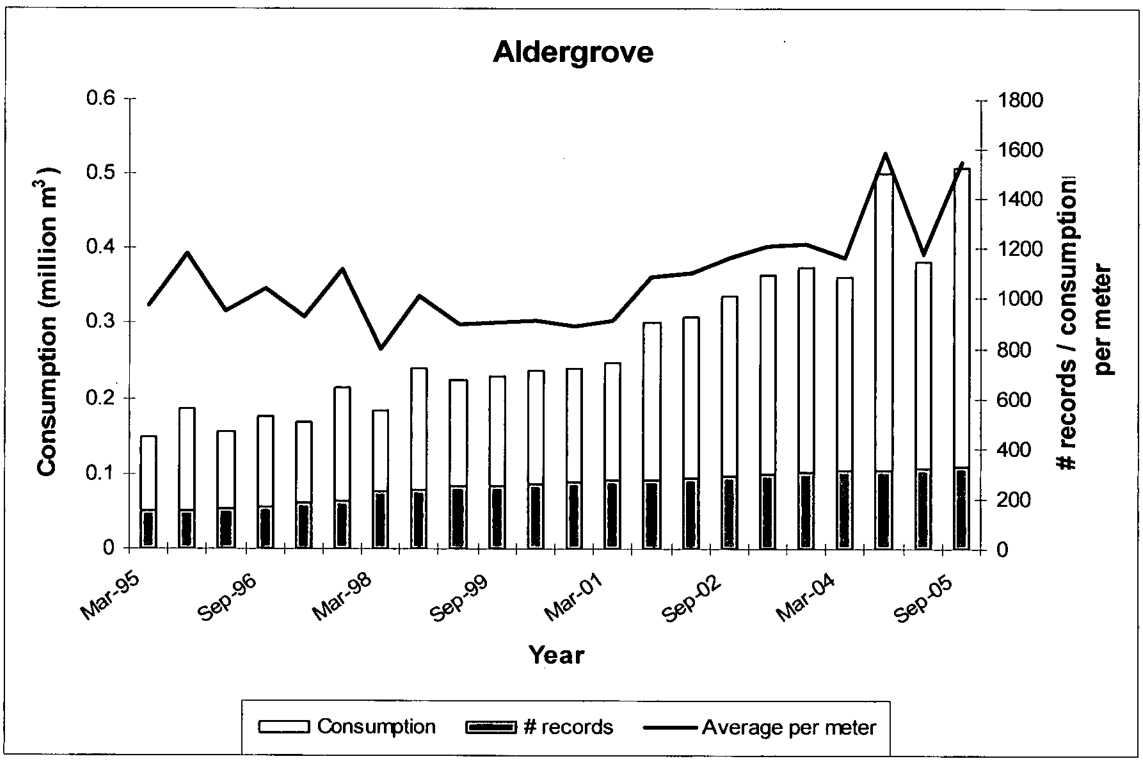
4.1.3 Results

Biannual Totals

In both Langley and Aldergrove, Figure 4.1 show that both consumption and the number of metered properties have increased with time, however, the average consumption per metered property shows a different trend. In Langley, there is a clear difference between winter and summer consumption, with a decrease in average water consumption per metered property up to 2001, then a slow increasing trend since. In Aldergrove, the difference between winter and summer consumption is less obvious, and a definite increasing trend can be seen with overall consumption since 1995.



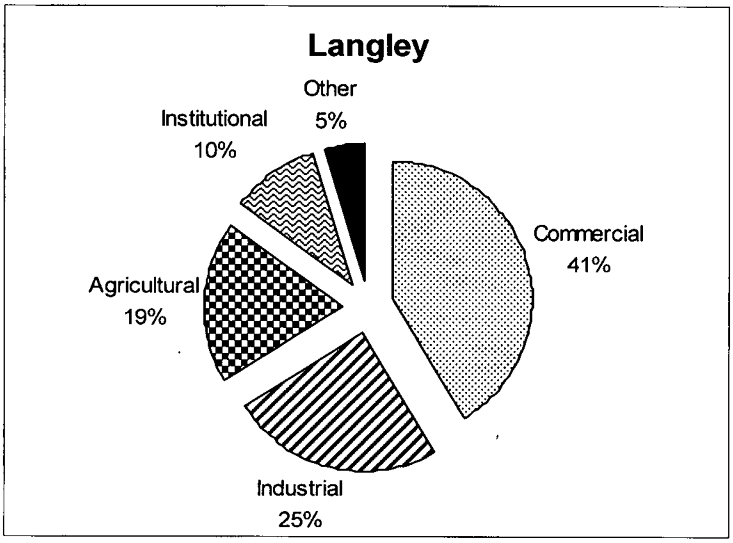
(a)



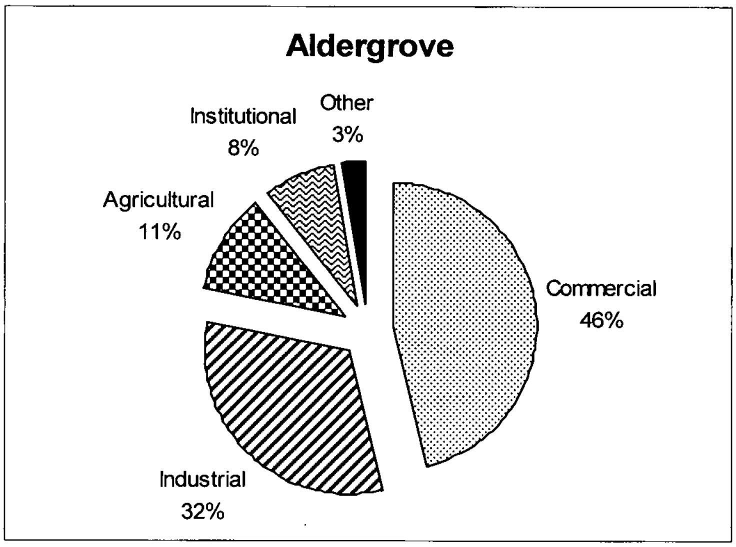
(b)

Figure 4.1 Biannual total consumption for (a) the Township of Langley, (b) the Aldergrove area within Langley. Consumption data are taken in March and September of each year.

Category Distribution



(a)



(b)

Figure 4.2 Distribution of metered properties within (a) the Township of Langley, (b) the Aldergrove area within Langley.

Table 4.2 Comparison between the number of metered properties and the number of unmetered properties for each category in Aldergrove.

	Total # properties	Total # metered properties	# Internal metered[1]	# External metered[2]	# Unmetered properties	% Unmetered
Agric	237	37	18	19	219	92.4
Comm	243	134	113	21	130	53.5
Ind	19	106	15	91	4	21.0
Instit	48	25	20	5	28	58.3
Other	115	8	5	3	110	95.7
Res	3078	0	0	0	3078	100.0
Total	**3740**	**310**	**171**	**139**	**3569**	

Agric – agricultural, Comm – commercial, Ind – industrial, Instit – institutional, Other – other, Res – residential.

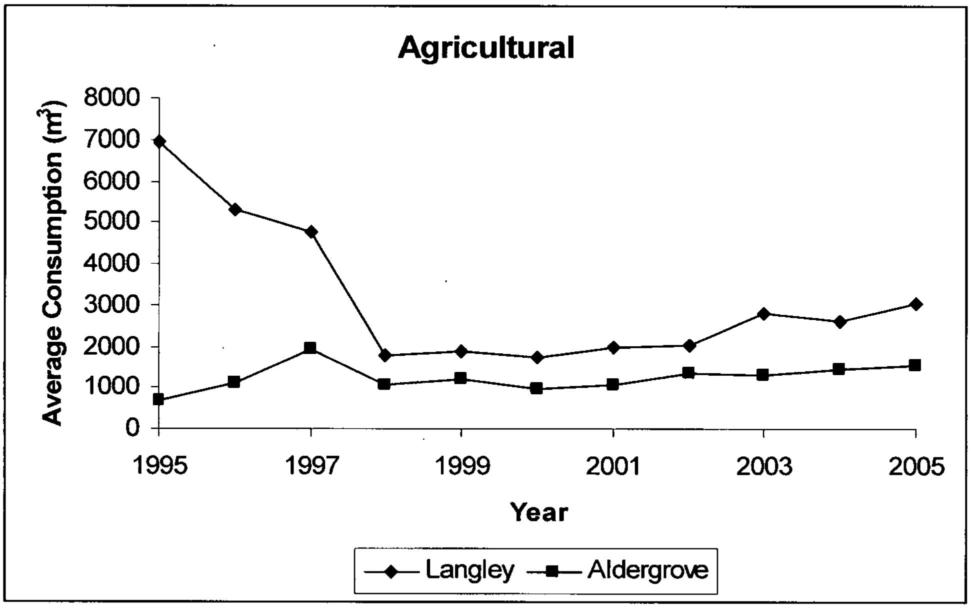
[1] Internal metered refers to those properties that exist within the Aldergrove area.

[2] External metered refers to those properties that actually lie outside of the Aldergrove area, but still obtain their water from Aldergrove.

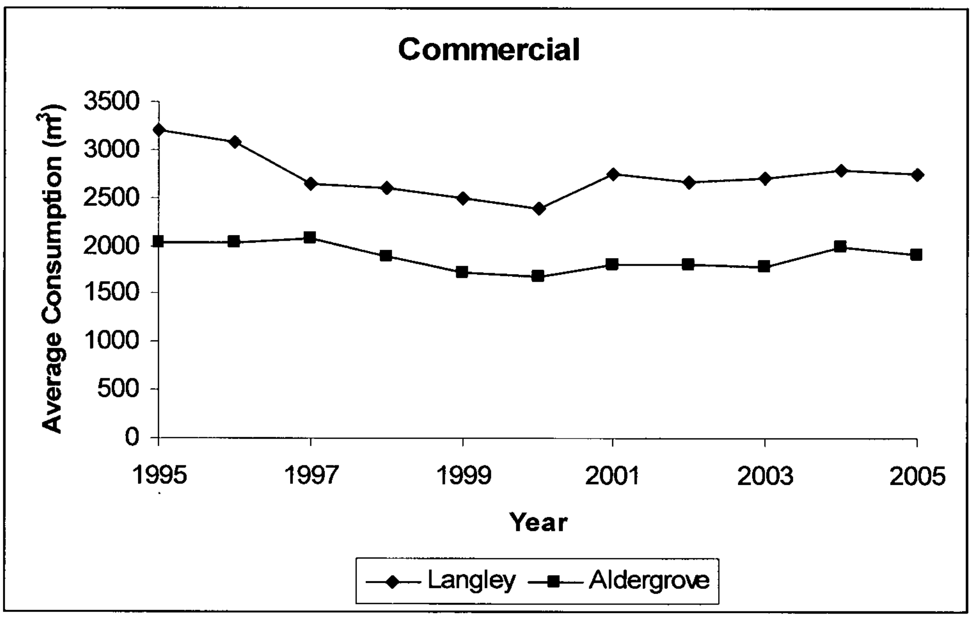
Figure 4.2 show that the proportion of metered properties is similar for both the whole Township as well as the Aldergrove area, with a tendency for commercial and industrial properties to dominate the number of properties metered. It is important to note that residential properties are not included, nor are the unmetered non-residential properties, and the results are independent of consumption by each category. On the other hand, Table 4.2 shows the total number of properties within each land use category, and from this, there seems to be a large number of properties for all categories within Aldergrove that are not metered, especially for the residential, agricultural and 'other' category, whereby no residential properties are metered at all.

Category Trends

The categorical trends in consumption are shown on Figure 4.3(a-e). Agricultural consumption shows a high discrepancy between Langley and Aldergrove until 1998, with a largely constant, relatively low consumption thereafter. Commercial consumption has been mostly constant in both regions, but the average for Langley is always greater than Aldergrove. Aldergrove industrial consumption shows a definite increasing trend while Langley industrial consumption appears to be decreasing slightly. With institutional consumption, there is a big difference between the two regions, with the Langley trend staying constant while the Aldergrove trend is decreasing slightly. Lastly, the results for 'Others' are very sporadic and there appears to be little or no overall trend in consumption patterns for either regions.



(a)



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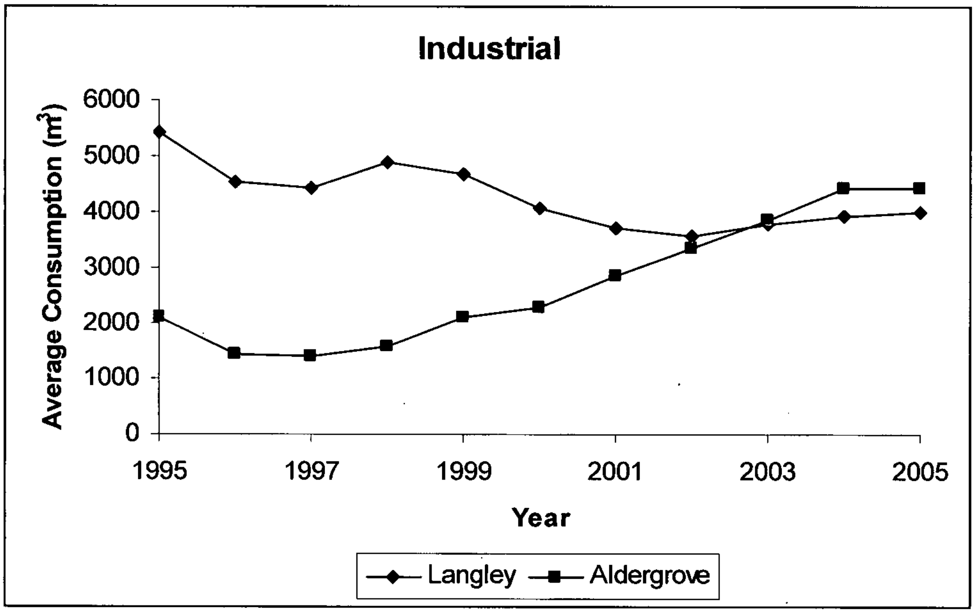
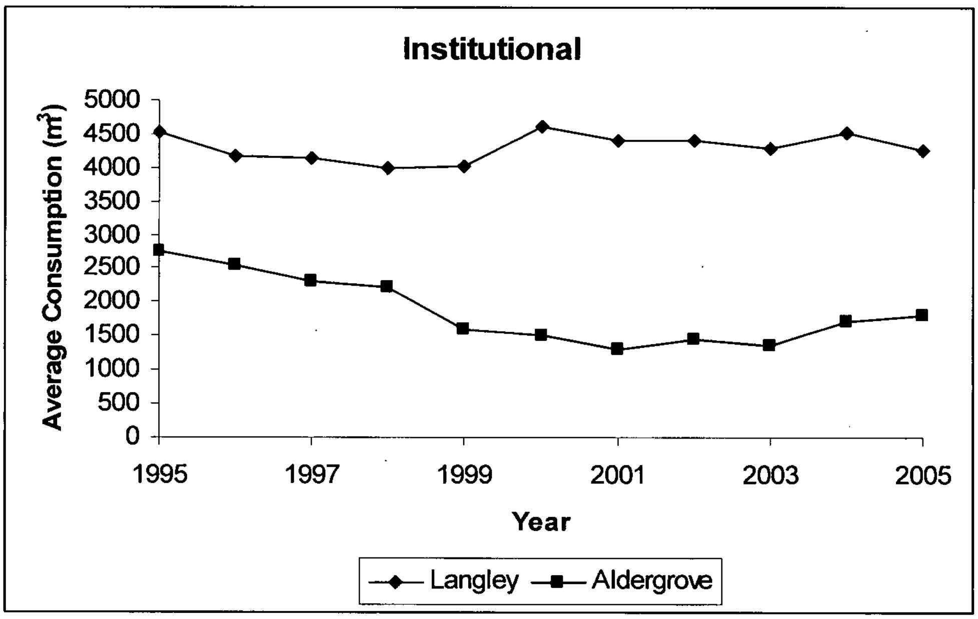
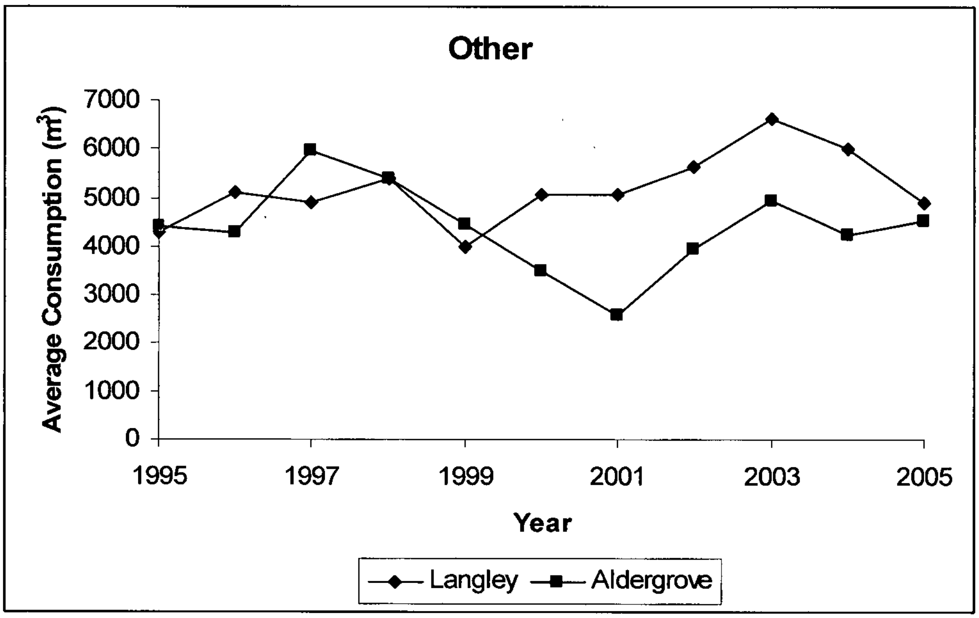

Industrial
Average Consumption (m³)
6000
5000
4000
3000
2000
1000
0
1995
1997
1999
2001
2003
2005
Year
Langley
Aldergrove

(c)


Institutional
Average Consumption (m³)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1995
1997
1999
2001
2003
2005
Year
Langley
Aldergrove

(d)



(e)

Figure 4.3 Comparison of the average annual consumption per metered property between the Township of Langley and the Aldergrove area within Langley for (a) agricultural, (b) commercial, (c) industrial, (d) institutional, and (e) other properties.

4.1.4 Discussion

Biannual Consumption Trends

In both Langley and Aldergrove, the total consumption appears to be increasing, but this is primarily due to the increasing number of properties being metered, thus adding to the total consumption each year. The average consumption per metered property gives a better indication of consumption trends, and there appears to be obvious differences between the patterns in Langley versus those in Aldergrove, with the Langley results showing a more obvious disparity between summer and winter consumptions.

The September records represent the summer half of each year, where water demands are greatest. Higher demands occur because previously rain-fed lawns and cropland now need to be watered due to the lack of precipitation characteristic of GVRD summers, at the same time, the hotter weather induces more outdoor water-based activities as well as indoor water usage, such as increased showers. Cumulatively, these activities lead to higher consumptions in the summer, but several factors can also influence the actual magnitude of this summer consumption relative to winter consumption. These factors include summer temperature and rainfall, GVRD water-use restrictions (which in turn are based on the amount of water storage in the GVRD reservoirs obtained from the previous winter, as well as the summer conditions) and to some extent, the level and nature of commercial and industrial activities, which are market-driven.

The reason why summer consumption is so variable and winter consumption tends to be fairly consistent each year, is that during winter, both indoor and outdoor water use is based on routine water needs rather than climatic conditions. Given that there is an abundance of precipitation and lower temperatures during winter, water use is less dependent on climate. In Langley, consumption during the winter period has remained very similar each year since 1998. However, a note of caution must be made regarding the reliability of these results. Even though the average consumption per property corrects for the discrepancies caused by the changing number of metered properties, this average is still internally dependent on the number of properties. In other words, a sharp change in the number of records could also present itself in the results from the average consumption per property. This may be the real reason why there is a marked difference in winter consumption before and after 1998, as between 1997 and 1998, the sharpest increase in number of metered properties occurred. The stronger summer trend changes pre and post-2000 could also have been partially influenced by the change in number of records, but it is also likely that significant improvements in best management practices and changing water use legislation has contributed at least to the initial decrease in summer water consumption from 1995-2000. However, it is interesting to note that the severe water use restrictions implemented in August 2003 (GVWD, 2003) whereby all non-essential water use was banned (stage 4) has not had a noticeable impact on the consumption of the summer 2003 records. A likely reason is that the consumption impact from that one month of severe water use restriction was buffered by the consumptions during the other months of that biannual period, which were probably higher than corresponding months as a result of such drought conditions, thus total water use did not decrease as a whole for that summer.

In Aldergrove, the driving forces behind the biannual consumption patterns are less obvious, as the pattern does not reflect that of the Township as a whole. Part of the reason may be due to the reduced number of properties being metered, which causes greater sensitivity of the result to the consumption of individual properties. Thus if there are a few atypical consumers in this area, it is possible that the consumption from these properties can skew the overall biannual average of the area. Nevertheless, the results suggest that there is greater growth and development within the Aldergrove area than in the Township as a whole, which implies that there will continue to be an increasing demand for water from the aquifer.

Category Distribution

Considering only metered properties, the results show that the categorical distributions between the two regions are very similar, but Aldergrove has a higher ratio of commercial and industrial metered properties. These additional commercial and industrial establishments support the growth trend seen in the biannual consumption data, and it is probable that they are responsible for the difference in biannual trend between Langley and Aldergrove. Regarding Table 4.2, the percentage of unmetered properties belonging to commercial, industrial or institutional is actually misleading, because the total number of properties actually refers to the number of land parcels belonging to that land use category. This means that a parcel of land in the commercial sector doesn't have to be developed or of the type that requires a water supply in order to be counted. This is the reason why so many commercial, institutional and other properties are not metered. The Township of Langley's waterworks regulation bylaw 1995 No: 3482 states in Part II that any service used for commercial, institutional or industrial purposes are required to be metered (ToL, 1995), thus it is expected that all such properties in Aldergrove are in fact, metered, meaning that the remaining unmetered land parcels are not ones that actually require a water supply, such as parking lots.

Category Trends

The results from the temporal trends within a category suggest that commercial and institutional properties are the most stable consumers in the Township, which is expected since their consumption is less likely to be seasonally dependent as a whole. Industrial consumption represents an interesting case whereby growth is only in the Aldergrove area. Part of this consumption increase could be due to the increasing number of industries residing in Aldergrove, but the strength of the increasing trend in average consumption suggest that industries must also be intensifying and using more water annually. Thus this particular land use category may turn out to have a big influence over water withdrawals from the aquifer. Conversely, very little inference can be made regarding consumption from agricultural and other properties. With agricultural properties, it is known that they are not representative of the true agricultural consumption trend, since only the small hobby farms are metered, and some of these may not even be operating as a farm at all, having since been converted purely to residential use. If commercial-scale agricultural operations were included, then the average consumption per property would definitely be much greater than what it currently seems from the metered selection. With the category known as 'other', the very miscellaneous nature of the properties housed within this category makes it such that no really useful conclusions can be drawn from its trend, or lack thereof. It should be noted that many properties – or rather land parcels – housed within this category are actually not water users, as they consist of woodland or other undeveloped land. Thus it can be assumed that this category has little effect on the total water consumption from the aquifer, and is not a priority concern with regards to data deficiencies.

Summary

Analysis of the biannual metered consumption data for Langley and Aldergrove has shown some interesting trends in all facets of the data, from disparities between winter and summer to similar categorical metering ratios yet opposing consumption trends between Aldergrove and the Township as a whole. All these results point to the conclusion that consumption in Aldergrove is significantly different to that of the Township overall, governed by its own dynamic collection of industries and businesses that potentially operate at different intensities with respect to water needs. The results also highlight the deficiencies in the representativeness of the metered properties to consumption from the Aldergrove aquifer, such that it is necessary to search for additional data sources in order to get a more accurate understanding of the consumption patterns for each category of land use over the aquifer.

4.2 Annual Consumption over the Aquifer

4.2.1 Introduction

The preliminary analysis of consumption from the metered properties in Langley has allowed for some initial inference of the magnitudes and trends from different land use categories, but also highlights the inadequacy of those properties for estimation of consumption over the whole aquifer. This means that in order to get an estimate of the annual consumption from this aquifer, additional data sources and methods must be sought. This applies particularly to estimates for agricultural and residential water use, since they are the least known water users in that area, at the same time, they make up a combined total of almost 90% of all the water using properties over the aquifer. For this reason, the importance of these two categories cannot be underestimated, and separate methods to determine their consumption were needed.

In this section, the analysis of consumption will be divided into three components:

1. Agricultural
2. CIIO – commercial, industrial, institutional and others
3. Residential

Each component uses a different method to estimate consumption, based on available data and category-specific aspects that need to be addressed separately from other land uses.

4.2.2 Agricultural Consumption

Method

Agricultural consumption is the most complicated category to estimate due to the number of operation types that have vastly different water needs and thus require individual estimation methods. For this category, water users had to be further sub-divided into 5 areas:

1. Outdoor fruits and crops
2. Livestock
3. Greenhouses
4. Pastures
5. Residential and hobby farms

<u>Data preparation (all sub-divisions)</u>

The first thing that needed to be done with the agricultural data was to separate the information on each of the sub-divisions from the overall agricultural data set. Data existed in the form of aerial photos and a detailed agricultural land use inventory taken in 2001, which provides information on specific agricultural uses of individual properties. The following procedure was used to separate the sub-divisions from the total data set:

1. Overlay the land use parcel map with the aerial photos map.
2. Visually record the types of operations seen on each agricultural property (verification of land use).
3. Estimate the ratio of outdoor fruits and crops, pastures and indoor operations (livestock and greenhouses).
4. Based on the size of the property, calculate the area occupied by each sub-division using 90% of the total property area (to allow 10% for areas that do not require water, such as driveways, the boundary of properties and any other areas that should be excluded from the analysis).

Outdoor fruits and crops

Berry farms are a common feature of agricultural operations in this region, occupying more than 5 km^2 of land over the aquifer, and accounting for about 17% of agricultural operations. Crops on the other hand, do not consist of a significantly large portion (in size of fields or number of properties) of agriculture, based on aerial photo interpretation and land use designation information, thus they were grouped with fruits for water consumption analysis.

The method for estimating water use in this sub-division involves obtaining data for evapotranspiration (ET) and the crop coefficients for berries. ET data was obtained from Farmwest (Farmwest, 2006), for the summer months from May to September inclusive, for the years from 2002 to 2005. The average ET for each month was calculated and assumed to be the typical ET for that month. Farmwest bases its ET calculations on that of a grass reference crop, so in order to estimate the ET potential of different crop types, a crop coefficient must be obtained for the respective crop in question. Crop coefficients for a range of berries were estimated based on values determined by the B.C. Ministry of Agriculture, Food and Fisheries (BCMAFF, 2001). The values from the ministry was matched to the corresponding months of the summer growing period, and used to re-determine the ET potential based on that of berries. In the calculation of water requirements, the following assumption is made:

Water needs/use = ET potential of berries (summer growing period)

The premise for this is that water use by plants is primarily for the purpose of facilitating ET rather than for incorporation into the physical structure of the plant itself, thus in order to maintain an optimum crop yield, water supply to the crop should always be equal to the ET needs of the crop. For this reason, ET can be used as an estimate of the water needs for irrigating these crops in the summer, with the assumption that irrigation is not needed in the other months where rainfall is sufficient or when these crops are not growing. Thus to obtain the total water needs of this sub-division over the aquifer:

Total consumption = Area (occupied by sub-division) * Total ET (from summer period)

Livestock

Aside from water needs for irrigation, agriculture also involves a significant water requirement for livestock operations, where water is needed for watering the animals as well as cleaning and sometimes, processing, as with dairy operations. For this reason, water needs in this sub-division is also very complicated, but it is beyond the capacity of this study to try and determine water needs for every aspect of livestock operations, thus the main component that will be considered is the watering requirements of the animals themselves.

Three sources of data were used to derive the watering estimates for livestock:

1. Types and number of livestock operations over the aquifer – obtained from GIS land use information.
2. Estimate of the number of animals per farm – derived from 2001 census of agriculture (StatsCan, 2001).
3. Estimate of watering needs for different livestock – obtained from B.C. Ministry of Agriculture and Lands (BCMAL, 2006).

The following method was used to derive the total water requirements from livestock agriculture:

1. Group livestock operations by major types (Beef, Dairy, Horse, Sheep/Goat, Poultry and Exotics).
2. Use the GIS database to count and total the number of farms that contain each livestock designation.
3. Isolate the South Langley and South Matsqui agricultural data from the 2001 census (representative of the Aldergrove aquifer area).
4. Use the number of farms and total number of animals counted in the census data to estimate the average number of animals per farm for each livestock group.
5. Multiply the average with the number of farms (determined in Step 2) to obtain an estimate of the total number of animals in each livestock group over the aquifer.
6. Use the estimate of watering needs from the ministry to determine the average annual water requirements of each livestock group on a per animal basis.
7. Multiply the total number of animals with the annual water requirements in each group, then add the values to get the total watering needs of livestock in one year over the aquifer.

The simple mathematical representation of the method is shown below.

Total consumption by livestock group:

$$T_x = C \times F \times \overline{X}_n$$

Total consumption of livestock over the aquifer:

$$T_{aq} = \sum T_x$$

T_x = total consumption for livestock group x

x = livestock group (beef, dairy, horse, sheep/goat, poultry, exotics)

C = watering requirements of x

$\overline{X}_n$ = average number of animals per farm

F = number of farms

T_{aq} = total consumption over the aquifer

Greenhouses

Greenhouses are an important agricultural operation over the aquifer, with sufficient density to occupy 3% of the agricultural area over the aquifer. Being intense and year round, they require a different estimation technique to that of outdoor fruits and crops. An estimation of greenhouse water use was provided by the BC Greenhouse Growers' Association (BCGGA. *pers. comm.*, 2006). This was split into summer and winter typical usage. The method for estimating greenhouse water use is as follows:

1. Obtain the average ET for every month between 2002-2005 – from Farmwest.
2. Apply the estimate of summer and winter consumption to the highest and lowest ET months respectively
3. Interpolate the consumptions for the other months based on this range between the highest and lowest ET months.
4. Multiply the monthly consumption estimates by the area of greenhouses, then sum up to one year.
5. Greenhouses tend to reuse 1/3 of their water (BCGGA. *pers. comm.*, 2006), so deduct 1/3 from the total consumption to give the estimated annual water use of greenhouses.

Pastures

Pastures occupy the biggest area out of all the agricultural sub-divisions, around 44% of total agricultural land use over the aquifer. Irrigation of pastures however, is less intensive than that of the other sub-divisions, occurring in approximately only 15% of total pasture area (Chieng. *pers. comm.*, 2006). At the same time, pastures are not irrigated for as many months during the summer, normally only between June and August. Aside from these differences, estimation of pasture water usage is the same as for outdoor fruits and crops.

Agricultural Residential

Many of the agricultural operations over the aquifer are small scale family-run businesses or simply hobby farms, meaning that aside from the water requirements of the agriculture, there is also a water use element associated with the houses that these families live in. These essentially residential properties cannot be excluded from the consumption analysis, however, since there is already a separate section that will deal with residential water use, consumption from these agricultural residential properties will be added to the total number of residential properties over the aquifer, and counted in that section instead.

Results

Table 4.3 shows that of the four agricultural sub-divisions, fruits and crop operations require the most water, followed by pastures, greenhouses and livestock operations. In total, agriculture uses a huge volume of water annually, however, the majority of water use comes from the Abbotsford side of the aquifer, which make up about 70% of the total agricultural consumption over the aquifer (see Appendix IV – Table 4.A-G). The water requirement pattern within each sub-division is discussed in more detail in the agricultural consumption discussion.

Table 4.3 Summary of annual water use (m^3) over the aquifer by different agricultural operations on each side of the municipal border.

Sub-divisions	Abbotsford-side	Langley-side	Sub-division Total	% of Total
Fruits and Crops	1,602,166	771,501	2,373,667	62
Livestock	157,949	37,869	195,818	5
Greenhouses	307,981	105,743	413,724	11
Pastures	631,637	226,597	858,233	22
Municipal Total	**2,699,733**	**1,141,710**	**3,841,442**	

Discussion

Fruits and Crops

Water requirements for growing small fruits and crops vary substantially during the length of the growing season, corresponding with their productivity and changes in mass. At the beginning of the season, the small seedlings require very little water, thus their crop coefficient value is very small compared to that of grass. As the crop matures, their water demands become more intensive and by June and July, they exceed the ET potential of grass. Once the crops are fully grown, water use decreases again until the crop is harvested. This parabolic trend is evident in all crop cycles, leading to variations in ET potential and thus the water needs of the crop. In terms of estimating crop water use, this constantly changing ET potential makes it very difficult to get an accurate estimate.

The results from the analysis has suggested that fruits and crops need more than 430 mm of water in total during their growing season, if the plants are not to be water-stressed (see Appendix IV – Table 4.A). Table 4.4 compares the climate normal rainfall with the amount that the fruits and crops actually need. The climate normal for the Aldergrove area suggests that typically 350 mm of rain falls between May and September, but of this amount, less than 130 mm falls during the height of the growing season (June and July), when the plants need water most. This disparity in rainfall availability versus water needs means that irrigation is essential in order to maintain the crop, leading to the high water use of this agricultural sub-division.

Table 4.4 Summary of total monthly precipitation normals versus water requirements of fruits/crops.

	Precipitation (mm)	
Month	**Climate Normal[1]**	**Fruit/Crop needs[2]**
May	99.1	39.1
June	78.9	122.5
July	50.2	141.9
August	49.3	81.7
September	75.9	52.5

[1] Based on climate normals between 1971-2000 at the Abbotsford meteorological station. Source: Environment Canada's Weather Office (EC, 2006a).

[2] Calculated from ET potential of berries.

Obtaining an accurate estimate of water use from this type of agriculture presents a number of difficulties. The first is due to the generic grouping of all fruit and crop agriculture under the same crop coefficient. Just within the 'berries' group, which was the basis of the crop coefficients used, there was a maximum of 0.3 difference in crop coefficients between berries, equivalent to 25% discrepancy between two different berry types. Since the crop coefficient is directly correlated to the estimated water use, this means that the result can have an error of ±25% associated with it as well. The second issue relates to the use of ET potential as a proxy for water use, not so much the validity of ET potential in representing the water needs of a crop, but in terms of how much these needs are appropriately translated into irrigation applied by farmers. Different farmers use different methods to irrigate their crops, ranging from the use of low-tech 'garden hose' type methods to indiscriminate sprinkler systems to the advanced-tech 'drip-irrigation' and computerized soil moisture sensors. Each method has a different level of efficiency associated with it, based on both the expert judgment of the farmer and the precision ability of the technique. For obvious reasons, under-irrigation rarely occurs, as the consequences would be clearly visible, thus it is the over-supply of water that poses a problem when trying to estimate the water use. The ET method gives the ideal volume of water needed to grow fruits and crops, but depending on the irrigation method of the individual farmers, the excess application of water can range from negligible to whatever the saturated water holding capacity of that soil is. *Chapter 2* has given an idea of the range of WHC for different soil types in the region, though the true range lies between 7-40% field moisture. Field moisture here means the amount of water that the soil can hold after it gravity drains from saturation. This large range is representative of the possible error associated with determining water use with the ET method. It must be noted however, that it is practically impossible to supply just the amount of water the plant needs, because the roots of a plant takes up water from the soil surrounding it, which means that the soil must have enough water to support the plant. For this to happen, the soil would have to contain more water than the plant is able to remove at any one time, and this is exclusive of the 'non-biologically extractable' water held by the soil at all times. Thus it is inevitable that more water needs to be supplied to the soil than the plant actually needs, to allow for other loss processes such as direct evaporation from the soil and removal by soil micro-organisms.

<u>Livestock</u>

This sub-division of agriculture apparently uses up the least volume of water compared to the other sub-divisions, but there are substantial differences in water requirements within livestock types. Table 4.5 gives more detail on the consumption of each of the major categories of livestock that exist over the aquifer.

Table 4.5 Summary of water requirements by different livestock types.

Livestock	Consumption[1] (L/animal /day)	Total # animals[2]	Consumption (m^3/yr)
Beef	34	2,370	29,468
Dairy[3]	136	644	32,029
Horse	45	750	12,434
Sheep/Goat	9	708	2,445
Poultry	0.23	1,436,336	119,060
Exotics[4]	8	138	381
Total			**195,818**

[1] values adapted from that of the BC Ministry of Agriculture Livestock Watering Handbook.

[2] estimated from Statistics Canada Agricultural census data for Langley and Abbotsford for 2001.

[3] dairy water use includes wash water for the milking operation as well as consumption water.

[4] includes llama, alpaca, ostrich, mink and other fur farms.

Table 4.5 shows that poultry farms make up the bulk of the water requirements of the livestock sub-division, due more to their large numbers than to their large water needs. Dairy cattle are the single biggest consumers, but they make up a relatively small fraction of the livestock over the aquifer, and thus their consumption is only ranked 2nd behind poultry. Notice that swine are not on the list of major livestock types. This is because swine farms do not exist at a detectable level over the aquifer, though they are significant in other areas of the Lower Fraser Valley. Between the two municipalities, there is a fairly even spread of dairy and exotic livestock, but Abbotsford has double the number of horses and sheep/goats and triple the number of beef and poultry operations. Consequently, Abbotsford makes up 81% of total livestock consumption over the aquifer. This ratio reflects the greater agricultural dominance in Abbotsford, not only because 2/3 of the aquifer exist in this municipality but also because Abbotsford contains 69% of all the livestock farms and 74% of all the agricultural area over the aquifer. Langley however, has been known as the 'Horse Capital of B.C.', with apparently the highest density of horse farms in the province (Schreier. *pers. comm.*, 2006), most of which are what's known as 'Hobby farms'. These are farms that are run as a hobby, as opposed to 'Commercial farms' which are run for profit. The Langley-side of the aquifer actually contains 49% of all the hobby farms over the aquifer. In terms of numbers, there are more horse farms in Abbotsford, but Langley has a higher density of horses per farm, meaning that there are actually more horses on the Langley-side, which serves to illustrate the density of these farms in this municipality.

The analysis of livestock consumption has two major limitations. The first stems from the lack of accounting for water use that is not directly consumed by the animals (with the exception of dairy), and the second is based on the method for estimating the total number of animals over the aquifer.

Livestock operations require water not only for consumption by the animals, but also for uses related to cleaning and hygiene maintenance. This is true for all farms, regardless whether it's a small barn, an indoor intensive rearing facility or a processing plant. However, non-consumptive water use will change with the intensity and type of operation, with an expectation that commercial farms will use more water than hobby farms. Of the different types of commercial farms in operation, it is expected that dairy farms will be among the biggest non-consumptive water users, as regular cleaning of the milking equipment is an essential part of health and safety protocol, constituting around 2/3 of the total water use (BCMAL, 2006). However, dairy farms do not make up a big portion of agriculture over the aquifer, so the bulk of the non-consumptive water use will probably be attributed to poultry and beef operations. A detailed study done by the U.S. Department of Agriculture in 1975 estimated that 59% of the total livestock water is used for drinking, while 25% is lost to evaporation from stockwater pond surfaces and only 10% is used for cleaning and sanitation. The remaining water is used for other purposes such as cooling and processing (SCS, 1975). This is in sharp contrast to another report in Ontario that suggests a typical flush system used to clean barns requires 100 gallons per cow per day of water (Irwin and Hicks, 1979). Assuming that all the beef farms over the aquifer flush their barns once a week, then 85,500 m^3 of water will be needed annually, accounting for 66% of all the water used for beef operations just in terms of cattle drinking and cleaning. This estimate is probably unrealistic for the Aldergrove aquifer area since not all farms are likely to have a typical alley flush system, but the contrasting results from just these two reports highlights the variability that can be found with the ratio of consumptive to non-consumptive uses of livestock water. More recent data on non-consumptive water use could not be found for the aquifer area, primarily because this aspect of water use is highly flexible depending on farmer preferences and is also rarely the main concern for livestock operations, leading to a general lack of interest in accounting for this water use.

In the second limitation, there are clearly concerns with the accuracy of estimating the number of animals on the aquifer based solely on the average number of animals per farm in the region. Many factors affect the potential number of animals on a given farm. This includes the time of year, the size of the farming operation, and marketing dynamics that can fluctuate annually. The agricultural census data of 2001 was used to estimate the animal numbers on the aquifer, and it can be assumed that these numbers have increased somewhat since 2001. In 2004 we saw a huge outbreak of Avian Influenza in the Lower Fraser Valley, which resulted in the depopulation of 410 commercial poultry farms and 553 backyard poultry flocks, totalling 14.9 million birds (Hudson and Elwell, 2004). Even though the affected area did not overlap the aquifer, they were adjacent farms within the same municipality, which highlights the potential volatility of livestock numbers to external disturbances. The scale of different operations is another factor that hasn't been accounted for in the estimate. Many of the livestock farms are not large, intensive operations, but small commercial or hobby farms with backyard herds and flocks. The average derived from the agricultural census includes all sizes of operations, such that the presence of a few intensive operations can skew the mean towards the higher end of the scale, which may not actually be representative of the majority of farm livestock populations. However, this may serve to help balance out the conservative numbers estimate.

Greenhouses

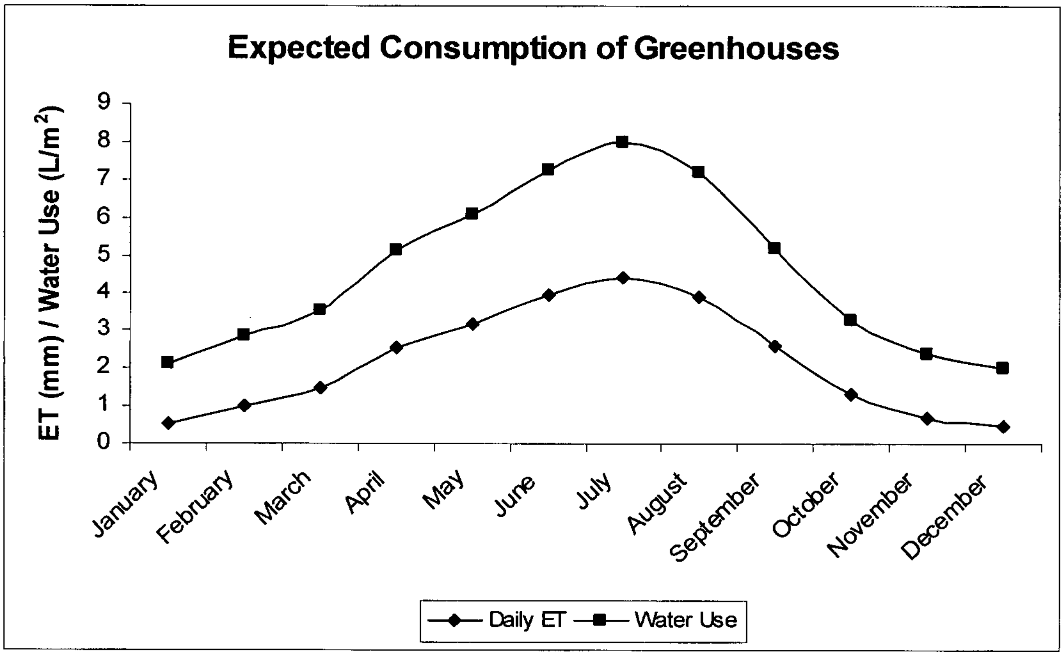


Figure 4.4 Water consumption patterns as a function of evapotranspiration. Water use is calculated on a daily basis.

Even though greenhouses occupy the smallest fraction of land area out of all the agricultural sub-divisions, they are not the least water demanding. Figure 4.4 shows that the water use of a greenhouse can be estimated from ET, as the same processes govern plants in a greenhouse as well as outdoors. Accordingly, water needs fluctuate seasonally, from a low of 2 mm per day to a high of 8 mm per day. This is higher than the water requirement of outdoor crops, which peak at 5 mm per day. There are several reasons why greenhouse crops need more water than outdoor crops. One of the most obvious is the higher density of plantation, as greenhouse crops tend to be grown on a medium that is specially created to maximize plant growth, thus allowing more plants to be grown in a smaller area. In addition to this, the temperature inside a greenhouse will tend to be hotter, and humidity is also strictly controlled, whereby drier conditions tend to be favoured, leading to a higher ET potential within a greenhouse operation. At the same time, greenhouse crops are grown year round, so greenhouses consume much more water per square metre of planted area than outdoor crops.

Table 4.6 Summary of greenhouse area and water consumption between the two sides of the aquifer.

Area	Area of Greenhouses (m^2)	Consumption (m^3/yr)
Abbotsford	275,587	307,981
Langley	94,621	105,743
Total	**370,208**	**413,724**

Table 4.6 shows that Langley has only about 25% of the greenhouse area over the aquifer. The rest of the greenhouses exist in Abbotsford, so the majority of water taken up by this sub-division is over at the east-side of the aquifer, where water availability from the aquifer also happens to be scarcest.

As with the other sub-divisions, there are limitations to the calculation of water requirement for greenhouse operations. Factors that will affect water use that have not been properly accounted for in the calculation are listed below:

1. Types of crops grown.
2. Method of crop irrigation.
3. Amount of water recycled back to the system.

The types of crops grown will have a major effect on direct water use as well as other factors that affect water needs, such as temperature and humidity, since different types of crops have different crop coefficients. Greenhouses in the Lower Fraser Valley tend to grow a certain variety of crops. These include tomatoes, peppers, cucumbers and lettuce (BCGGA, 2006). Crop coefficients for these varieties range from 0.6 – 1.05 based on a grass reference crop (BCMAFF, 2001). There may also be some horticultural greenhouses over the aquifer. Since the water requirements for a typical greenhouse was obtained from the BC Greenhouse Growers' Association rather than via direct measurement based on crop types and crop coefficients, it is uncertain what the range of error may be in the water use calculation. It must be noted that even if crop types and crop coefficients were used, they would not be adequate to properly gauge the water use of greenhouse crops since the controlled environment within the greenhouse is so different to that of the outside surroundings. Proper accounting of water needs would require knowledge of all aspects of the greenhouse operating environment, which is challenging to obtain.

The method of irrigation, as for the outdoor crops, is also important, not for estimating how much water is needed but for estimating how much water is wasted, i.e. the efficiency of the watering system. Greenhouses are more likely to be water efficient as there is a tendency for systems to be automated, and maintenance of optimum growing conditions is of a higher concern for greenhouse growers since the whole purpose of a greenhouse is to facilitate the growth of crops that would otherwise not be viable in that particular geographical and climatic condition. However, there are many types of greenhouse operations, not all of which are as modern and sophisticated as the major commercial ones, so inefficient watering can still be a significant contributor to water use, but estimates become more complicated when water reuse is considered. For the larger, commercial greenhouse operations, a portion of the water is recycled back into the system and reused, thereby increasing efficiency, but the true ratio of new versus recycled water differs between greenhouse operations. Thus even though an attempt was made to incorporate recycled water in the water use calculation, it is not necessarily representative of greenhouses over the aquifer.

<u>Pastures</u>

Results show that large quantities of water is used on pasture land, even though pastures do not require as much water per unit area than other agricultural plants. The reason they have such a high total annual water use is because pasture covers the majority of agricultural land over the aquifer, around 71%. Within this seemingly well defined land use, there are actually a number of different types of 'crops' that fall under this category. These include different types of grasses and leguminous plants such as alfalfa and clover. Estimating water use on pasture land is complicated, because depending on the type and purpose of the pasture land, more or less water is needed. For example, a pasture land that is used for free range grazing of livestock will require a different amount of watering compared to that which is used to make hay and silage. In addition, because pastures can be used to feed livestock in fresh or dried form, this makes it more amenable to ad hoc watering, which is even more difficult to estimate. For this reason, aside from contacting farmers directly about their pasture watering habits, it is unlikely that any one estimate of water use is sufficient to represent all the pasture land over the aquifer. Despite this, pastures are not the most important water users out of all the agricultural sub-divisions, nor are they the most sensitive to drought conditions. Thus when it comes to trying to manage agricultural water use, pastures may be the least essential component to deal with.

4.2.3 CIIO Consumption

The biannual consumption readings taken by the Township of Langley consist of a large number of properties under the land use categories of commercial, industrial, institutional and other/recreational. Originally, the idea was to determine a representative sub-sample of properties in the CIIO group where additional metering would be done so that more accurate estimates of seasonal water consumption could be obtained. Unfortunately, it was not possible to obtain seasonal consumption data for the ideal sub-sample of properties needed for this method, thus these sub-sampled properties could not be used to represent consumption of the CIIO. For this reason, estimates of consumption from the CIIO group had to be based on the results from the total number of biannual metered properties, and these four categories were grouped together because the same method applies to each category.

Method

The consumption for each category in the CIIO group was determined as follows:

1. Use the biannual metered data to sum up the total number of properties in each category.
2. Sum the total consumption for 2005 in each category and divide by the number of properties to give an average annual consumption by category.
3. Use the GIS land use information for Langley and Abbotsford to determine the total number of properties over the aquifer in each category.
4. Based on the specific land use descriptions and aerial photo observation, remove those properties that do not require water from the analysis.
5. With the corrected number of properties, sum up the properties on both sides of the aquifer and multiply by the average consumption for that category to determine the estimated total consumption for each category.
6. Sum up the totals by category to give the total consumption of the CIIO group.

Some of the properties over the Aldergrove aquifer on the Abbotsford side do not obtain their water from this aquifer, but instead are actually supplied by water from the City of Abbotsford, which uses surface water sources. Because of this, not all the properties over the aquifer can be considered dependent on the aquifer, so in order to see what effects this will have on the total consumption calculation, the number of CIIO properties that exist inside the 'City-supplied' zones are excluded from the totals and the calculation is repeated in the absence of these properties. Conversely, there are properties on the Langley side of that do not exist over the aquifer, yet they draw their water from the Aldergrove municipal wells, thus they are included in the analysis for consumption.

Results

Table 4.7 shows that the CIIO group uses more than 1.5 million m^3 of water from the aquifer each year. Of the two municipalities, Langley has a much greater portion of CIIO properties than Abbotsford, and this shows in Table 4.8, when properties in Abbotsford that are suspected to be supplied by water from other sources are removed from the total. Within the CIIO group, recreational/other properties uses up the most water per property on average, but they consist of the least number of properties over the aquifer. In contrast, commercial properties have only 1/3 of the average consumption of that of recreational/other, yet it makes up the bulk of the total consumption annually, due to their shear numbers in comparison to other land uses. The presence or absence of properties in Abbotsford appears to have little effect on the general consumption differences between properties, or the total annual consumption from the CIIO group (see Appendix IV – Table 4.H-I).

Table 4.7 Summary of annual consumption for the total number of properties in each category within the CIIO group.

Major Land Use	Average Consumption[1] (m^3)	Number of Properties[2] Langley-side	Abbotsford-side	Total	Total Consumption (m^3)
Commercial	2,275	264	21	285	648,479
Industrial	5,044	110	4	114	574,983
Institutional	1,956	52	14	66	129,081
Recreational / Other	6,783	34	7	41	278,110
Total					**1,630,652**

Table 4.8 Summary of annual consumption for each category within the CIIO group excluding properties on the Abbotsford-side that may have 'city-supplied' water, i.e. water is not taken from the Aldergrove aquifer.

Major Land Use	Average Consumption[1] (m^3)	Number of Properties[2] Langley-side	Abbotsford-side	Total	Total Consumption (m^3)
Commercial	2,275	264	1	265	602,971
Industrial	5,044	110	3	113	569,939
Institutional	1,956	52	0	52	101,700
Recreational / Other	6,783	34	4	38	257,760
Total					**1,532,371**

[1] Based on total consumption from the 2005 biannual meter readings in Langley, on a per property basis.

[2] Only those properties that are considered to need water have been included. Those considered not requiring water include woodlands, parking lots and railways.

Discussion

From the results, it is obvious that the combined consumption of the CIIO group represents a significant portion of water withdrawal requirements, but the fact that consumption is strongly biased towards Langley means that most of the withdrawal pressures lie on the west-side of the aquifer. It is perhaps fortunate that Abbotsford makes up so little of the CIIO water consumption, because of the uncertainties surrounding water supply to this side of the aquifer. Even though the 'city-supplied' zones were determined by locating water supply pipes along engineering maps provided by the City of Abbotsford, the maps do not show where connections to individual properties are made, only where the pipe itself extends to (see Appendix IV – Figure 4.B). Thus there are a number of properties that are in a potential 'grey' area as they are adjacent to a supply pipe, but there is no certainty that they actually obtain their water from that pipe. At the same time, there are uncertainties surrounding the representativeness of Langley CIIO properties for Abbotsford, which may not be the same as there could be different environments, bylaws and regulations that govern how the CIIO properties are built and operated.

Between land uses within the CIIO group, commercial and industrial properties are of most concern, since they occupy the majority of land use in the group, and thus take up the greatest portion of CIIO consumption. Historically, commercial properties have tended to use a relatively constant amount of water, but the consumption from industrial properties in the Langley area have risen in recent years, which may affect the total averages of the CIIO group. This will be an issue for future predictions based on these annual averages.

4.2.4 Residential Consumption

In terms of numbers, residential properties by far dominate land use over the aquifer, accounting for 74% of total land use (see Appendix IV – Table 4.M). However, along with agricultural properties, this category is the least represented in terms of available water consumption data. For this reason, attempts were made to help augment the existing metered data by adding a number of private residential/hobby farm properties, which agreed to have a meter installed in their water supply so that measurements can be made of their water use. Under this scheme, 9 private properties were metered in the Aldergrove area, 5 of which were residential and 4 were hobby farms.

Method

The methods used to estimate residential consumption are based on two data sources:

1. Township of Langley total municipal water flow plus population data for Aldergrove (obtained from the Township).
2. Consumption data from 5 residential properties on the privately metered scheme.

Using the Township data, residential consumption was estimated as follows:

1. Extract the total volume of water that flowed through the Aldergrove Water Treatment Plant (supplied by municipal wells) for 2005.
2. Total the consumption of the CIIO group that are metered in 2005, and subtract from the AWTP total. The resulting volume is an estimate of water supplied to residential properties on the municipal supply.
3. Assume that 15% of the water is lost via leakage, and re-determine total volume of water to residential properties on the municipal supply.
4. From the Aldergrove population data, assume that all 'Urban' residents are on the municipal supply, and 'Rural' residents are on private wells.
5. Divide the total residential water volume by the number of residents on the municipal supply to get a volume of water per person per year.
6. Multiply the estimate per person by the estimated total number of people residing over the aquifer to get a total residential consumption over the aquifer in 2005.

This method can be expressed with the following mathematical formulas:

$$C_{aq} = C_p \times P_{aq}$$

where:

$$C_p = 0.85W_R \div P_u$$

$$W_R = W_T - W_{CIIO}$$

$$P_{aq} = N_{Haq} \times \overline{X}_P$$

C_{aq} = total consumption of residential properties over the aquifer (m^3/yr)

C_p = consumption per person (m^3/yr)

P_{aq} = total residential population over the aquifer

W_R = total residential water use from Langley municipal supply (m^3/yr)

W_T = total municipal water supply (m^3/yr)

W_{CIIO} = total was use by CIIO group from Langley municipal supply (m^3/yr)

P_u = urban residential population over Aldergrove (assumed to represent residential population supplied by municipal water)

N_{Haq} = total number of houses over the aquifer

$\overline{X}_P$ = average number of people per household

$\overline{X}_P$ was determined using population census data for Langley - which is basically comprised of the Aldergrove community (ToL, 2005) - and Abbotsford, both of which contain data on the total population and the total number of households in each municipality. Aldergrove data was for the year 2004, while Abbotsford data originated from the 2001 national census. The $\overline{X}_P$ was determined to be 2.9 in Langley and 2.8 in Abbotsford, and is inclusive of all residential types, from single-family to multi-family residential units. Because $\overline{X}_P$ is different between the municipalities, P_{aq} is actually made up of the population for Langley-side plus the population for Abbotsford-side of the aquifer, so N_{Haq} needs to be split accordingly.

To allow comparison of the range of likely residential consumption, the above method was repeated without a 15% deduction for leakage. Note that the calculation of total residential consumption is based on estimates for average per person consumption over the aquifer. Another way to estimate residential consumption is by obtaining values on a per household basis. The method for this is essentially the same as the per person basis, only the number of suburban households is used instead of the number of urban residents. Since the data source is not the same (suburban households are determined from GIS interpretation of aerial photos), the estimated residential consumption between the two will differ (see Appendix IV – Table 4.J). In addition, the results from the 5 privately metered properties were combined and averaged to give the 'conservative' estimate of residential consumption (see Appendix IV – Table 4.K). The justification for this is that the privately metered properties are expected to be biased towards water conservation as they agreed to participate in the study, thus it would not be accurate to assume that they are representative of typical household consumption in this area.

As a final variant on the residential consumption calculation, residential properties in Abbotsford that are supplied by city water are removed from the total and the resultant reduction in consumption is compared to that obtained when all residential are considered supplied by the aquifer.

Results

Table 4.9 Summary of consumption (in m^3) using different estimates based on the total residential category over the aquifer.

	Langley	Abbotsford	Total
Total # Households	4,300	882	5,182
Total # People	12,470	2,470	14,940
Consumption (based on Households)			
100%	1,735,086	355,894	2,090,981
85%	1,474,823	302,510	1,777,333
Conservative	1,242,357	254,828	1,497,185
Consumption (based on People)			
100%	1,721,668	340,965	2,062,633
85%	1,463,418	289,820	1,753,238
Conservative	1,266,722	250,866	1,517,588

Table 4.10 Summary of consumption (in m^3) using different estimates excluding properties on the Abbotsford-side of the aquifer that may have 'city-supplied' water.

	Langley	Abbotsford	Total
Total # Households	4,300	328	4,628
Total # People	12,470	918	13,388
Consumption (based on Households)			
100%	1,735,086	132,351	1,867,437
85%	1,474,823	112,498	1,587,321
Conservative	1,242,357	94,766	1,337,123
Consumption (based on People)			
100%	1,721,668	126,799	1,848,467
85%	1,463,418	107,779	1,571,197
Conservative	1,266,722	93,293	1,360,015

Table 4.11 Calculated consumption values based on households and persons over the aquifer.

	Consumption (m^3/yr)	
Assumption	**Household**	**Person**
100%	404	138
85%	343	117
Conservative	289	102

Consumption for residential use is shown in Table 4.9, Table 4.10 and Table 4.11 where 100% denotes no leakage loss and 85% denotes leakage losses of 15%. Conservative values are based on the privately metered properties. The results show that total consumption over the aquifer can range from 1.4 million to 2.1 million m^3 annually, depending on the estimate considered. Most of the residential population exists over the Langley-side, which makes up more than 90% of people living over the aquifer. The inclusion or exclusion of possible city-supplied properties in Abbotsford makes about 10% difference to the final result. Between consumption based on household or people, there is practically no difference, but the conservative values are strongly different from those of the other estimates, constituting about 70% of the 100% household consumption estimate (see Appendix IV – Table 4.L).

Discussion

Residential consumption is an area that has been studied by many researchers, in the local and national context, which has led to numerous estimates over the years. However, very few of these estimates have actually been obtained as a result of widespread metering in that locality, particularly for estimates made for the Lower Fraser Valley region. Aside from the two sources of residential consumption used in the calculation, other sources have also quoted values for Langley. One is the GVRD, which gives an estimate of 584 L/person/day (213 m^3/yr) based on the fraction of water they supply to the Township of Langley (GVWD, 2003), which is much greater than the estimates in Table 4.11. This is likely due to the fact that they calculate values based on total population, which does not account for private versus municipal well water (Dixon-Warren, *pers. comm.*, 2006). The other estimate comes from the Township themselves, where they quoted 360 L/person/day (131 m^3/yr), which is very similar to the estimates in Table 4.11, but the source of their estimate is unknown (ToL, 2006c). From these values, it can be seen that estimates for residential consumption indeed covers a wide range, even when they all refer to the same municipality. This highlights the difficulties and potential bias of estimates depending on the representativeness of the sample. The sources for the calculation was considered to be the best out of all the available estimates since they were directly based on water withdrawals and consumptions from that aquifer, but even when that is the case, uncertainties exist pertaining to the amount of leakage, the number of households, potential differences between housing types and the actual number of people that reside over the aquifer.

The amount of leakage from a water supply that has always been difficult to quantify. Even though private wells are unlikely to have a significant leakage due to 'conveyance' of the water to the home, all households, whether municipal-supplied or self-supplied, will have 'internal' leakage where the main water pipe diverges into many smaller pipes leading to individual faucets and toilets, as well as leakage caused by the appliances themselves when they do not close off the water supply properly. Environment Canada has estimated that up to 30% of water entering the supply pipes can be lost via leakage (EC, 2006b), however, the GVRD has estimated its systems leakage to average 13% (GVRD, 2005) while studies in the U.S. has produced averages of less than 13% (DeOreo, Heaney and Mayer, 1996; Mayer, DeOreo and Opitz, *et al.*, 1999). The estimate of 15% used for the calculation is considered to be neither too conservative, nor too unreasonable, and helps to give an idea of the true residential consumption that would otherwise be hidden within the 'unaccounted for water' total. In addition to leakage, other loss mechanisms such as water used for firefighting also occur, but quantities lost from such circumstances are not likely to be as significant.

In terms of the number of households and people over the aquifer, there are difficulties with obtaining an accurate estimate because the boundaries of the aquifer do not conform to that of municipal and community boundaries. The estimate of the number of people on the Langley-side is based only on the community of Aldergrove, which does not coincide with the area of the aquifer in Langley. This means that there is no certainty that the Aldergrove area will properly represent those residential properties outside of this community. Similarly, Abbotsford estimates are based on the whole municipality, which may not be entirely representative of the region over the aquifer. The number of households do not have the same problem as these were determined more accurately using the GIS land use maps, however, discrepancies can occur due to the different types of housing over the aquifer, some of which are multi-family residential properties. This was only an issue in the Aldergrove community, and since the total number of multi-family apartments can be visually determined in GIS while the number of housing units was also documented in the Aldergrove statistics report, it was possible to determine the equivalent number of 'single-family' units within the area, and thus add this to the total number of households over the aquifer. This helps to correct for most of the housing types discrepancy, but it is possible that the average number of people per household does not properly account for those living in multi-family properties, which could affect the estimated total population over Aldergrove.

4.2.5 Total Consumption over the Aquifer

Table 4.12 Summary of the ranges and best determined consumption estimate (m^3/yr) for each land use group.

	Langley			Abbotsford		
	Min	Max	Best	Min	Max	Best
Agricultural	-	-	1,141,710	-	-	2,699,733
CIIO	-	-	1,487,831	44,539	142,820	44,539
Residential	1,242,357	1,735,086	1,474,823	93,293	355,894	112,498
Grand Total	3,871,898	4,364,627	**4,104,364**	2,837,565	3,198,447	**2,856,770**

Table 4.12 shows the amalgamated results from all the land use groups for both Langley and Abbotsford, and there appears to be a clear difference in total consumption between the two municipalities. In Abbotsford, agricultural water use dominates consumption, while in Langley, both CIIO and residential consumption are greatest. If the results for both municipalities were combined, then the total annual consumption over the aquifer ranges from 6.7 to 7.6 million m^3, with a best estimate of 6.9 million m^3.

Of the two municipalities, Langley is more reliant on the aquifer than Abbotsford, given that its annual consumption is greater than that of Abbotsford despite that Langley only covers 1/3 of the aquifer. Even though Abbotsford has more agricultural properties that consume a lot more water, Langley has a much denser population over the aquifer, resulting in much more CIIO properties, which can consume a greater volume of water per unit area of land over the aquifer. This is perhaps the main reason why consumption in Langley is so high. At the same time, the estimates generated for Langley are likely to be more accurate than those for Abbotsford. The main reasons are listed below:

1. Estimates for the CIIO group are based on Langley CIIO biannual consumption.
2. Agricultural properties in Langley are more likely to obtain water from the Aldergrove aquifer than those in Abbotsford.
3. There is a major uncertainty factor surrounding which properties are 'city-supplied' versus 'self-supplied' in Abbotsford, due to the difficulty with obtaining data from Abbotsford.
4. Population for residential estimates was based on municipal averages in Abbotsford while Langley values were based on the community of Aldergrove.

Of the 4 reasons why Langley estimates are more accurate, the two most important ones are related to the agricultural properties and the city versus self-supplied issue in Abbotsford, the latter of which has already been discussed in the CIIO Consumption section. With respect to the agricultural issue, the reason why this is considered one of the most crucial limitations to the Abbotsford results is because agricultural properties make up the majority of land use on this side of the aquifer. However, there is very little confidence that these agricultural properties, given that they are self-supplied, actually obtain their water from the Aldergrove aquifer. The argument for this is that if the historic water level fluctuations found in *Chapter 3* still holds true, then there should be practically no water available on the Abbotsford side of the aquifer as the storage results suggest that the water level is below the aquifer base. If this is the case, then any wells dug over the aquifer cannot be extracting their water from the Aldergrove aquifer, but instead, are extracting water from another aquifer deeper than the Aldergrove. This will not be true for the whole area covered by Abbotsford since there are some areas, particularly those closest to the border with Langley, that were intermittent in terms of their wet/dry state, and thus are likely capable of still supporting consumption withdrawal, but at the same time, the areas where the aquifer is dry will affect CIIO and residential properties over Abbotsford as well. This means that it is possible for Abbotsford to have a much lower consumption than Langley, should the majority of the aquifer be dry, which will have a knock-on impact on the total annual consumption estimate. The true extent of this implication can only be determined if an extensive water level analysis is made for the current situation in Abbotsford, which would then allow inference of the availability of water from the Aldergrove aquifer. Until then, it is wise to treat the results on the Abbotsford side with caution, or rather to see it as a potential withdrawal capacity in the future, provided that the original natural capacity of the east side of the aquifer is actually capable of supporting artificial withdrawal.

In Langley, the situation is different. It is known that water from the aquifer still exists in this municipality, since there are currently 7 major municipal wells tapping this aquifer. Given this situation, it is natural that self-supplied properties over the aquifer will also tap into this aquifer rather than go to the added expense of drilling deeper, provided that the water quality can be maintained. For this reason, it seems that consumption from the Langley-side is perhaps more important to control, as it is this side of the aquifer that will suffer the most when aquifer depletion becomes critical.

4.3 Sub-sample Trends

The sub-sample is a selection of properties on the Township of Langley's municipal distribution system that were selected for the purpose of getting more detailed seasonal consumption information. The selection criteria was originally made based on a three-tiered criteria system that was meant to identify the best properties in each CIIO group with which to represent consumption over the aquifer. However, due to unforeseen difficulties with getting data from the selection of ideal properties, it became meaningless to try to represent consumption with these sub-sampled properties despite attempts to correct for the discrepancies caused by the non-representative properties. As a result, the original purpose of this sub-sample could not be met, however, the data was retained to give an idea of the seasonal variations in consumption between different land uses. Figure 4.5 shows the average weekly consumption for different land use categories between September 2005 and May 2006 (see Appendix IV – Table 4.N).

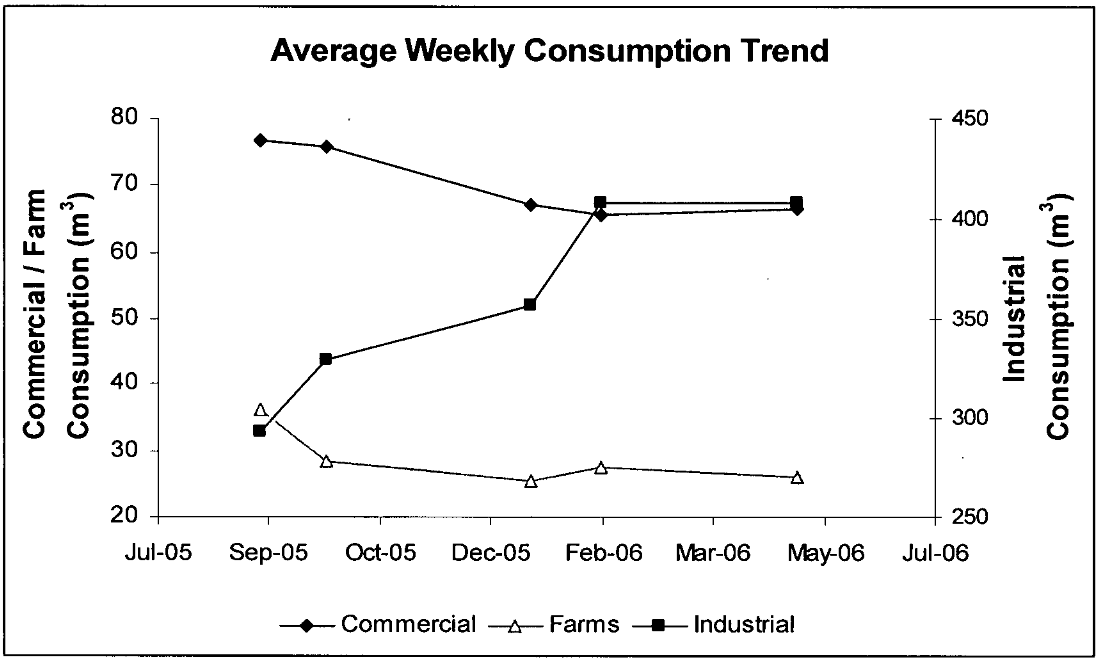


Figure 4.5 The weekly averaged consumption trends of commercial, industrial and farm properties within the sub-sample. Industrial consumption is shown on a secondary axis to allow a better comparison of trends between the land use categories.

Farm properties were originally labelled as agricultural on the municipal supply, but do not necessarily remain so, since many are now just residential use. It is important to note that the actual numbers for consumption are not important because they were derived from only the sub-sampled properties, which are no longer representative of their respective categories. What is more important is the trend itself. Figure 4.5 shows that between September and May, both commercial and farm consumption had a general decreasing trend, suggesting that winter consumption is less than that of summer consumption. This is expected since demands for water are generally greater in the summer due to greater outdoor water use, however the average results hide a large variability within each category, both in terms of the actual volumes of water used weekly and the individual trends of each property. With the commercial properties, even though the majority showed reduced consumption in winter, there were a few that had greater consumption in winter and some were more seasonally variable than others. The same can be said of the farm properties. Conversely, the industrial average trend shows a strong increase in consumption during the 9 months of readings, peaking around late winter to spring. This suggests that industrial water use is greatest in the winter, but the industrial average is perhaps the most uncertain out of all the sub-sampled properties, since only 5 industries were actually read. One of the 5 industrial properties also happens to be one of the top ten biggest consumers on the municipal supply in Aldergrove, making it probable that the results are somewhat biased towards the trend of just this one property.

In conclusion, the sub-sample was useful in providing additional insight into the highly variable consumption patterns of different properties, and shows how difficult it is to try to estimate consumption for different categories since each category contains a wide variety of land uses that have different factors governing their need for water. Despite the lack of conclusion that can be drawn from the results of the sub-sample, the attempt provides a 'first look' at the dynamics of water consumption in greater detail than the biannual results can show, and can be considered a stepping stone towards more detailed study of water needs for the purpose of water management.

4.4 Natural Discharge

Based on the analysis by Piteau, (1997) and Golder, (2005), the Aldergrove aquifer is what is known as a 'leaky' aquifer, because this aquifer naturally receives and transmits water through the aquitards that surround it. For this reason, natural discharge estimation with leaky aquifers can be tricky, since it is difficult to determine how much water leaks out of the aquifer. One way to estimate leakage loss is to use a mass budget method.

If we assume that leakage represents all natural processes by which water is lost from the aquifer (thus inclusive of natural discharge to streams and via springs as well as between aquifers), then the mass budget of the aquifer can be defined as:

$$\partial S = R - C - L$$

∂S = change in storage
R = recharge
C = consumption (artificial withdrawal)
L = natural discharge

This can be rearranged as:

$$L = R - C - \partial S$$

If the estimates for recharge and consumption calculated for 2005 were used, then R and C can be assumed to be 26.5 and 7 million m^3 respectively. ∂S can be estimated from water level trends observed at the Township of Langley's municipal pumping wells. Graphs of the water level for the municipal wells were obtained from the Golder report (Golder, 2005). The trend from the pumping wells (which span up to 18 years) showed an average decline of 0.3 m/yr. Using the same type of method as with determining the aquifer's storage capacity, it was estimated that the volumetric water decrease within the aquifer ranged from 2.9 to 6.3 million m^3/yr (see Appendix IV – Table 4.O). This is with the assumption that the aquifer is unconfined with a uniform thickness and uniform decrease in head.

Thus natural discharge (in million m^3/yr) was calculated as:

$$L = 26.5 - 7 - (-[2.9 \rightarrow 6.3])$$
$$L = 22.4 \rightarrow 25.8$$

This estimate range is in accordance with the estimate derived by Golder, which is approximately 22 million m^3/yr (Golder, 2005). Annual variability for natural discharge is as large as that for natural recharge, but also more complex due to the equilibrium relationship between water already within the aquifer and water in the adjacent aquifers and aquitards surrounding it. As the aquifer's water content decreases, it can be expected that natural discharge will also decrease to a certain extent, and vice versa, which helps to soften any actual changes in water content in the aquifer on an annual basis, but it is expected that this equilibrium will not be able to adjust to rapid changes caused by artificial withdrawal.

4.5 Chapter Summary

The analysis from this chapter has shown that the Aldergrove aquifer area is unique, since its development is considerably distinct from that of either municipalities on the whole, at the same time, there are also differences within the aquifer (between land uses on either side of the border). As a 'transboundary' aquifer, the Aldergrove requires data from both Langley and

Abbotsford, forcing the analysis of the aquifer to be split into two parts. This creates issues when one side of the aquifer suffers from a greater data deficiency. For agricultural and residential land uses, both sides of the aquifer suffer from the same limitations with respect to the assumptions used, but for the CIIO group, most of the uncertainty lies in the Abbotsford-side. The discharge component of an aquifer is often of most concern for water managers because it is the component that is most controllable, and the way in which it is manipulated results in the beneficial or adverse effect on the ecosystem. Since natural discharge is partially based on the consumption estimate, being able to confidently estimate consumption is doubly important for the management of the aquifer.

Chapter 5 – Changes over the Aquifer

All natural systems in the world are subject to evolution with time, which means that the type and magnitude of the processes that shape a region will not stay constant, but will in fact, change slowly to reflect the driving forces that shape the region. Over the limited extent of the Aldergrove aquifer, there are two types of changes; those that are natural and those that are developmental. Both are important in understanding the ways in which this aquifer will change with time.

5.1 Natural Changes

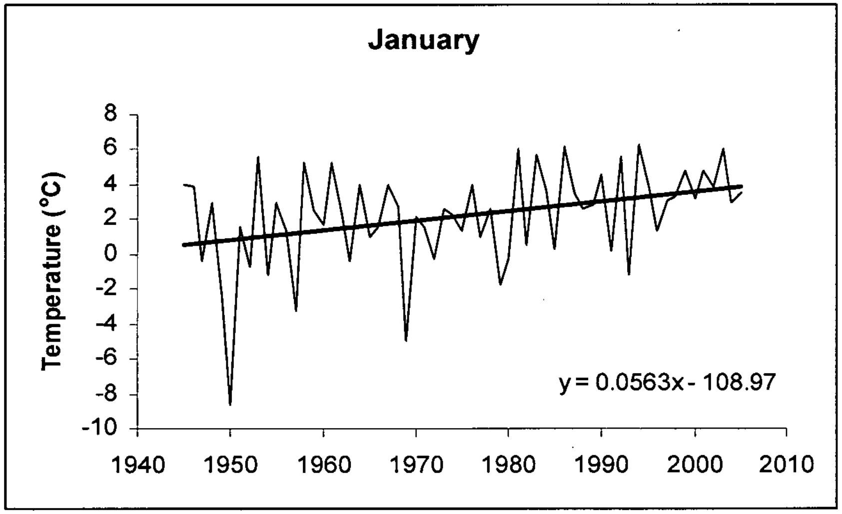
The types of changes that happen naturally with time that are the main concern for an aquifer system consists primarily of climatic changes. This refers to factors that affect the water cycle, the most important of which are temperature and precipitation.

All climatic data was obtained from Abbotsford Airport (EC, 2006a).

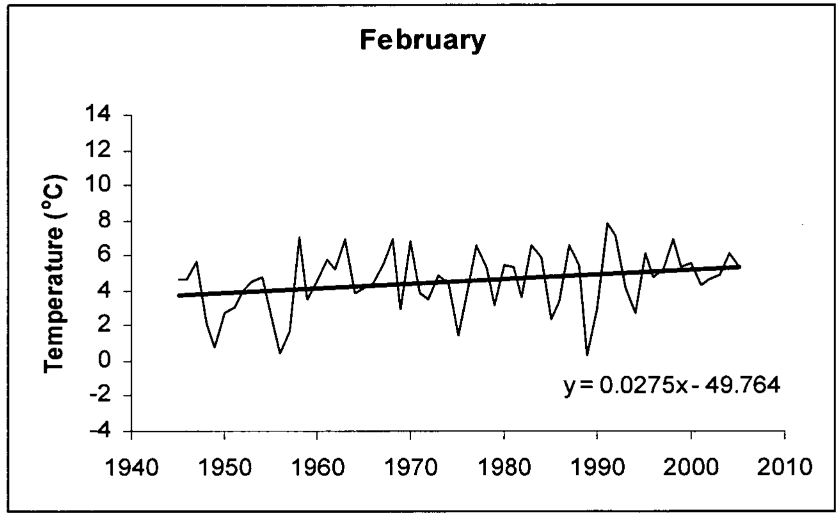
5.1.1 Temperature

Long-term Trend

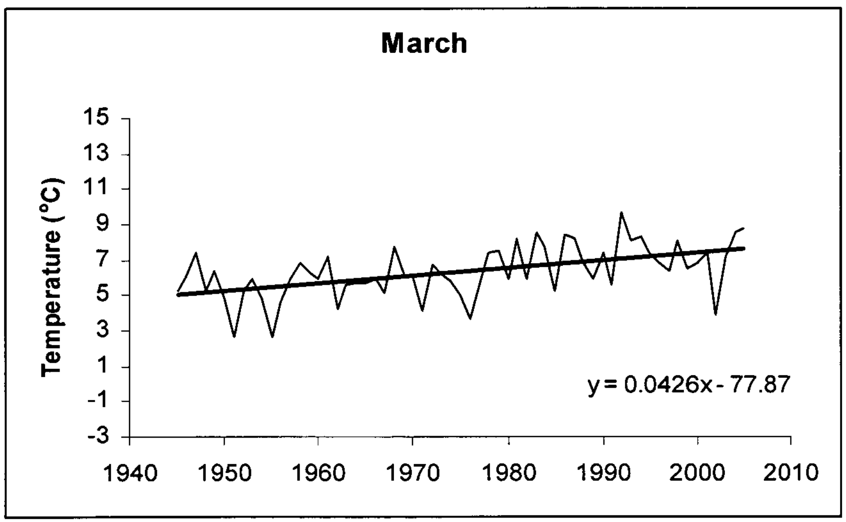
Temperature records for Abbotsford airport dates back to 1945, and include data on monthly temperature means each year. Figure 5.1(a-l) shows how the mean temperature has changed for each month of the year.


January
Temperature (°C)
y = 0.0563x - 108.97

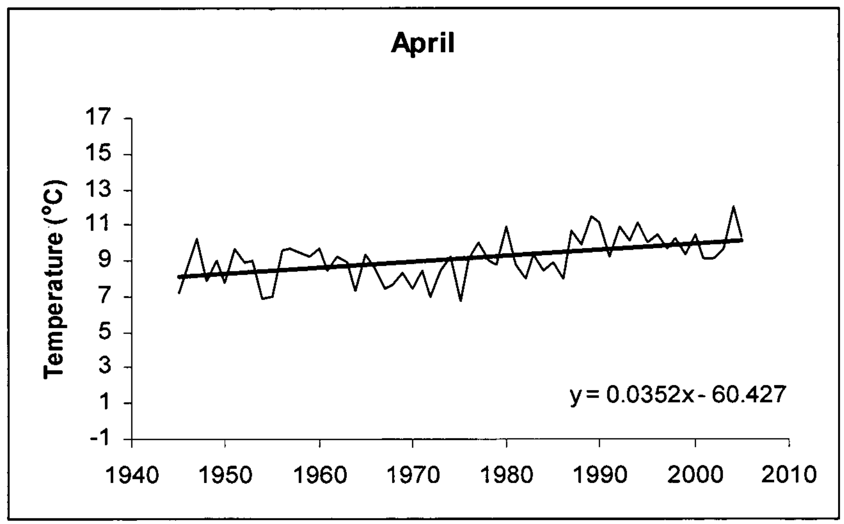
(a)


February
Temperature (°C)
y = 0.0275x - 49.764

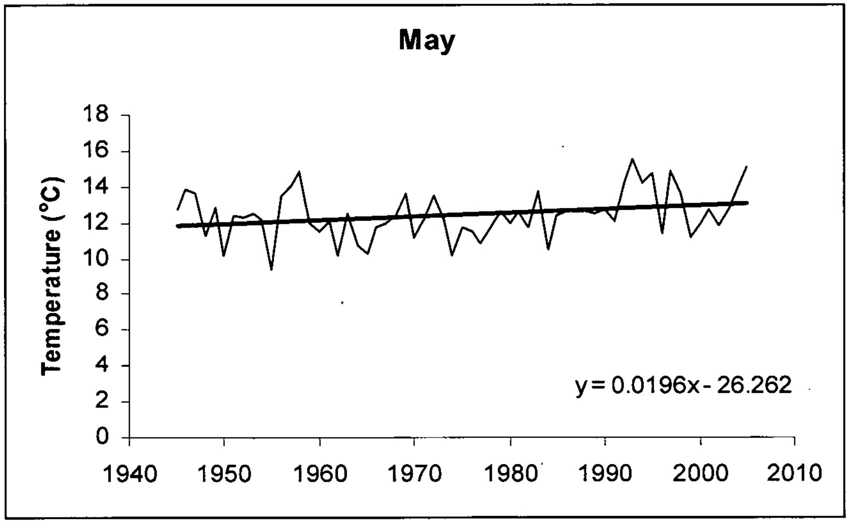
(b)


March
Temperature (°C)
y = 0.0426x - 77.87

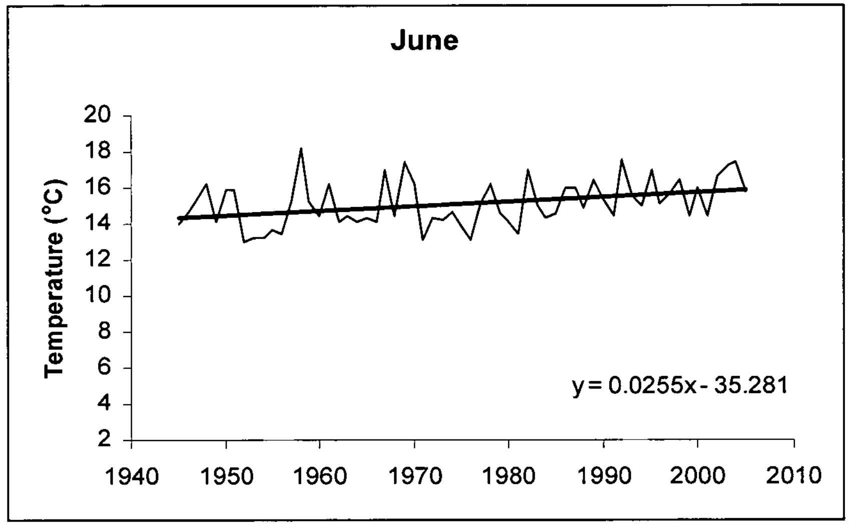
(c)


April
Temperature (°C)
y = 0.0352x - 60.427

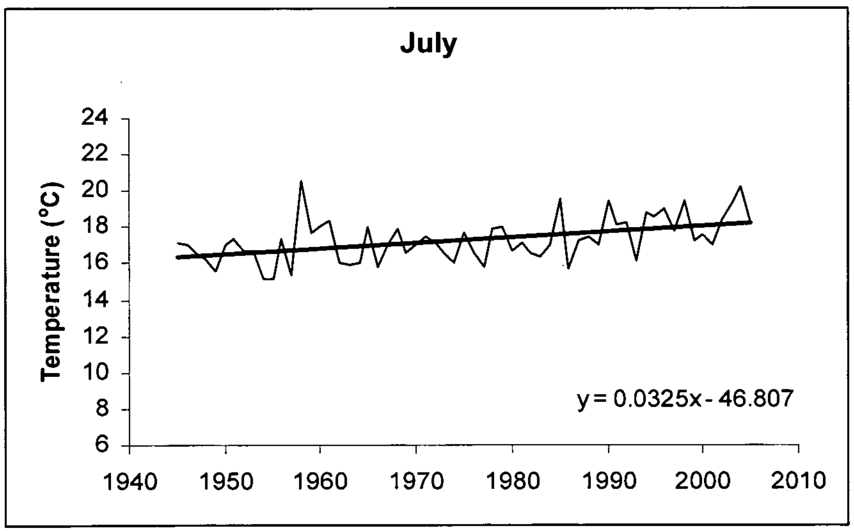
(d)


May
Temperature (°C)
18
16
14
12
10
8
6
4
2
0
1940
1950
1960
1970
1980
1990
2000
2010
y = 0.0196x - 26.262

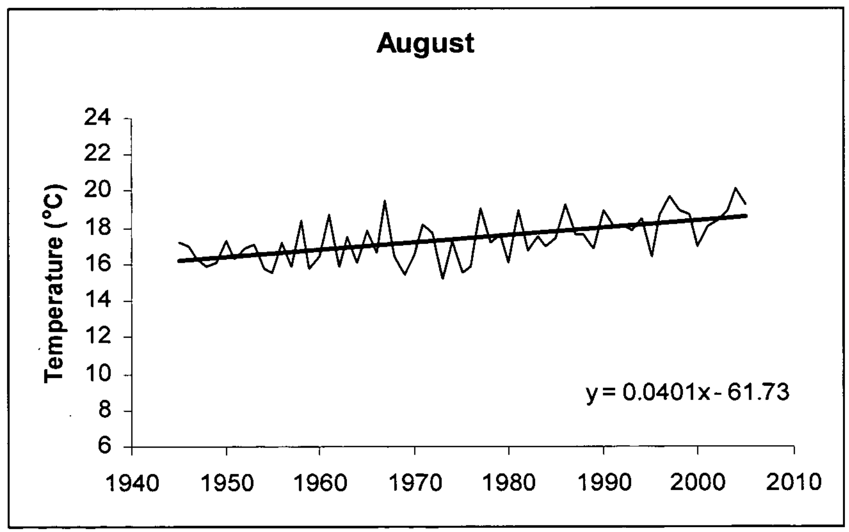
(e)


June
Temperature (°C)
20
18
16
14
12
10
8
6
4
2
1940
1950
1960
1970
1980
1990
2000
2010
y = 0.0255x - 35.281

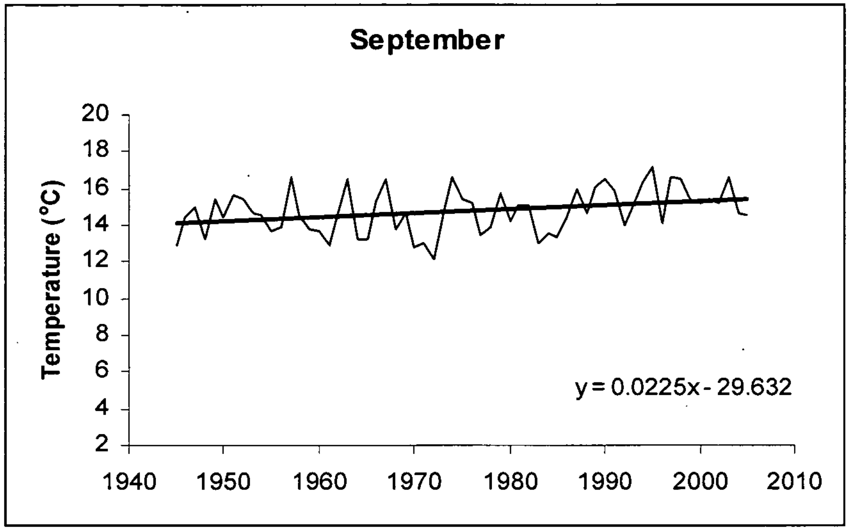
(f)


July
Temperature (°C)
24
22
20
18
16
14
12
10
8
6
1940
1950
1960
1970
1980
1990
2000
2010
y = 0.0325x - 46.807

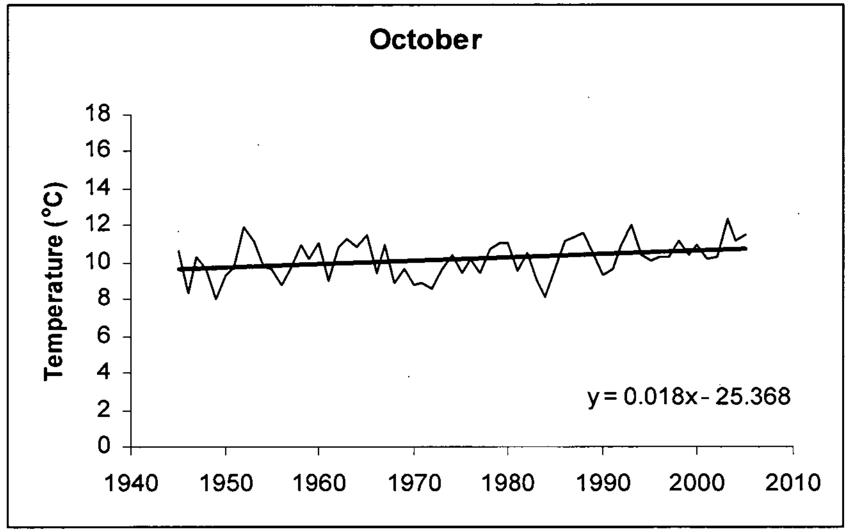
(g)


August
Temperature (°C)
24
22
20
18
16
14
12
10
8
6
1940
1950
1960
1970
1980
1990
2000
2010
y = 0.0401x - 61.73

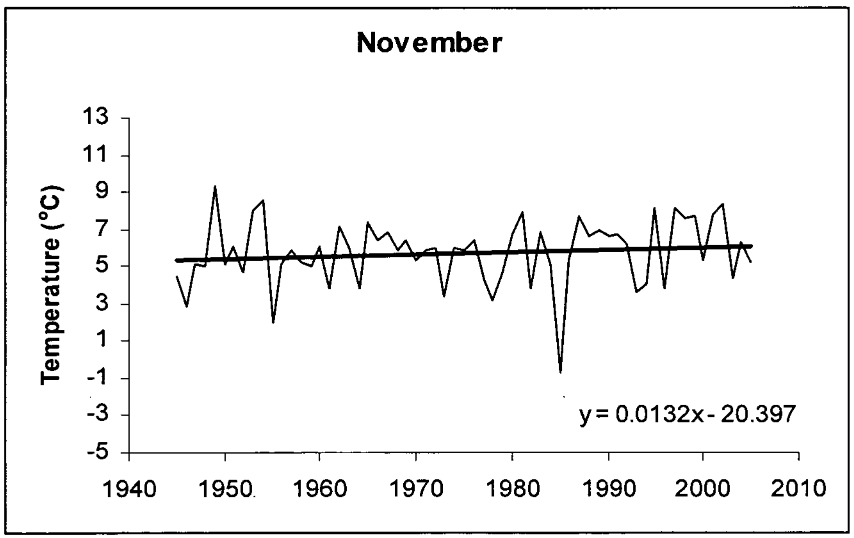
(h)



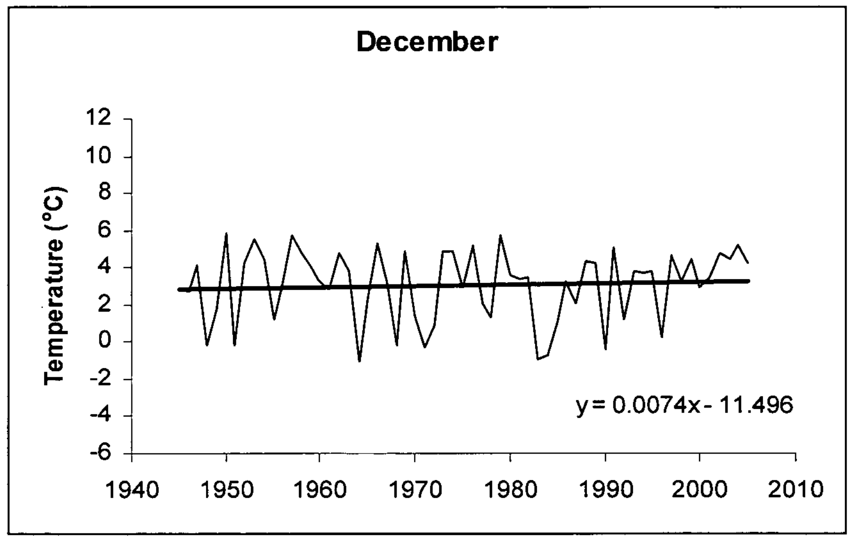
(i)



(j)



(k)



(l)

Figure 5.1(a-l) Long term monthly average temperature at Abbotsford Airport. The equation is that of the linear trend.

All monthly means show an increasing trend with time, suggesting that temperatures have been getting warmer in the long term, however, some months show faster increases than others. January is the month that has had the largest increasing trend since 1945, while December is the month with the smallest trend. This means that winters have been getting significantly warmer, which could impact recharge conditions by reducing snow coverage and the period of time when the ground is frozen. This could lead to more infiltration over the winter months, potentially increasing recharge into the aquifer during this time. The spring and summer months also show relatively large increasing trends, while the autumn months are less obvious in comparison. These warming trends are likely to influence consumption as well, especially for outdoor water use. Increases in evapotranspiration will likely change recharge volumes also, potentially reducing recharge to the aquifer during these months. This could result in an increased seasonal stress on the aquifer.

Comparison of Temperature and Consumption

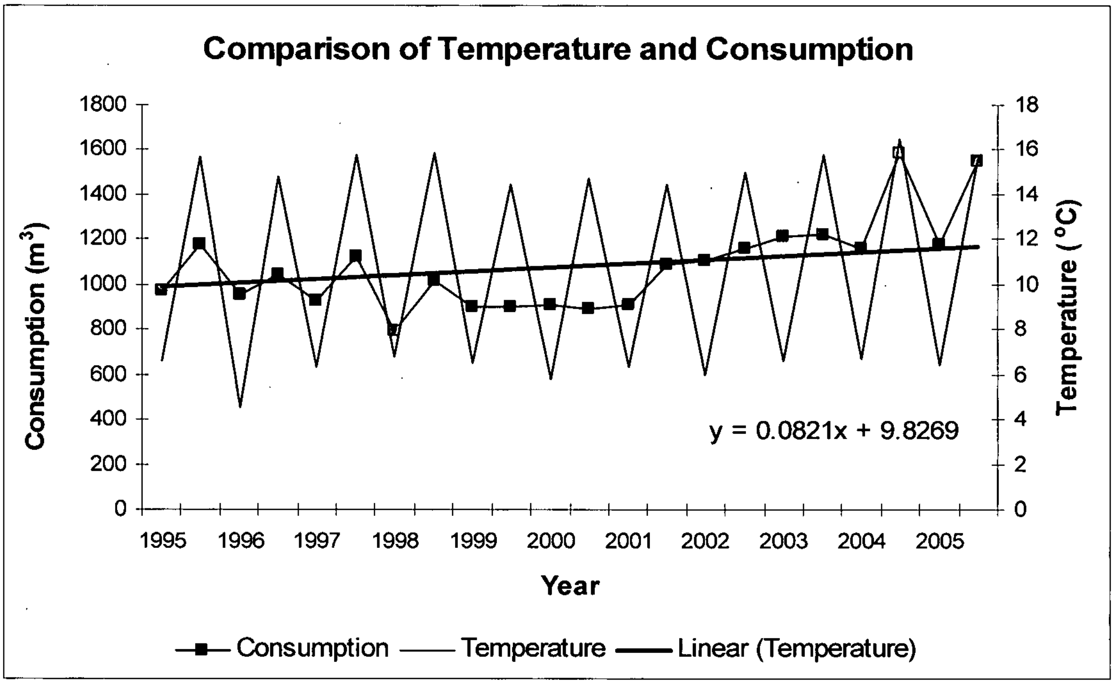


Figure 5.2 Comparison of the average biannual temperature change with the average biannual consumption trend from municipally metered properties in Aldergrove. The equation for the linear temperature trend is shown.

Figure 5.2 shows how temperature has changed in relation to average consumption from the metered properties. To compare the temperature data with the biannual consumption data, the temperature data had to be further simplified into the same biannual time periods. This resulted in a loss of much of the detail of the temperature changes, however, an increasing trend in temperature can still be discerned from the data, which is somewhat cumulative of all the increasing trends for each month, resulting in an even larger increase than in any single month. Even so, at first glance, there is no real correlation between temperature and consumption, only that both are increasing with time. There is some evidence to suggest that there could be a link between the sharper increase in mean temperatures in the past 4 years, and the change in consumption trend since 2001, however, it is not very obvious, and certainly does not explain the sudden spikes and dips in consumption since 2004. It is expected that temperature will not be the dominant factor affecting water use, but the results do support the theory that temperature is related to consumption, though an estimate of the actual magnitude of dependence will require a more detailed analysis of the interactions between climate and water needs.

5.1.2 Precipitation

Long-term Trend

Total precipitation data was obtained annually since 1945. Figure 5.3 shows that the long-term trend has been relatively constant, in that there seems to be only a very slight increasing trend of just under 1 mm/yr. However, this long-term precipitation increase is well hidden under the high variability of the annual totals, which ranges from a low of 952 mm/yr to a high of 2002 mm/yr. Within the long-term variation, it is possible to differentiate a weak cyclic pattern to the peaks and troughs, with a group of years being dominated by higher than average precipitation, followed by a corresponding group of years being dominated by lower than average precipitation. This cycle seems to last mostly between 3 to 5 years, and has been somewhat more prominent since the mid-1970s. It is likely that this pattern is somewhat linked to the Pacific Decadal Oscillation (PDO), which describes mayor shifts in climate (warm phase versus cool phase) over a period of a couple of decades. However, the significance of this large-scale and long-term climatic variability is not clearly distinguishable in Figure 5.3, though it has been found that the El-Nino Southern Oscillation (ENSO) has an impact on the unconfined Abbotsford aquifer (Fleming and Quilty, 2006), which partially overlies the southern portion of the deeper Aldergrove aquifer.

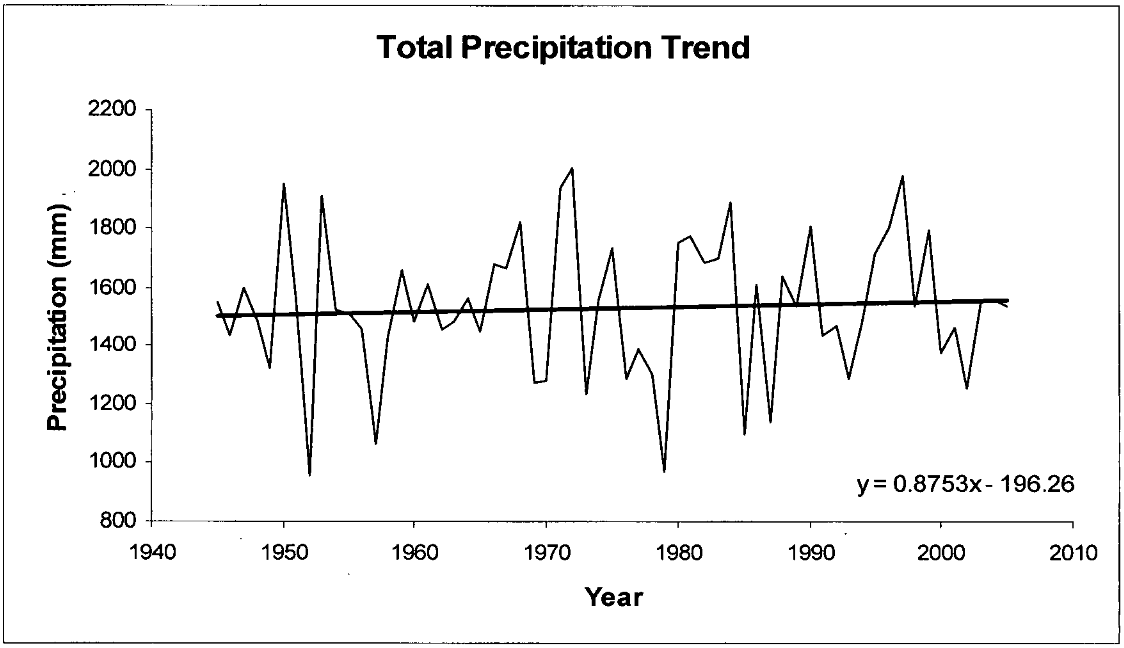


Figure 5.3 A graph of the total annual precipitation over Abbotsford Airport, with the equation of the linear trend.

In the long run, there is no evidence to suggest that the total precipitation trend will have caused any major shifts in the pattern of recharge determined by precipitation volumes, as the precipitation over the aquifer has arguably been consistent over the long-run in terms of its mean, though the variance of precipitation seems to be decreasing slightly with time. In terms of a shorter timeframe however, the observed cyclic pattern of highs and lows could cause measurable effects on the aquifer water level that is not simply a result of changes in consumption or land use. Indeed, according to Piteau, (2004) the slightly sharper declines in water levels in the aquifer since 1999 are likely due to the less than average precipitation between 1999-2004 as well as increased consumption withdrawal.

Comparison of Precipitation and Consumption

Since the consumption data is in the form of biannual (dry and wet season) totals, the precipitation data was also converted into biannual totals and then compared with the average consumption per meter for each biannual period. The results are shown on Figure 5.4.

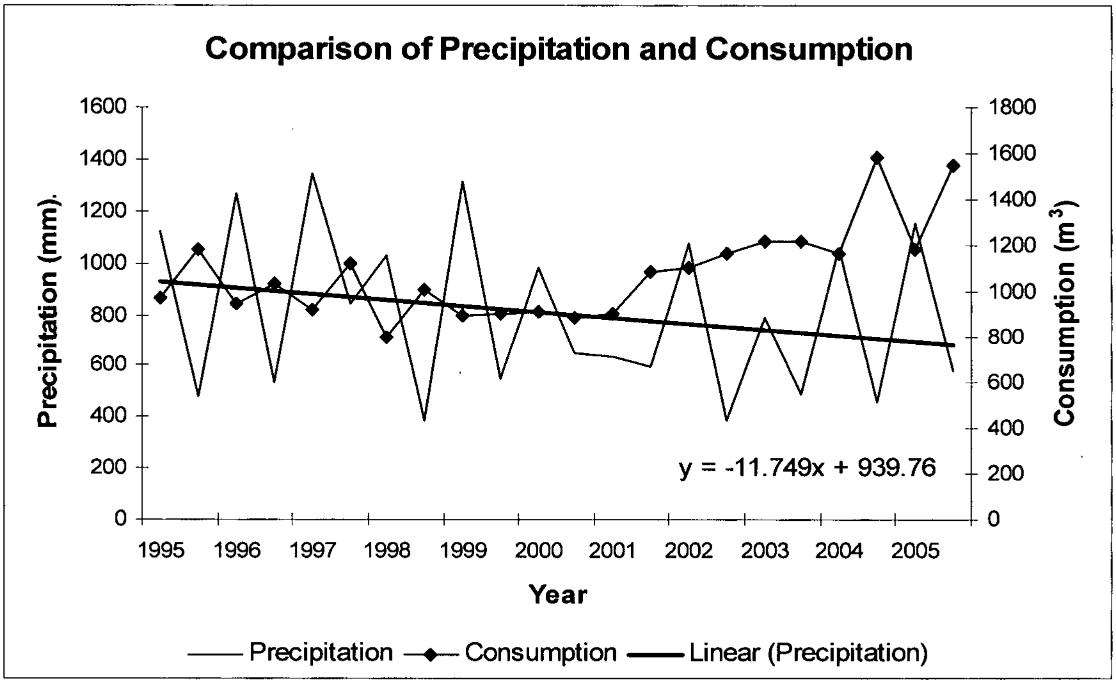


Figure 5.4 Comparison of the average biannual precipitation change with the average biannual consumption trend from municipally metered properties in Aldergrove. The equation for the linear precipitation trend is shown.

The precipitation data shows that there has been quite a strong decreasing trend in overall precipitation for the past 10 years, in contrast to the long term annual precipitation trend from Figure 5.3. There is also a strong difference between dry and wet season precipitation (except for the wet season of 2000-2001, which had the lowest precipitation for that biannual period out of the 9 years being compared). Conversely, consumption trends in Aldergrove for the first half of the time period (1995-1999) shows a trend directly opposite to that of precipitation, in that consumption is higher in the dry season whereas precipitation is lower. This contrasting pattern is less obvious in the latter half of the time period (2000-2004), as consumption remains relatively uniform between the periods of 1999-2001 and 2002-2004. However, the two 'step' increases in consumption observed in 2001 and 2004 both occurs during the dry season, in correspondence with the trend prior to 1999. The fact that consumption is highest in the dry season is not surprising, especially when outdoor water use is involved, however, the periods of relatively uniform consumption seems to occur irrespective of the precipitation patterns during that time, which in turn suggests that non-climatic factors were involved in influencing the consumption during these time periods. These non-climatic factors could include things like the initiation of conservation programs, changes in policy and legislation regarding water use (especially for industry and agriculture), changes in economy and thus economic outputs that used water, as well as many other possible influencing factors on behaviour and water needs. In addition, the consumption data itself is based on a small number of metered properties with a doubling of the number of metered properties between 1995 and 2005, thus the changes in consumption averages could also be partially an artefact of the change in number of metered properties.

5.1.3 Potential Future Effects on the Aquifer

Both precipitation and temperature are highly important climatic factors that will influence the sustainability of the aquifer, whether affecting recharge or influencing discharge, so any changes to the climatic pattern in the future can also be expected to cause some repercussions to the current climate-aquifer equilibrium. It is important to note that change doesn't necessarily have to be an increase or decrease in the factor observed, because a change in the variability of the factor (even though the mean stays the same) can also cause real changes in the aquifer.

The temperature data has shown a notable increasing trend, which suggests a definite change in the winter/summer recharge/discharge patterns. Since snow and the other forms of non-rainfall precipitation are not significant in this area (making up ~1% of total annual precipitation), it can be assumed that increasing winter temperatures will not lead to much increase in recharge, as runoff losses are unlikely to be reduced, while evapotranspiration may increase. Meanwhile, hotter summers will result in greater evapotranspiration as well as outdoor water consumption, meaning that water availability in the summer will decline.

The precipitation data has shown a slight increase in mean annual precipitation since the mid-20th century, which hides a more recent decreasing trend in the last 10 years, while the annual variability of precipitation has decreased very slightly with time. If the current rate of decrease continues, then there may be concerns about the natural recharge potential to the aquifer, but at the same time, if the variability was to decrease significantly also, then this would imply that monthly precipitation is more constant, and thus water available for recharge has the potential to increase. This would be a result of reduced runoff losses due to the elimination of long periods of over-saturation, even though evapotranspiration could potentially increase with the lack of long dry periods.

5.2 Developmental Changes

Developmental changes refer to those changes that occur as a result of development of the land. In terms of the effects that development can have on the aquifer, there are two main components of concern; impermeability and land use. Impermeability is directly linked to development in that increasing development means more roads, buildings and pavements that cover the ground and block infiltration of rainwater. Similarly, a change in the land use can lead to a change in water use as well, thus having the potential to affect the water balance of the aquifer.

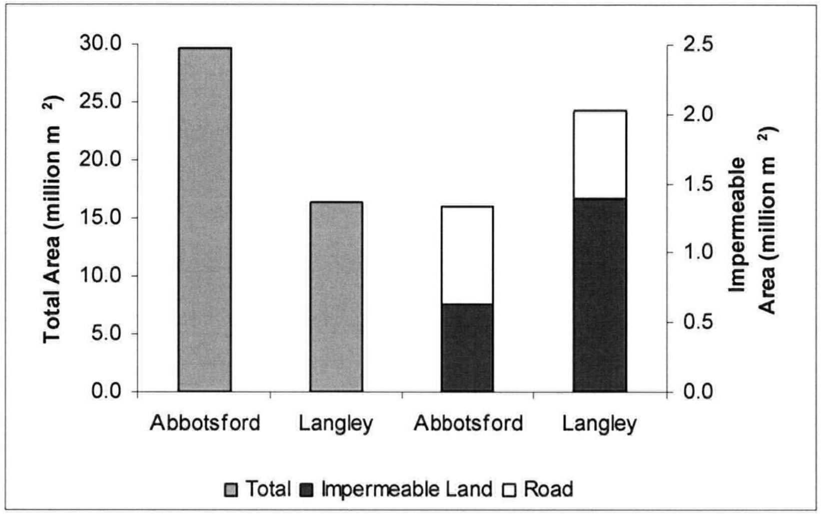
Both impermeability and land use information were derived from GIS analysis of aerial photos supplied by the Township of Langley and the Municipality of Abbotsford. Langley provided photos taken in 1995 and 2005, accompanied by land use designations determined in 2004. Since the 1995 photos also covered Abbotsford, only the 2004 photos and 2001 land use designations were requested from Abbotsford. Note that only the land directly above the aquifer was analyzed for developmental changes.

5.2.1 Impermeability

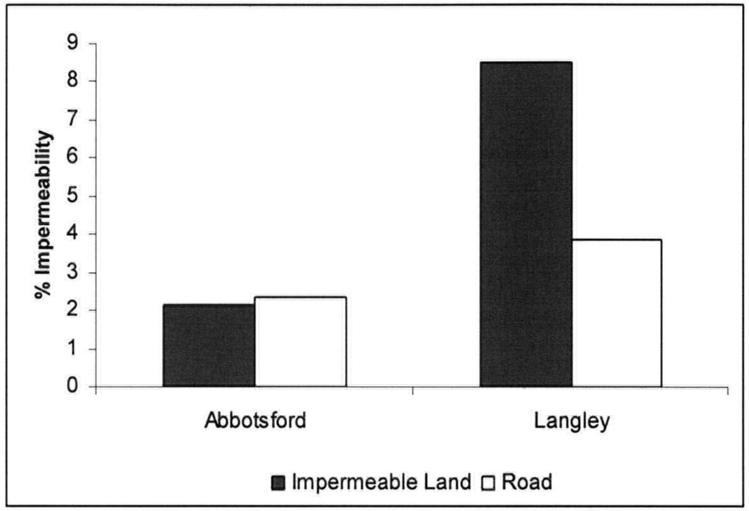
Chapter 2 has already highlighted the importance of impermeability in the recharge analysis, but it did not show how impermeability has changed with time. The method used to determine impermeability involved manually delineating impermeable areas on GIS, via visual analysis of the aerial photos. This was done for all land use categories with the exception of residential properties in Langley. With more than 3000 residential properties on the Langley-side of the aquifer, most of which were suburban homes, the impermeability of these properties were estimated based on grouping similar residential block types and randomly sampling blocks in each type. The impermeability of roads was estimated based on measurements of the length. These were grouped into several road width categories which are multiplied by the cumulative lengths to give an impermeable surface area.

Total Change from 1995 to 2005

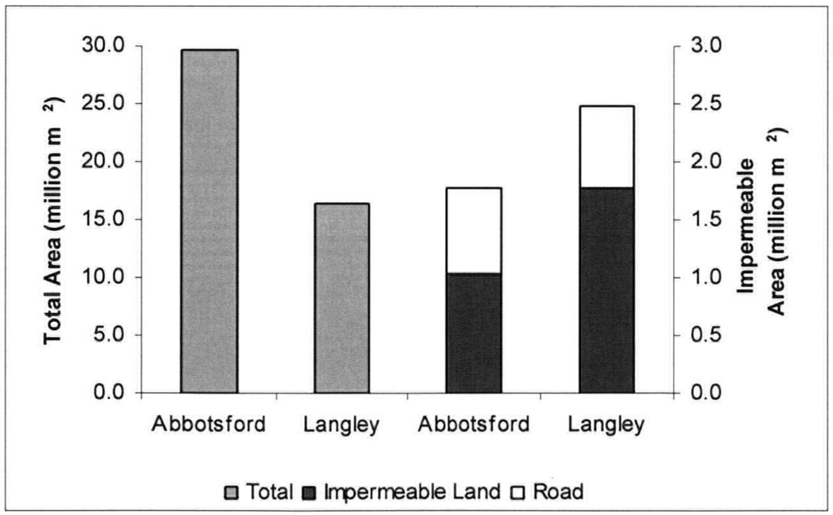
Figure 5.5(1a-b) shows the magnitude of impermeability in 1995. When all the impermeable areas are added up and compared to the total area of land over the aquifer, the result is a total impermeability of 7.4%, however, the spatial distribution of these impermeable areas differ considerably between municipalities, with 12.4% impermeability in Langley and 4.6% impermeability in Abbotsford. This means that the Langley part of the aquifer is much more urbanized than Abbotsford, since it has a greater impermeable area over a smaller total area. The impermeable areas attributed to roads are more or less the same for both municipalities. Ten years after the previous impermeability analysis, Figure 5.5(2a-b) shows that the overall impermeability of the aquifer has increased to 9.3%, which represents a 27% increase in the total impermeability over the aquifer. On a municipal scale, Abbotsford impermeability has increased to 6.1% while Langley impermeability has risen to 15.2%. This is equivalent to a 34% and 23% increase from 1995 respectively. Meanwhile, the addition of new roads has not risen as fast as land parcels, with both municipalities showing a much larger increase in imperviousness due to new buildings than due to new transportation routes (see Appendix V – Table 5.A-D).



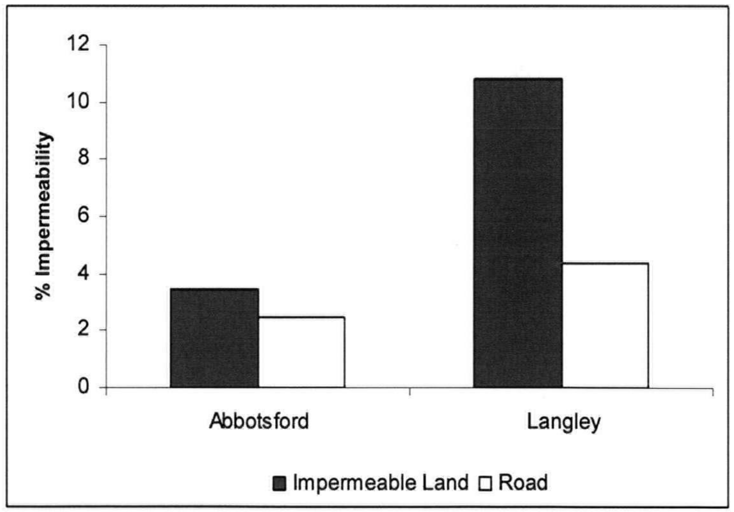
(1a)



(1b)



(2a)

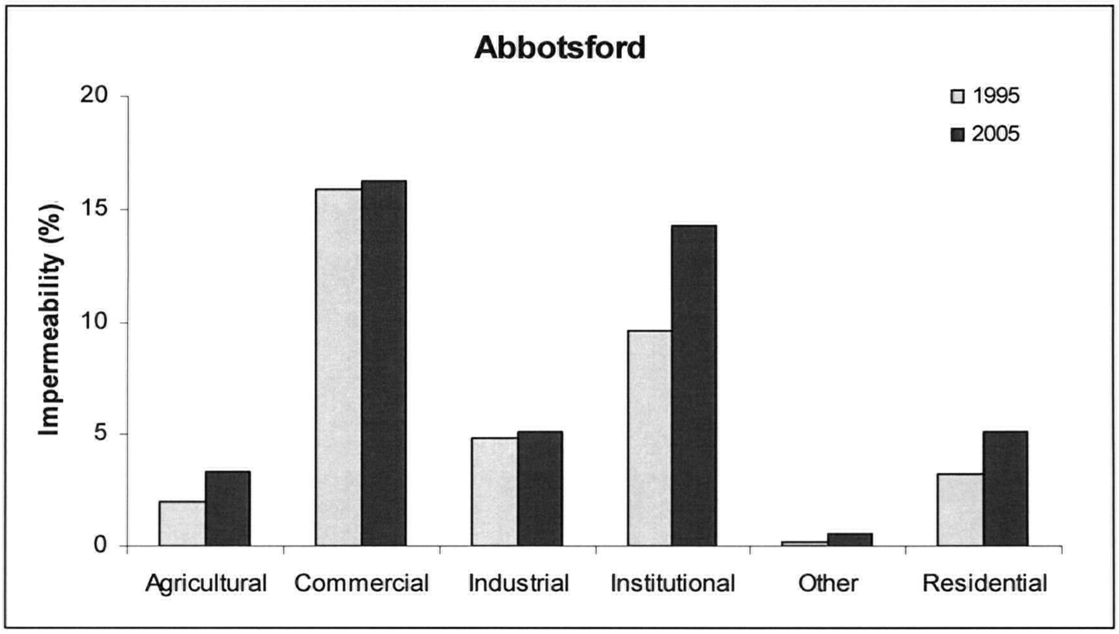


(2b)

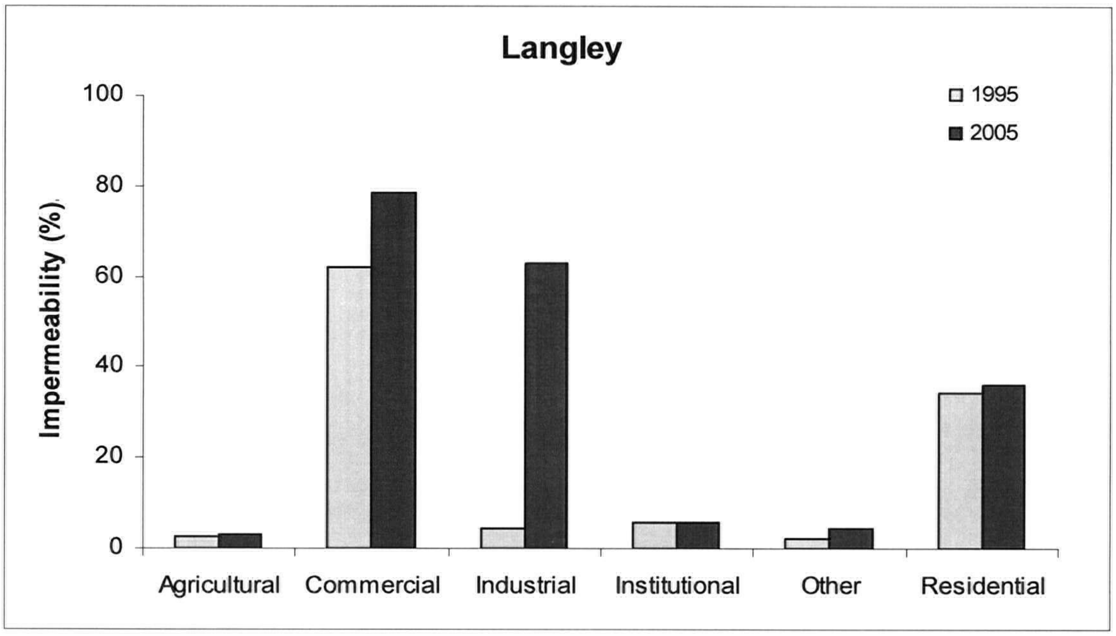
Figure 5.5 Changes in impermeability between (1a-b) 1995 and (2a-b) 2005. (1-2a) compares the total area of the 'aquifer' part of the municipality with the impermeable areas on a secondary axis, while (1-2b) compares impermeability as a percentage of the total area for each municipality.

The results for 1995 and 2005 show that total impermeability has increased substantially over the past 10 years, yet there is still a lot of permeable surface despite the overall increase in development. This can be attributed to the agricultural properties, which tends to be large parcels of land with very little imperviousness (with the exception of indoor agricultural operations). However, the distribution of imperviousness can be just as important as the total imperviousness, which is demonstrated by the highly impermeable urban area over the aquifer known as the town of Aldergrove. In this urban area, most of the rainfall will be intercepted by buildings or tarmac, which then funnels the water to storm drains thereby removing this water from the potential aquifer recharge supply. Such centralized areas of impermeable surfaces are much more effective at removing water than isolated patches of impermeable surfaces, due to the more thorough network of storm drains that usually accompany such areas. On the Abbotsford side of the aquifer, the situation is different, as there are no major central urban areas located directly above the aquifer, at the same time, land parcels in this municipality tends to be larger, which helps to reduce the impact of impermeability over the aquifer by allowing more rainwater to find its way onto permeable surfaces.

Difference between Land Use Categories



(a)



(b)

Figure 5.6 Changes in impermeability between land use categories in (a) Abbotsford and (b) Langley.

Figure 5.6(a-b) show that in both municipalities, impermeability has increase for every land use category since 1995, but the biggest increases have come from institutional properties in Abbotsford, and both commercial and industrial properties in Langley. There are also big differences between the impermeability of commercial, industrial and residential properties in comparison to their counterparts on the other side of the municipal border (see Appendix V – Figure 5.A-D).

Impermeability increases due to development of new land and the expansion and modification of existing developments. For some land use categories, the rate of increase in impermeability is quite large, reflecting the strong urbanization trend in those areas. Most of the additional development seems to come from new residential properties, which in turn create more opportunities for commercial and institutional properties to grow. With agricultural properties, Abbotsford shows a greater expansion of paved areas than Langley, likely due a greater intensification of agricultural operations in Abbotsford, such as more greenhouses. Conversely, most of the increase in impermeability in Langley originates from increasing development of the Aldergrove urban town centre and the new industrial park north of Aldergrove. Note that increases in impermeability of the 'others' category is an artefact of the reduction of undeveloped land, which have been converted to other land uses, rather than an actual increase in the impermeability of existing properties in this category.

Limitations of Impermeability Analysis

The main areas where errors and limitations to the analysis can occur include:

1. Date and resolution discrepancies between parcel maps and aerial photos.
2. Interpretation and visibility of impermeable areas, with the assumption that water from impervious surfaces are removed from the aquifer.
3. Assumptions for residential impermeability in Langley.
4. Use of aquifer boundaries as cut-off points for impermeability analysis.

<u>Data and Resolution Discrepancies</u>

Delineation is highly dependent on the accuracy with which the impermeable areas are identified and resolution of the aerial photos and parcel maps used. One of the issues affecting impermeability delineation was the discrepancy between the dates when the aerial photos, parcel maps and land use designations were made, which largely did not coincide. This resulted in some problems when the designated land use does not match the land use seen with the aerial photos. In addition to temporal discrepancies, resolution discrepancies can also cause a problem when they result in non-matching overlays. All the impermeable areas were determined from the aerial photos, yet the total area within each land parcel is determined by the parcel map and in terms of areas, the two maps do not align very well within GIS, with the parcel map areas often smaller in size than what the aerial photos show for each land use parcel. Moreover, the resolution of the aerial photos, particularly for 1995, makes it difficult to be certain of the boundaries between individual land parcel units, thus exacerbating the 'alignment' issue.

<u>Interpretation and Visibility</u>

Impermeability is visually determined, which can create some confusion when there are areas that appear to be impermeable via aerial view, but may not actually be so on the ground. Examples of this include undeveloped areas that have a parking area composed of loose gravels, and structures that have a roof, but the area below is actually permeable. Similarly, the reverse can happen when impermeable areas are not visible, leading to their exclusion from the analysis.

This can include buildings or paved areas hidden under tree canopies. Another interpretation issue which is perhaps more important is the inability to distinguish between total and effective impermeable surfaces. Ideally, it would be best to only determine effective impermeable surfaces as this is what will affect the water balance of the aquifer, however, this cannot be done by aerial photo analysis alone. Deciding what is effective impermeability is also a challenge, an example being the open ditch 'drains' alongside most of the roads in the area. These drains are not impermeable per se, but they do facilitate the rapid removal of water from the roads, leading the water to streams. Then again, water has a chance to infiltrate before reaching the streams, so can they really be considered impermeable? For the purpose of this analysis, total impermeability was determined, so this issue does not apply, but this is something that needs to be defined should a proper attempt be made to determine effective impermeability.

Assumptions for Langley Residential Properties

For residential impermeability delineation based on housing types, there are inevitably errors due to the approximation and assumptions used to estimate total impermeability. When large data sets prevent the practicality of manually delineating all the residential areas, the best that can be done is to try and obtain a representative sub-sample of the existing population, and the method used to sample residential properties did take into account the different types of residential properties over the aquifer. In addition, those residential properties that did not fit into the typical categories of 'block', 'cul-de-sac' and 'multi-family units/apartments' were placed in a 'miscellaneous' category where impermeable was manually delineated for each property, thus the error associated with inappropriate grouping was reduced.

Aquifer Boundaries as Cut-Off Points

This relates to impermeability changes as a measure of the potential effects on aquifer recharge. Only the surface immediately above the aquifer was used to estimate impermeability, even though it is likely that areas immediately outside of this region can contribute to recharge of the aquifer. Likewise, any below surface heterogeneity that may result in channelling of recharge water into or outside the aquitard area immediately above the aquifer is not accounted for. These are limitations of the impermeability analysis that needs to be considered should attempts be made to compare recharge based on changes in impermeability.

5.2.2 Land Use

Land use changes were determined based on a comparison of the aerial photos. This means that changes can only be recorded based on building footprints, and will not be able to account for changes that occur when an existing facility is converted to uses that fall into a different land use category.

Changes between 1995-2005

Table 5.1(a-b) shows that residential properties consist of the majority of new developments over the whole aquifer. Aside from this category, very little change has occurred in Abbotsford, though there have been quite a number of agricultural facility expansions. In Langley however, growth in new developments can be seen with every land use category except institutional, and there are also a greater number of property expansions on this side of the aquifer. Most of the growth in the Langley-side of the aquifer can be attributed to the increasing urbanization of the Aldergrove town centre, where the population has grown by about 2,500 people in the last 10 years (Dixon-Warren, pers. comm. 2006); however, both municipalities are under pressure from the increasing demand for residential properties. This is likely to be the driving force for an increasing number of suburban residential areas in Abbotsford, which in turn may attract more commercial, industrial and institutional land uses. Part of this has already been evident in Langley, where the growth of the Aldergrove area may have facilitated the boom in industrial facilities, concentrated in the northern part of the aquifer. The effect of this increasing development trend for both parts of the aquifer is that more extract will occur from the aquifer in the future, while water availability from the aquifer simultaneously declines. Increasing development not only heralds increasing extraction, but also increasing pollution and contamination of watersheds that are hydraulically connected to the aquifer. This applies not only to new developments but also the expansions of existing facilities that has been prevalent in the agricultural sector, which implies the intensification of operations and thus an increasing potential for environmental degradation.

Table 5.1 Changes in building footprints between 1995-2005 for (a) Abbotsford and (b) Langley. Residential Type 1, 2 and 4 refer to residential blocks, cul-de-sacs and rural/miscellaneous properties respectively.

Abbotsford	**Number of Properties**			
Land Use	New	Expanded	Reduced	Demolished
Agricultural	-	32	-	6
Commercial	-	-	-	-
Industrial	-	-	-	-
Institutional	-	1	-	-
Other	-	-	-	1
Residential	144	2	-	1
Total	*144*	*35*	*0*	*8*

(a)

Langley	**Number of Properties**			
Land Use	New	Expanded	Reduced	Demolished
Agricultural	13	40	7	-
Commercial	8	4	-	1
Industrial	10	-	-	-
Institutional	-	4	1	1
Other	19	3	-	2
Residential	125 (Type 1)	-	-	-
	24 (Type 2)	-	-	-
	64 (Type 4)	2	-	-
Total	263	53	8	4

(b)

The Effects of the Agricultural Land Reserve

The Agricultural Land Reserve (ALR) is a provincial designation for land that is 'reserved' primarily for agriculture, and covers 95% of the total land area over the Abbotsford part of the aquifer, and 68% of land area in Langley. According to the land use designations found in the land use codes for each land parcel provided by the Township of Langley, a considerable amount of land that has been designed as commercial, industrial, institutional as well as residential and 'others' are also found on the ALR. Land over the ALR represents 64% of the total individual land parcels in Abbotsford, and only 7% of the properties in Langley, which seems like a very small number compared to the total land area cover due to a large number of small sized properties (mostly suburban residential) that are excluded from the ALR. Since the ALR regulates land use, , it is difficult for such lands to be converted to different uses, particularly for major changes of the sort that would replace the original land use category with another. In both Abbotsford and Langley, the only changes that occurred on such lands were the creation of some new residential properties (on land that was previously undeveloped), the expansion of existing agricultural properties and a few operations that were demolished. According to the Agricultural Land Commission (ALC), one single family dwelling is allowed per land registry parcel within the ALR (ALC, 2003), thus non of the above 'land changes' that occurred within the ALR represent an actual change of land use subject to approval by the ALC Act. This means that for the past 10 years, land use in the ALR has effectively not be altered at all, suggesting that provided the ALC Act remains in place and is not significantly amended, it can be predicted that land use within the ALR will not really change in the near future. In the perspective of aquifer management, this is a very positive step, as this will have the additional benefit of limiting the amount of development and subsequent imperviousness that can occur over the aquifer, thereby slowing down the rate of recharge loss. The presence of the ALR may not be able to make much difference on the consumption side though, as intensification of agricultural production is expected to be one of the major contributors to increasing groundwater withdrawals.

5.3 Chapter Summary

The climatic trends seem to indicate a likelihood that water availability to the aquifer could decrease on the whole in the future. Whether this actually translates into reduced annual recharge to the aquifer depends on how sensitive the aquifer is to surface climatic conditions, given that most of the water recharges to the aquifer via adjacent geological units that may function more or less dependently from the variability of the climate above.

In terms of development, both impermeability and land use change are closely correlated, and can act as a double impact on the aquifer. Impermeability has the potential to reduce recharge to the aquifer while simultaneously, increasing development of the land will lead to increased water withdrawal. It is likely that the widespread coverage of the ALR over the aquifer has helped to slow down the rate of developmental changes, but it is questionable whether the current restrictions under the ALC Act can be maintained in the face of increasing developmental pressures. Overall, it is likely that reduced recharge due to climate change and increasing consumption due to development will drive aquifer depletion in the future.

Chapter 6 – Past, Present and Future Water Needs

Water withdrawal from the aquifer is constantly changing as a result of changes in development and other human activities. It is important to try and get an estimate of what the future needs may be so that appropriate planning can be done to reduce the negative impacts of depletion. Estimating the future requires first knowing the water balance of the past and the present, thus this chapter will consist of the following sections:

1. Water balance of the Past and the Present
2. Future consumption scenarios

6.1 The Past and the Present

6.1.1 Comparison of Consumption

The way in which development has altered land use above the aquifer in the past ten years has already been analyzed in *Chapter 5*. From that analysis, it can already be expected that consumption back then was not as high as it is now. Water extraction for human uses in the Past was determined in exactly the same way as that of the Present, detailed in *Chapter 4*. The only difference is that the data was based on 1995-1996, ten years prior to the present consumption estimate. The sources for the data remain the same as for those of the Present consumption analysis.

Table 6.1(a-b) shows the consumption portion of discharge for the Past and the Present. From this comparison, it would seem that consumption has increased by 31% in ten years. Agriculture in Abbotsford appears to account for the bulk of growth, but the CIIO properties in Langley also make up a large share of total growth over the aquifer. These two factors suggest that agricultural intensification in Abbotsford and urbanization in Langley are likely to be the main sources of increased water abstraction (see Appendix VI – Table 6.A-M).

Table 6.1 Summary of estimated consumption (m^3) from the aquifer in (a) 1995 and (b) 2005.

1996	Abbotsford	Langley	Total
Agriculture	1,764,519	931,853	2,696,372
CIIO	39,318	1,091,469	1,130,787
Residential	112,498	1,370,557	1,483,055
Grand Total	1,916,335	3,393,879	**5,310,214**

(a)

2005	Abbotsford	Langley	Total
Agriculture	2,699,733	1,141,710	3,841,443
CIIO	44,539	1,487,831	1,532,370
Residential	112,498	1,474,823	1,587,321
Grand Total	2,856,770	4,104,364	**6,961,134**

(b)

6.1.2 The Water Balance

A simple way of determining the water balance is to compare recharge against discharge. Since discharge is made up of two components (natural and consumption), it is possible to determine what the maximum consumption can be in order to prevent a loss of water from the aquifer.

Recharge in 2005 was estimated to be 26.5 million m^3/yr. Natural discharge in 2005 was estimated to be between 22.4 – 25.8 million m^3/yr. Thus the maximum consumptive withdrawal C_{max} that can be supported without depleting the aquifer is:

$$C_{max} = 26.5 - 22.4$$
$$= 4.1 \text{ million m}^3\text{/yr}$$

It is difficult to give an error margin for this value because both recharge and natural discharge are highly dynamic and will change annually. Natural discharge is also partially dependent on the magnitude of consumptive withdrawal, thus it is unlikely that the C_{max} calculated for 2005 can be applied to years with different recharge and consumption values. Nevertheless, the calculated C_{max} suggests that both the consumptions from 1995 and 2005 have exceeded the threshold for aquifer depletion, but only if Abbotsford is added to the total. If just the consumption from Langley was considered, then the aquifer may not yet have exceeded the depletion threshold, despite contrary suggestions from the decreasing water levels observed during the past twenty years at the municipal pumping wells, as shown in the report by Golder (2005). However, it is important to note that a decreasing water level does not necessarily mean that the sustainable yield of the aquifer has been exceeded, as it could just be a temporary adjustment prior to a new equilibrium within the aquifer (Sophocleous, 2005), but in this case, the relatively long time frame of decrease observed by most of the wells make this explanation less likely. The distinction between consumption from Abbotsford and that of Langley may be important because of the uncertainty surrounding water sources for properties in Abbotsford. Evidence from the previous chapters have already suggested that many properties in Abbotsford are not likely to be dependent on this aquifer, therefore, addition of the 'theoretical' Abbotsford consumption to the water balance is more likely to be an upper estimate of the true consumption.

The water balance indicates the current state of the aquifer and how anthropogenic consumption is affecting the overall water budget, and the results suggest that the aquifer is likely to be at or just exceeding its development capacity. This means that continued development of the aquifer, in the absence of additional recharge, may not be desirable, as 'mining' of the water is not a sustainable practice. It is important to note that 'sustainable development', can be interpreted at different scales. On a more local scale, sustainable development refers to the rate of pumping relative to the rate of capture, such that pumping must not exceed the rate at which water can travel through the aquifer. This implies that sustainable development is dependent on the dynamics of the aquifer rather than recharge, and several hydrogeologists have written about this in depth (Bredehoeft, 2002; Bredehoeft, 1997; Devlin and Sophocleous, 2005). On a more aquifer-wide scale however, recharge is connected to sustainability, because capture depends not only on the storage of the aquifer but also the boundary conditions. Induced recharge and/or reduced natural discharge are both part of the response of an aquifer to water extraction (Sophocleous, 2005), but there is a finite amount of 'induced natural response' that can occur given increasing extraction. Thus the point at which the induced natural response can no longer match the extraction is the point where the aquifer becomes unsustainable. This study on the

Aldergrove aquifer concentrates mostly on the latter interpretation, whereby sustainable development actually means sustainability of the entire aquifer-water supported system, as the intention is not to look at the sustainable yield of specific pumping wells but rather the overall ability of the aquifer to continue meeting annual demands for water, while maintaining its ecosystem functions. Given the additional complexity of aquifer-ecosystem relationships, it is beyond the scope of this study to adequately account for effects on the ecosystem due to groundwater extraction, but it can be expected that if extraction is already past the point where the induced natural response can compensate, then ecosystem impacts are imminent.

In summary, the analysis from all the previous chapters gives a strong suggestion that the current state of the Aldergrove aquifer is becoming unsustainable. Even though it is not certain whether extraction has already exceeded the steady state potential of the aquifer, ecosystem impacts will occur before this happens, and this may have repercussions for development in the surrounding regions of the aquifer as well as above the aquifer itself.

6.2 Future Scenarios

It is undeniable that additional development over the aquifer will continue in the future, leading to greater consumption needs from the aquifer. The real question is how much more development will occur ten years from now, and what are the potential estimates of this future consumption? To explore the answers, three scenarios will be developed:

1. Business as Usual
2. Greater Growth
3. Conservative Growth

6.2.1 Business as Usual

The 'Business as Usual' (BAU) projection is based on a linear growth trend such that consumption in 2015 for a particular land use category was simply determined using the equation:

$$B = (C_{2005} - C_{1995}) + C_{2005} \qquad \text{(Eq.1)}$$

Whereby B is 2015 consumption given the BAU trend and C denotes consumption in that subscript year. Table 6.2 shows the results for each of the individual CIIO properties.

Table 6.2 BAU projection for 2015 for the CIIO group. Values in m^3.

Land Use	Abbotsford	Langley	Total
Commercial (C)	2,281	620,356	622,637
Industrial (I)	22,516	851,415	873,932
Institutional (I)	0	61,052	61,052
Recreational/Other (O)	24,963	351,370	376,333
Total	**49,760**	**1,884,194**	**1,933,954**

On comparing these results to those of individual CIIO properties in 2005 (found in *Chapter 4*), it can be seen that consumption for all land uses increased in 2015, with the exception of institutional properties in Langley and recreational/other properties in Abbotsford, which showed less consumption in 2015 compared to 2005. The reason for this is because consumption by these land uses was higher in 1995 than in 2005, meaning that extrapolating the linear trend gives a corresponding continued reduction in consumption. These decreasing consumption trends perhaps should not be allowed in the calculation due to the inherent assumption that the number of properties in each category will increase, however, since the BAU trend is supposed to be a linear extrapolation of consumption, and the 'adjustment' of the negative trends (for example, by assuming consumption for these land uses stay the same as 2005 levels) makes only a 2% change to the total CIIO consumption result, it was deemed acceptable to leave the results as is.

Combining the CIIO results with that of agriculture and residential gives the total BAU projection for the aquifer, shown in Table 6.3.

Table 6.3 Summary of estimated 'Business as Usual' projection for 2015. Values in m^3.

BAU Projection	Abbotsford	Langley	Total
Agriculture	3,634,947	1,351,567	4,986,514
CIIO	49,760	1,884,194	1,933,954
Residential	112,498	1,579,089	1,691,587
Grand Total	3,797,205	4,814,850	**8,612,055**

Table 6.3 shows that if development was to grow for the next ten years in the same way that it has in the past ten years, then total consumption from the aquifer will amount to approximately 8.6 million m^3 in 2015. This estimate is double that of the C_{max} determined for 2005, and will undoubtedly cause considerable stress on the aquifer.

6.2.2 Greater Growth

The 'Greater Growth' projection is an attempt to estimate the upper limit of consumption needs in 2015, based on historic trends. Obtaining estimates for this projection is more complicated than with the BAU projection, and details of the methodology for each of the three land use categories are described below.

Agricultural Estimate

The estimate for each component of agriculture (fruits and crops, livestock, greenhouses, and pasture) was determined based on data from the census of agriculture in 1996 and 2001 (StatsCan, 2001). Values for the area of land occupied by each agricultural component were extracted from the census data, and used to determine the average area for each component on a 'per farm' basis. The difference between the two time periods was then used to project values for 2006 (since the 2006 census data is not available until the summer of 2007). On comparing the extrapolated 2006 areas with the observed 2005 areas (determined with GIS maps), it was found that the two results showed huge discrepancies, making it unrealistic to use the extrapolated 2006 area to project the agricultural area for 2015. For this reason, the alternative method to estimate agricultural growth was to base it on the observed area of agriculture in 2005, multiplied by the growth factor as determined between 1996 and 2001. This is considered a 'limited growth' estimate, since the growth between 1996-2001 (five year difference) was used to project growth between 2005-2015 (ten year difference). However, this is not considered to be a major problem since agricultural land use over the aquifer is already near capacity, thus the growth rate is expected to slow down naturally. Note that the projection represents a growth in agricultural area. Since the total agricultural area over the aquifer is not likely to actually expand in the future, any expansion of fruits and crops, livestock and greenhouse area was offset by an equivalent reduction in pasture area.

Based on the new estimates of agricultural area occupied by each component, the consumption for each component was calculated using the same method as described in *Chapter 4*. For obvious reasons, the ET values in 2015 are not yet known, thus the climate normal ET values obtained from Farmwest (Farmwest, 2006) for each month was used. The actual number of farms in each agricultural component remained the same as for 2005, since no new farms are expected to be created from the existing land available. Similarly, the water requirements per individual livestock remain the same as 2005 (see Appendix VI – Table 6N-V).

CIIO Estimate

For the CIIO group, 'growth' is simply the linear trend from 2000 to 2005, extrapolated to 2015. This is because for every CIIO group, it was found that the five year linear trend is always higher than the ten year (1995 to 2005) linear trend, making it possible to give a somewhat more realistic estimate of 'growth' potential based on real trends. The methodology for extrapolating 'growth' is discussed below.

The growth trend is related to the BAU trend, and the relationship can be expressed with the equation:

$$G = B \times K_C \qquad \text{(Eq.2)}$$

Whereby G is 2015 consumption given the growth trend and K_C is the 'growth' constant. This equation can be rearranged as follows:

$$K_C = \frac{G}{B} \qquad \text{(Eq.3)}$$

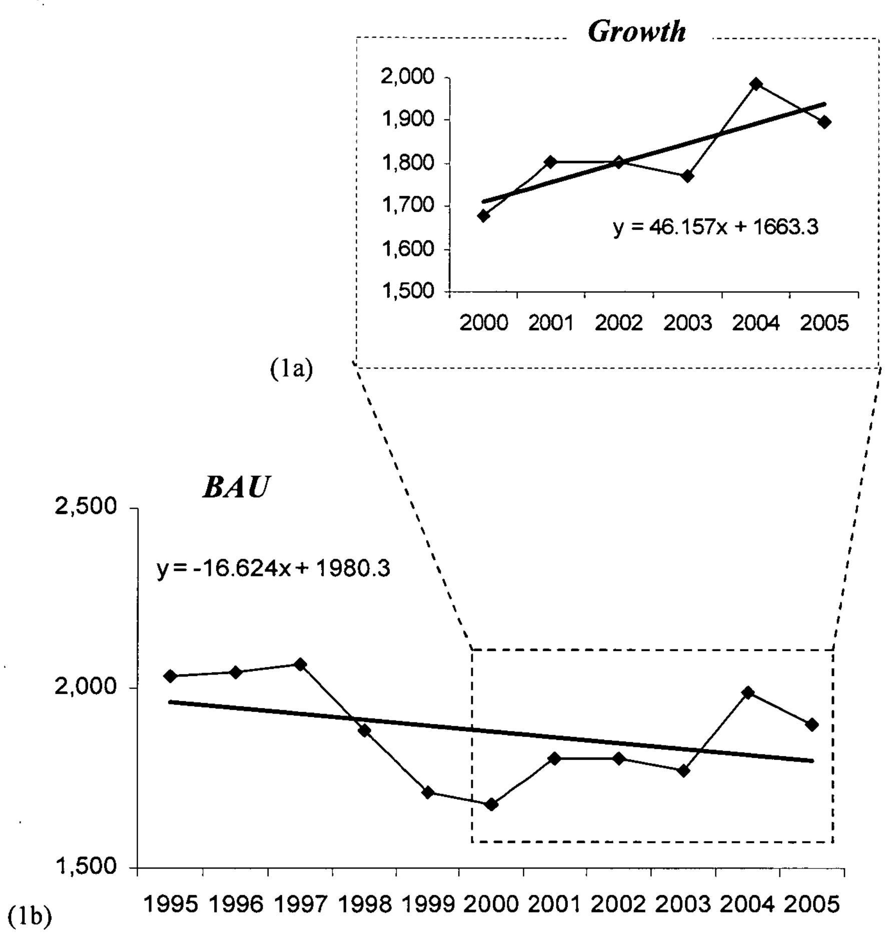
In order to derive K_C, a sample of properties from each land use category was selected. The sample consists of all the properties in each land use category that has a full 10 year consumption record from 1995 to 2005 (except for commercial, whereby the average of all the metered properties were used). The reason why the sample was used for most of the land use categories was because the number of metered properties in each category changed as more properties became metered since 1995. This makes it necessary to try to distinguish between consumption change as a result of existing properties using more water, as opposed to changes as a result of new properties adding their water consumption to the total for that category. In addition, the sample linear trends from 2000 to 2005 gave larger differences (between G and B) than those for the population linear trends from 2000 to 2005. This makes the K_C value larger for the sample than for the population, meaning that the resultant extrapolated G will also be greater. This is preferable since the growth trend is supposed to be an estimate of the uppermost limit of consumption in 2015, thus the sample trends were used to infer the population trend, assuming that:

$$K_C(sample) = K_C(population) \qquad \text{(Eq.4)}$$

To distinguish between B and G for the sample versus the population, sample B and G will henceforth be denoted as B_S and G_S respectively.

B_S is determined by using the 1995 to 2005 linear trend and solving the equation of the line to obtain a consumption result for 2015. G_S is determined by using the 2000 to 2005 linear trend and solving for consumption in 2015. Figure 6.1 shows the results of the linear 'BAU' and 'Growth' trends.

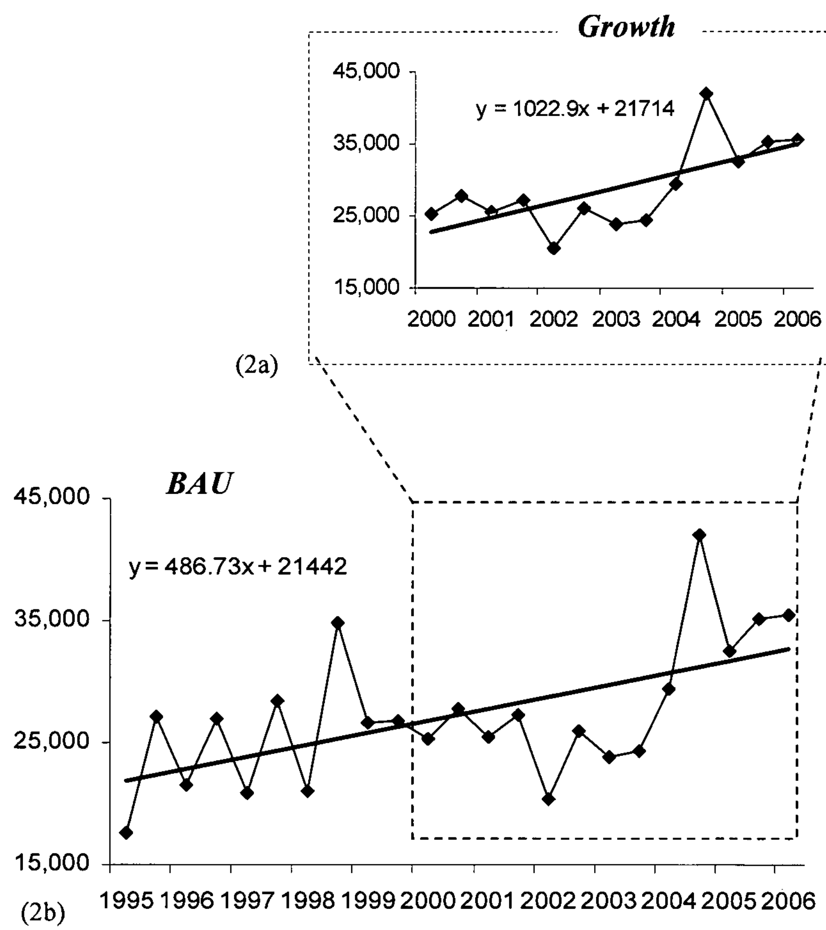
Commercial



B_S = negative, therefore:
$B_S = G_S(2000) = 1{,}663.3$

$G_S(2015) = 2{,}356$
$K_C = 1.42$

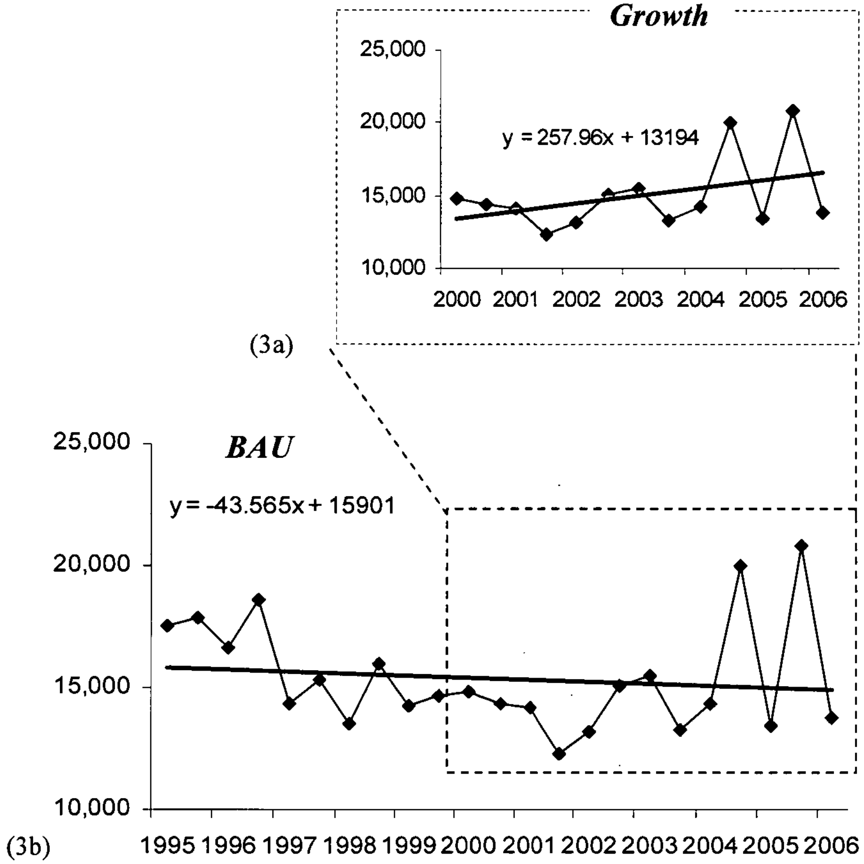
Industrial



$B_S \neq$ negative, therefore:
$B_S = 31{,}177$

$G_S(2015) = 52{,}401$
$K_C = 1.68$

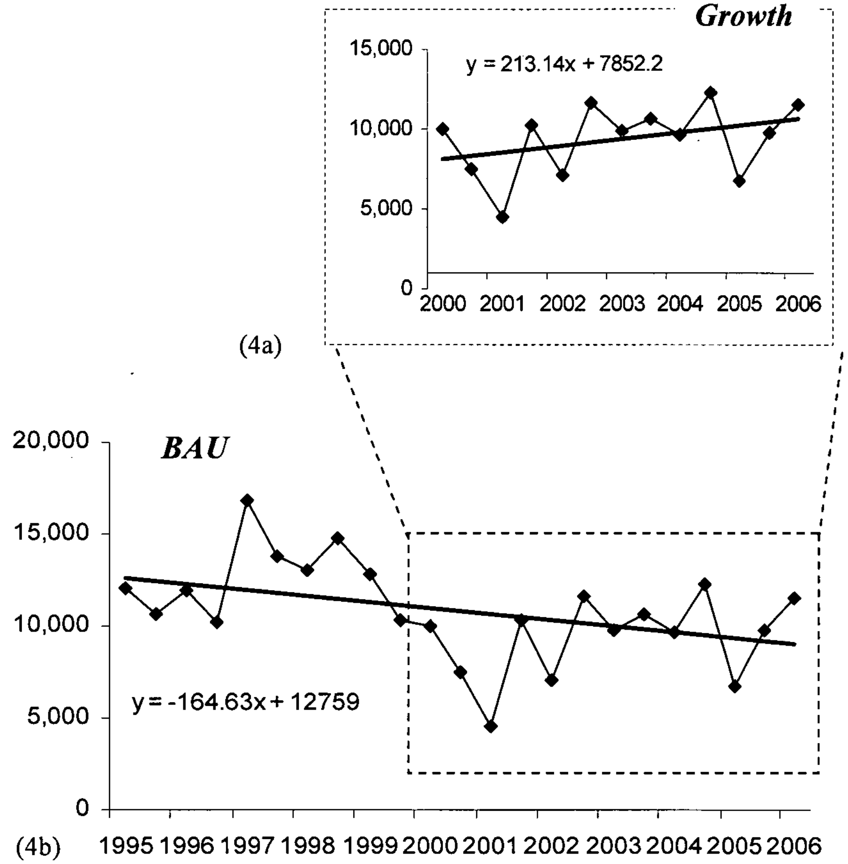
Institutional



B_S = negative, therefore:
$B_S = G_S(2000) = 13{,}194$

$G_S(2015) = 20{,}933$
$K_C = 1.59$

Recreational/Other



B_S = negative, therefore:
$B_S = G_S(2000) = 7{,}852$

$G_S(2015) = 14{,}246$
$K_C = 1.81$

Figure 6.1Graphs of linear trend for Growth (1-4a) and BAU (1-4b). The y-axis shows total consumption (m^3) for the sample (with the exception of commercial, which is based on average annual consumption), but the absolute values are not important since the purpose is to determine K_C.

Note that for all land uses except industrial, B_S is negative (declining), meaning that consumption is decreasing with time. The actual 'population' BAU projection allows for this decrease to subsequently project reduced consumption in 2015 for those land uses, however, when considering B_S for the Growth projection, using the negative B_S results may result in a highly exaggerated K_C, especially when the B_S is strongly negatively sloped. For this reason, it was considered too extreme to allow the negative B_S in the Growth projection, and instead, the following principle was adopted:

When the 1995 to 2005 linear trend = negative,
B_S = the G_S linear trend solved for the year 2000.

The reason why the result for the G_S in 2000 was used is because the consumption in 2000 is always less than that of consumption predicted by the B_S linear trend between 1995 and 2005. This means that using the G_S in 2000 allows for a greater difference between B_S and G_S without being over-exaggerated as with the negative B_S, thus a greater growth estimate for 2015 can still be produced.

Once both the B_S result and the G_S result for 2015 have been produced, K_C(sample) can be calculated using eq.3, and since eq.4 holds, G can be determined using eq.2 with B(population) and K_C(population) instead. The total result for the CIIO is shown in Table 6.4.

Table 6.4 Summary of the resultant 'growth' projection for 2015 using the derived growth constant K_C.

	BAU Projection for 2015			Growth Projection for 2015		
Growth Trend 2015	Langley (m^3)	Abbotsford[1] (m^3)	Growth Constant	Langley (m^3)	Abbotsford[1] (m^3)	Total (m^3)
Commercial	620,356	2,281	1.42	878,582	3,231	881,813
Industrial	851,415	22,516	1.68	1,431,042	37,845	1,468,887
Institutional	61,052	0	1.59	96,861	0	96,861
Recreational/Other	351,370	24,963	1.81	637,498	45,290	682,788
			Total	**3,043,983**	**86,366**	**3,130,349**

[1] Only those Abbotsford properties that are not supplied by City of Abbotsford water are included in the analysis.

Residential Estimate

The residential estimate was based on the population changes between 1995 and 2005. In Langley, the compounded annual growth rate (CAGR) for the town of Aldergrove was determined using the population numbers between 2001 and 2006 (ToL, 2005). The value obtained was used to extrapolate the population in 2015, and consumption was estimated assuming that the average consumption per person stays the same as that of 2005 (an average of 117 m^3/person/yr). The same method was used for Abbotsford, only the CAGR was determined from the 1996 and 2001 population census data for the Municipality of Abbotsford (see Appendix VI – Table 6.W).

Overall Projection

Table 6.5 Summary of estimated 'Greater Growth' projection for 2015.

Growth Projection	Abbotsford (m^3)	Langley (m^3)	Total (m^3)
Agriculture	4,201,176	1,523,843	5,725,018
CIIO	86,366	3,043,983	3,130,349
Residential	125,665	1,685,193	1,810,858
Grand Total	4,413,206	6,253,019	**10,666,225**

Table 6.5 shows that the upper limit of consumption in 2015 can reach 10.7 million m^3. Compared to the 'Business as Usual' scenario, most of the additional consumption in the 'Greater Growth' projection is expected to come from the CIIO group. This is supported by the greater growth trend seen from these sectors in the past five years, suggesting that water use by these businesses could be an important consideration in the future, particularly for Langley. Greater growth in the agricultural sector is expected to be limited, as the total amount of agricultural land is not likely to increase in the future, and there is only so much intensification that can be supported by the land. Since intensification of fruits and crops, livestock and greenhouse operations means an equivalent reduction in pasture land, there is naturally a limit to how much pasture land can be given away to other agricultural uses, since pasture is equally important for the maintenance of livestock operations, assuming that feed imports do not increase significantly. With the residential sector, the limited change in consumption compared to the other sectors does not reflect a limited growth of the residential sector but rather, is a result of the relatively small quantities of water that are used per property compared to the other land use categories. Of the three groups of land uses where future consumption is estimated, only the residential sector was estimated based on projected changes in the number of people by 2015. Agricultural consumption was based on changes in intensification, while CIIO consumption was based on the increasing water requirements of existing businesses as a proxy for increasing consumption given the addition of new properties in the future. Since the amount of water consumed per person is not projected to increase in the next ten years, the only changes in total residential water use will come from the addition of new residents over the aquifer. Thus according to the trends of the past, residential growth was estimated to have a CAGR of 1.4% in Langley and 1.5% in Abbotsford. For both municipalities, these estimates are low, since the Township of Langley gave an estimated CAGR of 1.9% (MacKinnon, 2006) while the City of Abbotsford population estimates gave a CAGR of 2-2.6% between 2006 and 2016 (CoA, 2006). Nevertheless, the estimates that were used for the 'Greater Growth' projection is considered to be more accurate, as it is more directly obtained from the locality of the aquifer as opposed to the whole municipal region, and the preliminary consumption analysis in *Chapter 4* has already shown that the trends of the municipality does not necessarily reflect that of the Aldergrove aquifer area.

6.2.3 Conservative Growth

The 'Conservative Growth' projection is an attempt to estimate what total consumption from the aquifer will be like given that future development does not use up more water than it already is. This is the 'lower limit' of consumption for 2015.

Estimates

Of the three projections for 2015, the 'Conservative Growth' projection is arguably the most difficult one with which to determine future consumption, since a lot of the reduction will rely on changes in practice and technology that are not fully realized yet. For this reason, the methods used to determine consumption was kept very simple.

For agriculture, consumption was assumed to stay the same as 2005. The justification for this is that despite inevitable intensification, agricultural properties have the ability to convert to more efficient watering systems which could potentially water, such that water use can be maintained at 2005 levels despite increases in productivity. Economic factors such as increasing the cost of water can also encourage conservation. Greater reductions in water use to levels prior to 2005 is unlikely however, as agricultural water use is largely a 'non-return' use, in that water is taken up by plants and generally is lost from the system and cannot be recaptured for use. Thus the goal of maintaining water use at 2005 levels should not be particularly unreasonable and could easily be achieved through conservation.

For the CIIO group, consumption was assumed to be able to reduce to 1995 levels. The justification for this is that water used by most of this sector has a high potential for recycling and reuse, as there is very little 'non-return' use. In a study of commercial, industrial and institutional water use in California, water use in all businesses could be grouped into six broad end uses: sanitation (washrooms), cooling, landscaping, process, kitchen and laundry (Gleick, Srinivasan and Henges-Jeck, *et al.*, 2004). With the exception of certain forms of process water use, all the other end uses are 'return' uses and have a significant potential for water recycling and reuse. End uses such as washroom, laundry and landscaping also have a great potential for improvements in efficiency. For these reasons, it is plausible that the overall water use in this group can be greatly reduced.

For residential consumption, estimates are based on real values obtained from the 'privately metered' properties in Langley. In *Chapter 4*, the conservative estimates of residential water use were based on the consumption of the privately metered properties, which are more water conscious consumers. By averaging the consumption from these properties, it was found that annual water use can drop to 102 m^3/person/yr. Using this new value, residential water use could be determined given the same increase in population as with the 'Greater Growth' projection. Note that this conservative residential consumption is nowhere near the level of true conservation that can be attained, as residential consumption in Europe demonstrates that average consumption can be as little as 55 m^3/person/yr (Brandes and Ferguson, 2003).

Overall Projection

Table 6.6 Summary of estimated 'Conservative Growth' projection for 2015.

Conservative Projection	Abbotsford (m^3)	Langley (m^3)	Total (m^3)
Agriculture	2,699,733	1,141,710	3,841,443
CIIO	39,318	1,091,469	1,130,787
Residential	108,774	1,458,689	1,567,463
Grand Total	2,847,825	3,691,868	**6,539,693**

Table 6.6 shows that if all development over the aquifer was to become highly efficient and conserving, then total water consumption by 2015 can be as low as 6.5 million m^3, despite increases in the number of properties and intensification. With this scenario, the grand total consumption is lower than that of the 2005 estimate, as a result of the reduced consumption in both the CIIO and residential sectors, however, it is important to note that

this conservation projection still shows water consumption to be above the theoretical 'sustainable' limit.

6.2.4 Range of Consumption for 2015

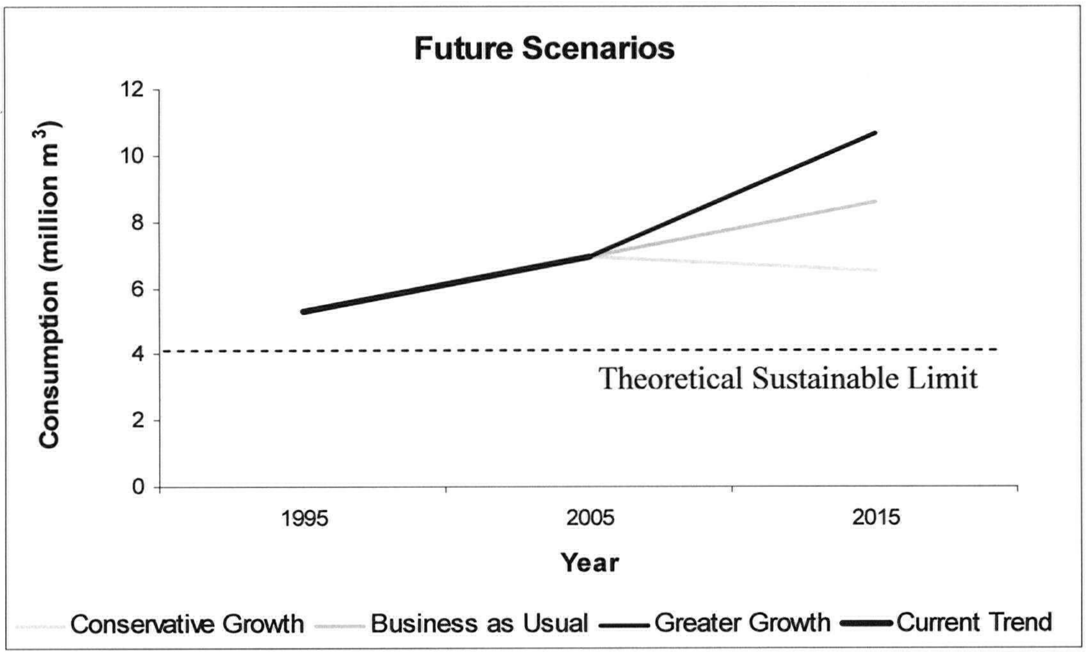


Figure 6.2 The current trend in consumption and the 3 potential scenarios for 2015.

Figure 6.2 shows the overall range of consumption that may be encountered in 2015 according to the situations as expressed in each scenario. The higher and lower limit has a difference of 4 million m^3, which represents a big range of potential future consumption estimates. If development over the aquifer is allowed to continue in much the same way as it is now, then there is a danger of facilitating a future consumption that is closer to the 'Greater Growth' estimate. Assuming that the C_{max} does not increase substantially corresponding to the increased extraction, then it is certain that by 2015, the level of consumption would be sufficiently past the equilibrium point, meaning that the aquifer is being mined, whereby water which cannot be replaced by natural recharge is drawn out of the aquifer. Once mining of the aquifer occurs, the length of time that this mining extraction can be sustained will depend on the magnitude of 'over-extraction' relative to recharge, and the existing storage of the aquifer. However, the effects of a depleting aquifer are likely to be observed at the extraction locations even before the wells run dry, and wells will dry up before the aquifer has been completely depleted. Negative impacts on the ecosystem will also be seen and felt at an early stage. Thus if this consumption scenario is expected to be the case in the future, then action needs to be taken now to consider alternatives, either in terms of importing water or enhancing recharge.

On the lower end of the scale, if development over the aquifer can be restricted and water use made more efficient, then there is a chance that total consumption from the aquifer can tend towards the 'Conservative Growth' estimate. Assuming that recharge and natural discharge is not affected by climate change and increased urbanization, then the rate of decline will be approximately the same as current rates, which is still unsustainable, but it will help to prolong the life of the aquifer while alternative solutions are sought. Unfortunately, facilitating more water-efficient development will not be an easy task, and to achieve the reductions of the 'Conservative Growth' estimate will require not only insuring that new developments are made to be as water-efficient as possible, but that all existing properties and businesses are retrofitted for water-efficiency as well. Both tasks will undoubtedly require time and resources and involve multiple hurdles, thus it may be unrealistic to expect this to be achievable in ten years time. Nevertheless, a number of initiatives and conservation options can be adopted that are not as difficult to implement, yet will set the first steps towards reducing consumption, and can start to highlight the issues to the public so that additional and potentially more drastic measures can be accepted and implemented sooner in the future.

Chapter 7 – Demand Management Strategies for the Aquifer

The challenge of ensuring sufficient water availability for the growing needs of the community over the Aldergrove aquifer can be tackled in a variety of ways. Since the shift towards more demand-based management (DM), numerous methods to reduce water use have been devised, some of which are general, while others are highly specific to a particular end use of the water. It is impractical to consider each and every method given the scope of this research, thus efforts will be focused on DM via improving the efficiency of water use, and the reductions that can be achieved for water demands from the aquifer.

7.1 Agricultural Efficiency

Water is used in agriculture for a variety of purposes. There are water needs for the purpose of growing the produce, such as the evapotranspiration needs of plants and drinking water needs of livestock; and there are water needs for non-consumptive purposes such as for salt leaching, temperature control, evaporation and cleaning/washing (Pereira, Cordery and Iacovides, 2002). Proper accounting of the potential for increasing agricultural water use efficiency requires that all necessary uses of water be considered. Note that the term *water use efficiency* is somewhat ambiguous when considered in the agricultural context, and can be subject to many definitions (Howell, 2006), but the specifics of this term are not important for this study.

7.1.1 Crops

Irrigation involves artificial supply of water when natural precipitation is insufficient for the crops' needs. There are two major avenues by which efficiency can be improved with crop agriculture: changes in farming practice, and changes in irrigation technology.

Farming Practice

Farming practice refers to the ways in which a farmer chooses to operate the farm in order to grow crops or raise livestock. There are several factors that tend to dominate how each farmer runs their establishment. This includes economic, convenience, and factors that relate to the yield of the produce per unit input. The goal of the farmer is almost always to maximize output while minimizing input (Pereira, 2006), where input can refer to things like the cost of fertilizer, the labour needs, and machinery/equipment. When trying to instigate water conservation into farming practice, factors of cost, convenience and the effect on produce output must also be considered, as it is seldom that farmers will conserve water purely for the sake of saving water. Water savings must be tied to economic, convenience or produce output gain in order to have any standing in a typical farmer's agricultural practice, or else the water saving practice must be legally enforced (Clemmens and Dedrick, 1994).

There are many benefits to conserving water. At the same time, there are also certain disadvantages that can be encountered. Table 7.1 shows some of the arguments for and against water conservation via increasing water use efficiency, and there are clearly trade-offs that need to be made when trying to maximize output while minimizing input. Efforts to encourage farmers to shift towards a more water-conscious practice require strategies to promote the advantages while simultaneously reducing the disadvantages.

Considering the economic factor, the low cost of water has frequently been cited as a major hindrance to conservation efforts. For many of the agricultural properties over the Aldergrove aquifer, the cost of water amounts to no more than the capital cost of installing a well on their property, and minimal pumping/maintenance costs. Yet the water they withdraw comes from a shared communal resource, and every individual user will have an impact on the long-term viability of this resource. Thus strategies aimed at the economic influence of farming practices could include:

1. Initiating a 'common resource use' charge or levy on extractions from the aquifer.
2. Allocating a quota for extractions from the aquifer – exceedance of the allocated quota incurs additional charges.
3. Introducing a 'graduated' scale of pricing for water use to encourage conservation.
4. Subsidies for demonstrated water-efficient practices.

5. Incentives for acquiring water-efficient technologies.

Table 7.1 The advantages and disadvantages that water use efficiency and conservation can produce for individual farmers and the overall society respectively.

	Advantages	Disadvantages
To Individual Farmers		
Economic	• Reduced water cost • Reduced energy/pumping costs	• Capital cost of efficient technology • Maintenance cost of technology
Convenience	• Reduce manual labour needs	• Increased planning/scheduling
Crop output	• Provides ideal water needs of crop • Improve crop quality and yield	• Need to have superior knowledge of crop water requirements, soil type and climate • Trade-offs with leaching and temperature control uses of water
To Society		
Environmental	• Increase water availability for ecosystem needs by reducing the non-reusable losses of water • Reduce environmental degradation	• May reduce artificial recharge of aquifers (where irrigation source is not groundwater)
Human	• Helps to enable long term sustainability of water resource • Foster communities and stewardship for common resources	• Requires changes in traditional mindsets and practices

Some of the methods for encouraging efficiency and conservation in the economic standpoint unavoidably require certain institutional reforms, which are not without complications and resistance. Nevertheless, the effectiveness of properly planned and executed institutional pressures on influencing water use habits cannot be denied, and the need for such institutional intervention is arguably inevitable when faced with the prospect of a depleted water resource. Awarding water-conscious behaviour is a more pleasant way of encouraging efficiency and conservation, but the effectiveness of such methods tend to be low scale and limited in the impact on the water resource. Even so, this type of method can be good as a starting point to spread the word about the problems facing the aquifer, and can help to ease the transition to more forceful methods should the need arise.

Aside from economic influences, all the other costs and benefits of efficiency and conservation can be tied to education. The lack of the knowledge or understanding of the aquifer system, their crop water needs and proper use of irrigation technology are some of the reasons why efficiency and conservation are not practiced. Thus many of the disadvantages that may arise from implementing efficient conservation practice can be alleviated by focusing efforts on farmers' education. This can include things like:

1. Creating and distributing educational material such as how to check your soil type and how to plan irrigation scheduling.
2. Running demonstrations and workshops to showcase efficient technology and how to use them properly.
3. Setting up a program of the sort where farmers can seek assistance with their specific agricultural situation, and get hands-on help and advice on how to optimize for efficiency and conservation.

The Township of Langley has already played an active role in trying to educate its residents about the importance of water conservation, via its Water Wise program. The Langley Environmental Partners Society (LEPS) have also contributed significantly towards environmental education and stewardship, and they also have an Agricultural Stewardship program which provides information on sustainable management practices for farmers. However, the focus has been more on quality issues as opposed to agricultural water use in the quantity sense. Thus it is possible to supplement existing efforts with similar programs based on agricultural water use efficiency and conservation. The B.C. Ministry of Agriculture and Lands runs a website called *Farmwest*, which is a very useful source of information and guides regarding many aspects of agricultural operations. Such information can be tailored to the needs and circumstances of farmers over the aquifer in order to help farmers achieve optimum efficiency and conservation while maintaining their productivity.

Irrigation Technology

One of the primary ways by which water is wasted is attributed to the method of water delivery to the crop. The water needs of crops is dependent on the climate, soil type and the particular crop, but the way in which water is supplied to the crop can vary dramatically in its water use, regardless of actual needs. The same can be said for other agricultural operations such as livestock, which have a fixed water requirement, yet the amount of water supplied for drinking and things like cleaning can often be in excess of true needs. For the purpose of condensing the scope of this section, only irrigation for crops will be analyzed, but it is important to note that many other areas of agriculture can also benefit substantially from increased water use efficiency and conservation efforts.

There are many different methods by which modern irrigation is facilitated. These can be categorized into 3 broad types: surface, sprinkler, and micro-irrigation (MI). Surface irrigation is the type where water is supplied to crops by way of flooding the surface to a lesser or greater extent. Since water is supplied at a rate that is greater than infiltration, ponding of the water will occur for at least a short time, if not indefinitely, for example, rice paddies in Asia. There are some areas in the Lower Fraser Valley that use this type of irrigation method, for those with access to surface water sources. In the region of the Aldergrove aquifer however, surface irrigation is negligible since most of the water supply is from groundwater. Thus the focus of this section will be on sprinkler and MI technologies.

Sprinklers

There are many different types of sprinkler irrigation systems, some of which are fixed and immobile, while others move periodically via mechanical methods or constantly via automated systems. The way that water is distributed to the crops can also vary, from gun-type spray systems to fountain-style or downward-facing conical sprinklers. There are many factors that determine the efficiency with which each method applies irrigation.

These include variations in pressure caused by pipe friction and topography, sprinkler pattern effects, differences in wind drift, runoff due to excessive application rates, and variations in timing (Clemmens and Dedrick, 1994). Table 7.2 shows some of the water application efficiencies that can be attained with different types of sprinkler systems. In general, periodically moved systems such as the spray gun or the side-rolling systems are the least efficient, followed by fixed systems. The constantly moving systems such as the center-pivot and the lateral-move tend to be most efficient as a group, but the low-energy precision application (LEPA) system has the ability to reduce the efficiency range towards the higher end of the spectrum.

Table 7.2 Summary of water application efficiencies found in different types of sprinkler systems.

General Type	Efficiency Range (%)
Fixed	60-88
Periodic Move	50-85
Constant Move	75-90
LEPA	80-98

Sources: (Clemmens and Dedrick, 1994; Keller and Bliesner, 1990; Schneider, 2000; Van der Gulik, 1988).

The LEPA system is actually a modification of the center-pivot and lateral-move systems. This system is designed to apply water closer to the soil surface, and the lower pressure of water application reduces evaporative/wind drift losses, thereby allowing such systems to be more efficient. Thus it seems possible to improve agricultural water use efficiency just by converting to more efficient sprinklers systems, but unfortunately, there are many complications. The wide variety of crop types and characteristics, coupled with the variability of soil and topography means that there are limits to the type and method of irrigation that is viable. Most of the highly efficient systems require uniform planting shapes, crop heights and flat land in order to perform at their most efficient, but few agricultural parcels can fit this description. For this reason, it is likely that current irrigation using sprinklers, which is likely to be the norm for the Aldergrove aquifer area, is not at optimum efficiency.

Micro-irrigation

These are a group of localized and sophisticated low pressure irrigation systems that apply water at or below the soil surface, either to individual plants or to small groups of crops. Considered the most efficient irrigation systems available, they also have a variety of types and efficiencies as with the sprinkler systems. Table 7.3 shows that the range of efficiencies are notably higher than that of sprinkler systems, with the best option being the subsurface drip method, which eliminates the majority of water loss problems encountered with above-surface irrigation.

Table 7.3 Summary of water application efficiencies found in different types of MI systems.

General Type	Efficiency Range (%)
Spray/Microjet	85-90
Bubbler	80-90
Drip/Trickle	85-90
Subsurface Drip	95

Sources: (Clemmens and Dedrick, 1994; Van der Gulik, 1999).

There are certain limitations to the widespread applicability of these systems. One of the main ones is cost-related. These systems are capital intensive, and maintenance can also be quite high, thus the tendency has been for only high-value crops and greenhouses to employ such irrigation systems (Plaut and Meiri, 1994). Other disadvantages include problems associated with emitters clogging, the need for high quality irrigation water, and a highly skilled labour force (Clemmens and Dedrick, 1994). Thus it is obvious that micro-irrigation cannot be employed by all agricultural operations, however, there is certainly potential for more of the viable agricultural operations to adopt such technologies. Currently, only some greenhouses and vineyards are known to use MI, yet it has been proven to improve crop quality and yield. Thus there are clear reasons for farmers to switch, and an opportunity exists for the municipality to give guidance on proper installation and use, helping to encourage adoption of this ultra-efficient irrigation method.

Water Savings

Knowing what the efficiency ranges for different irrigation methods are and what current water use for crop agriculture is, it is possible to derive an estimate of the potential savings in water that can be achieved from switching towards more efficient irrigation technologies. Table 7.4 shows the water savings that can be brought about when all the MI-viable agriculture is switched, assuming that they were all sprinkler irrigated originally (see Appendix VII – Table 7.A). Greater savings can be achieved in Langley than in Abbotsford because Langley has a greater proportion of MI-viable land out of all the crop agricultural land existing on this side of the aquifer. Although Abbotsford has a larger total area of MI-viable land, the ratio of non-MI to MI is larger, thus the percentage of water savings is lower than that for Langley. When the two municipalities are combined, a volume of greater than half a million m^3 of water can be saved annually over the aquifer (equivalent to about 7% of current consumption).

Table 7.4 Potential water savings that can be achieved when all viable MI agriculture is implemented.

	Abbotsford		**Langley**	
Water Savings Potential	Non-MI	MI[1]	Non-MI	MI[1]
Normalized Area[2]	0.43	0.57	0.29	0.71
% Average Efficiency[3]	72	95	72	95
Weighted Average (efficiency)	85%		88.3%	
Water Savings	15.3%		18.5%	

[1] Viable MI agriculture includes berry, field vegetable, nursery, orchards and vineyards. Greenhouses are assumed to already be under MI, thus have not been factored into the water savings calculation.

[2] 'Normalized Area' is simply the fraction of the total area that is 'Non-MI' or 'MI' viable.

[3] Based on the average efficiency of sprinklers (for Non-MI) and the maximum efficiency for MI. Source: (Van der Gulik, 1988; Van der Gulik, 1999).

Conversion of the irrigation system presents an effective way to reduce water consumption without resorting to changes in agricultural policies and restrictions, which are forceful and can often arouse discontent amongst farmers. Granted that widespread implementation of MI for viable agricultural operations will likely require institutional encouragement, but such efforts are seen as less vicious and more geared towards deriving a benefit for the individual farmer, hence acceptance of this change can be more easily obtained. Note that the success of an MI shift does not depend solely on the replacement of old irrigation systems to MI systems. The efficiency potential of MI is primarily reliant on the proper installation and running of the system, as an MI system that has been installed ineffectively and operated in a way that is irrespective of the soil, climate and crop water needs is neither going to conserve water nor produce better yields. The same can be said for non-MI viable agriculture. Irrigation technologies provide the tools for increasing efficiency, but ultimately, it is the farming practice that will determine whether improvements in efficiency are actually made. Thus the farming practice side of agricultural efficiency must be promoted in conjunction with efficient technologies, in order to achieve the optimum benefit for all.

7.1.2 Livestock

Water use for livestock operations generally centre around the drinking water requirements of the livestock themselves, and water needs for cleaning, processing and temperature control. Most farmers are concerned primarily with the drinking water needs, and often, there is little consideration for the other uses of water. This is reflected in the scarcity of publications relating to the non-consumptive water use of a livestock or poultry operation (with the exception of dairy operations as these tend to also have a specific washing water requirement due to the extra hygiene needs of this type of operation). In one of the privately metered hobby farms consisting of horses, correspondence with the owner suggests that approximately 3 m^3 of water is used for cleaning per month on a per animal basis. This works out to be double the estimated drinking water requirement of the animals, suggesting that water use for cleaning does make up a large portion of total water use, but this one estimate is not sufficient to use for aquifer-scale extrapolation, nor would it be accurate. In addition, little documentation of the different types of cleaning methods for livestock operations and their associated water requirements can be found, making it near impossible to assess the water savings that can be achieved over the Aldergrove aquifer by changes in farming practice or technology. Even if the data was available however, it is not expected that much water use reduction can be achieved in this area, because unlike the situation with irrigation, the flexibility around water requirements for livestock operations are going to be limited. Most of the livestock water use is fixed, governed more by the number of animals than by the water-using appliances involved. So it is unlikely that any more than a 10% reduction in water use can be achieved, which is largely inconsequential on the scale of the aquifer, considering that livestock operations use the least amount of water out of all the agricultural sub-divisions. For this reason, any efforts to improve water use efficiency and conservation in the agricultural sector would be better spent on issues related to irrigation.

7.2 CIIO Efficiency

The CIIO group consists of a highly diverse mixture of properties, each with its own unique set of uses for water. As mentioned in *Chapter 6*, water use for this group can be summarized into six major areas: process, sanitation (washrooms), cooling, landscaping, kitchen and laundry (Gleick, Srinivasan and Henges-Jeck, *et al.*, 2004). However, with the exception of sanitation and to some extent, kitchen water uses, not all of these uses apply to every property. Water used for cooling is likely to only apply to select industries, while processing, landscaping and laundry water will apply to most but not all of the institutional, commercial and industrial properties to various degrees. This makes it extremely complicated to try and determine the potential for increasing water use efficiency and conservation without conducting an in-depth review of every type of CIIO land use over the aquifer. In spite of this limitation to analyzing the efficiency and conservation potential of CIIO properties over the aquifer, it is still possible to suggest ways in which improvements can be made to most of the major water use areas. Water used for sanitary, kitchen and laundry purposes overlap those of the residential sector so they will be described in Section 7.3.

7.2.1 Processing

Process water can be considered the water that is used in producing the product or service for a particular business. This includes not only the water that is incorporated into the product itself but also the water needed to prepare, process and wash the product or the equipment used to make the product (Gleick, Srinivasan and Henges-Jeck, *et al.*, 2004). This can overlap with some of the other major water use areas, such as kitchen uses when referring to commercial food establishments, or laundry uses when referring to launderettes, but since both uses are part of the end product or service, it is categorized as process water use. For most cases, the amount of water used in processing is largely inflexible, as the end product requires a relatively fixed unit of water input per unit output. However, for the portion of the water that is not consumed in the end product itself, opportunities may arise for reducing water needs or increasing water reuse, bearing in mind that water does not have to be reused for the same purpose as the initial use, but instead, can be put to uses that do not require high quality water, such as for toilet flushing or landscaping.

7.2.2 Cooling

Some of the industries, particularly the manufacturing sub-sectors require water to cool heated equipment as part of the production process, while many commercial and institutional properties also use water as part of the air conditioning of the building (Gleick, Srinivasan and Henges-Jeck, *et al.*, 2004). Since water used in cooling is not considered a consumptive use, there is a significant potential for water to be reused and re-circulated in the system. This concept is not new, and many industries already implement a percentage of reuse as part of their production process, but it is unlikely that all industries have realized the maximum potential of this water saving technique. The same can be said for commercial and institutional water uses in cooling. In 1996, increased recycling of water allowed the manufacturing industry in Canada to reduce water intake by 17% overall from 1991 levels (Scharf, Burke and Villeneuve, *et al.*, 2002). Another study in California suggested that approximately 26% savings in water can be achieved specifically in the cooling end use (Gleick, Haasz and Henges-Jeck, *et al.*, 2003), but the applicability of this scenario to that of the properties over the Aldergrove aquifer will depend on the current state of water use and reuse for cooling in this region, which is currently unknown.

7.2.3 Landscaping

Many properties in the CIIO group employ some form of landscaping around their buildings. This is often more significant for the commercial and institutional establishments than for industries, and can form a sizeable portion of the total water use by that property, especially in the summer period. Landscaping water is mostly in the form of water features or water requirements of decorative plants. With water features, there is a tendency for water to be recirculated, but summer losses due to evaporation can still be quite significant. One commercial water feature company's catalogue cited water needs ranging from 49 litres per minute (lpm) for a single 12 inch diameter bell jet feature to 4,920 lpm for a 100 inch high cascading jet feature[1]. Unfortunately, not much can be done to save water with this end use, other than to simply avoid having the feature altogether. Water use for irrigation of landscaping plants however, is different. There are generally two groups of vegetation used for landscaping: shrubs and turf (grasses). Where turf is used in landscaping, it is likely to require more water than shrubs (Gleick, Srinivasan and Henges-Jeck, *et al.*, 2004), and is less amenable to efficient irrigation technologies as a means to reduce water use. However, since landscaping vegetation is not grown for consumption, this makes them more amenable to other water conservation methods, namely xeriscaping and the use of re-cycled (grey) water.

Xeriscaping refers to the use of native and drought-resistant plants for domestic gardens and landscaping. In the past, many of the plants used in landscaping were exotic species that are not accustomed to the soil and climatic conditions found here. Due to this reason, they require a lot more maintenance and care, often needing much more water and fertilizer than is naturally available to stay healthy. Native plants on the other hand, are already adapted to the climatic conditions of that region, so for this reason, they require much less care and attention (in the form of water and fertilizer) to stay healthy. Drought-resistant plants are even more adapted to dry conditions, and the use of these plants in landscaping would further reduce water needs, even though they may not necessarily be native to the region. Since turf is considered more water-intensive than shrubs, efforts should be made to either replace turf with more native and drought-resistant grass species

[1] Interestingly, no mention was made about recirculation pumps.

or to consider removing grasses from the landscaping itself, provided that it does not serve additional purposes (such as a sports field).

Coupled with xeriscaping, greywater reuse has significant potential for conserving water use in landscaping. Greywater can be considered the wastewater from all domestic uses with the exception of toilets. For CIIO properties, this would largely encompass water used in faucets. Under most conditions, the quality of this water is sufficient for use in landscaping as well as toilet flushing, meaning that no new water needs to be taken up for such purposes, which represents a huge potential water saving. Unfortunately, the implementation of any reuse system will require changes in current building practices and will also create substantial cost and health related issues that need to be solved before such practices can be put to use.

7.3 Residential Efficiency

Residential water use and conservation is perhaps the most thoroughly researched area in terms of the potential for DM strategies to increase the efficiency with which water is used. Yet the quantity of water savings that can be achieved is highly dependent on the lifestyles and habits of residents on a local scale, and can vary depending on many factors such as:

1. Local climatic and geographic conditions
2. Housing type and age
3. Number and age of residents
4. Economic status
5. Social and cultural norms
6. Environmental awareness

In general, residential water use can be split into two areas; indoor use and outdoor use. Since the general purpose of these two uses is fundamentally different, it is useful to try and separate them so that both can be tackled effectively.

7.3.1 Indoor Use

In a typical modern North American home, there are several major indoor end-uses for water: toilets, showers, washing machines, dishwashers and faucets.

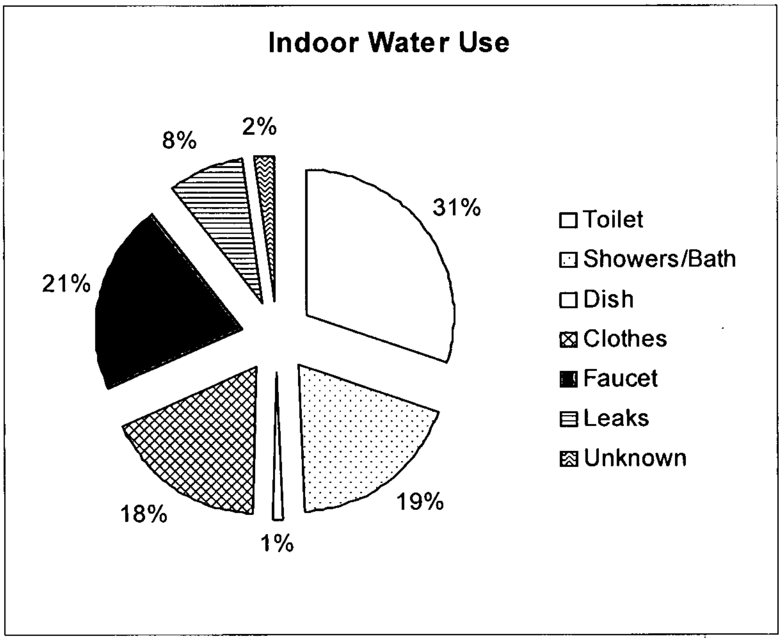


Figure 7.1 Distribution of different indoor water uses. Source: Bronsro, Siu and DeOreo (2005).

Each end-use has a potential for increasing water use efficiency by switching from the conventional appliance to the ultra-efficient appliance, without causing any changes in social and lifestyle norms. Another use for water that is not part of the beneficial use list but is still a major indoor end-use is leaks. This non-beneficial use will also be partially addressed.

Toilets

Toilets have been known throughout North America to be the single largest indoor end-use for water. In the U.S., estimates of the percentage of indoor use attributed to toilets ranged from 28-40% (Gleick, Haasz and Wolff, 2004), while a study conducted in the GVRD estimated toilets to account for 31% of total indoor use (Bronsro, Siu and DeOreo, 2005). Toilet use is mostly a factor related to the number and ages of people in the household, while the actual quantity of water used per flush is based on the age and type of toilet in use. Conventional toilets are those that were never built to take into account water conservation, and thus use a maximum of 20 litres of water per flush (not counting leaks). Nowadays, the most efficient type of toilet that requires absolutely no changes in toilet use habits requires just 6 litres per flush. This equates to a 70% water savings potential if all the 20 litre flush toilets were converted to 6 litre flush toilets.

To derive an estimate for the water savings that can be achieved over the aquifer, inferences must be made regarding the number and ages of people living over the aquifer and the current dominant type of toilet in use. The population dynamics for the Aldergrove community was used as proxy for the whole population over the aquifer (ToL, 2005), and the distribution of ages was categorized into 3 groups, where each group is assigned an arbitrary number of times of toilet use per day, based on expected norms. If the estimated total toilet uses over the aquifer was based on the conventional toilet models, then approximately 1,600 m^3 of water is used by toilets each day. Similarly, if all the toilet models were the ultra-low flush type, then just 500 m^3 of water would be used by toilets each day. This means that converting all conventional to ultra-low flush would present a water savings of 1,100 m^3 per day for the aquifer (see Appendix VII – Table 7.B).

Showers

Showers and baths are often the second or third highest category of indoor water use (Gleick, Haasz and Wolff, 2004) and was found to make up 19% of total water use in some parts of the GVRD, 17% for showers and 2% for baths (Bronsro, Siu and DeOreo, 2005). Of the two methods of bathing, baths can be considered irrelevant when it comes to reducing water use by increasing efficiency, since baths are a fixed volume use, thus with the exception of changing people's behaviour, no reductions can be achieved on this aspect. Showers however, represent a large potential for water savings if the standard 19 litres per minute (lpm) flow rates of the showerhead can be converted into the ultra-low flow 5.7 lpm models. However, with showerheads, there is a somewhat larger variety of flow rates that can be encountered in different residential homes, thus a comparison of the savings will also be made for conversions of 13 lpm and 9.5 lpm models.

Table 7.5 Summary of the daily water savings (m^3) that can be achieved over the whole aquifer with the range of conversions from conventional to efficient showerheads.

Conventional \ Efficient	13	9.5	5.7
19	532	887	1,242
13		355	709
9.5			355

Table 7.5 shows that the daily savings potential with showerhead conversions can range from 350 m^3 to over 1,200 m^3 for residential properties over the aquifer. This calculation was based on assumptions that each person over the aquifer takes one, 7-minute shower each day (see Appendix VII – Table 7.C). Obviously, this assumption is very simplistic and does not take into account a multitude of factors that affect the number and length of showers, including things like the weather, people's age and gender, their level of physical activity and whether the shower involves washing their hair or not. As important as it may be to try and account for all the significant factors affecting water use for the purpose of showering, a very detailed database of people's personal habits would be needed in order to get the most accurate record of water use, and this has clear practical as well as ethical limitations.

Washing Machines

Water use via washing machines is a fixed volume use depending on the type of appliance in the household. In North America, the type of washing machine that dominates is what is known as the 'top-loader', which requires the clothes to be immersed in water. These typically use more than 160 litres per load (Gleick, Haasz and Wolff, 2004). Another type of washing machine is what is known as a 'front-loader', where clothes are only partially submerged in water and thus, uses only 92 litres per load, but unfortunately, this type of machine (although dominant in Europe) is still only an emerging, rather than dominant trend, in North America. Thus switching from top-load to front-load can present a water savings of 45%.

Assuming that each household has a top-loading washing machine and each uses this once per week, then a total of more than 770 m^3 of water is needed to wash clothes over the aquifer. If all these machines were then converted to front-loaders, then only 424 m^3 of water is needed on a weekly basis (see Appendix VII – Table 7.D). However, the accuracy of water savings from washing machines also depend on factors like the number of people in a household, the types of activities done daily (such as intensive sports versus office work) and their washing machine use habits, in terms of how often the machine is ran on a full load.

Dishwashers

According to estimates from Statistics Canada, approximately 56% of households in Canada in 2004 were equipped with a dishwasher. Like washing machines, dishwashers also come in different types in terms of their water use efficiency. A conventional dishwasher uses 35 litres per load, while an efficient model uses only 17 litres per load. This translates to a 52% reduction in water use, however, water use attributed to dishwashers may only account for about 1% of the total indoor use (Bronsro, Siu and DeOreo, 2005).

If 56% of the households over the aquifer had a conventional dishwasher and used it 4 times a week, then 365 m^3 of water is needed each week. Conversion to efficient models has the potential to bring this down to 177 m^3 per week. Again, the actual level of water savings would depend on the habits of the individual household, including the number of people and household cooking preferences, such as how often and what type. Water use also depends on the age of the dishwasher, as the more recent models are more likely to have a greater water use efficiency than the older versions.

Faucets

Of the 5 major indoor end-uses, water use by faucets is the most difficult one to estimate, since there is no fixed volume of water use as with appliances, and no average timeframe of use as with showers. In addition, water use in faucets are often based on the actual quantity of water needed (such as for filling a kettle and cooking) which would be unaffected by changes in the flow rate of the faucet, meaning that no water savings can be attained by increasing flow efficiency. However, faucets also often deliver water for the purpose of washing, and there is a potential here to reduce water use by reducing the flow rate of the faucet. Unfortunately, to calculate the potential water savings that can be achieved over the aquifer would require knowing the total amount of water used by faucets per household, as well as the proportion of fixed-quantity needs versus washing needs. This is highly variable by household and impossible to determine without getting more detailed information on specific end uses for water in a typical household, thus it was not possible to derive an estimate for this major indoor end-use over the aquifer, though it has been estimated that faucets use about 21% of the total indoor use for parts of the GVRD (Bronsro, Siu and DeOreo, 2005).

Leaks

Leaks are by far the most unnecessary form of water use that can occur, whereby there are no beneficiaries of the lost water. Because of this, there is every reason to reduce leakage as much as possible. There are generally two different types of leaks; one during water flow through the pipes and the other due to faulty appliances. Of the two sources, faulty appliances are responsible for the majority of the water loss, namely leaky toilets and leaky faucets. Leakage accounted for 8% of total indoor water use in parts of the GVRD (Bronsro, Siu and DeOreo, 2005) but can have a very wide range, going up to 24% for some homes in the U.S. (Mayer, DeOreo and Opitz, *et al.*, 1999). Out of all the appliances that can leak water, toilets have generally been found to be the biggest leakers (DeOreo, Heaney and Mayer, 1996). Since individual appliances are the biggest source of leakage, leakage reduction is easy to achieve by homeowners, either by fixing or replacing faulty appliances. However, the amount of water savings that can be achieved with such replacements depend on the amount of original leakage from that appliance, and the performance of the new one. Since appliances are more likely to leak with age, due to mechanical, chemical and even biological wear, it is improbable to be able to completely stop any leakage, but for the homes that are found to exhibit a large percentage leakage rate, there are clear reasons for spending the capital on fixing the problem given the longer-term beneficial returns that can be obtained.

Total Annual Effect of Efficiency

Table 7.6 Summary of annual water use and savings for the total number of residential properties over the aquifer.

Indoor Total Use (m^3)	Excluding Faucets/Leaks	Including Faucet/Leak Estimate[1]
Conventional	954,713	1,241,127
Efficient	396,760	559,061
Total Savings	557,953	682,066

[1] Faucets and leaks are assumed to make up 20% and 10% of indoor use respectively, with an efficiency potential of 40% and 50%.

Table 7.6 shows that with the exception of water use by faucets and leaks, the results from the estimated water use for each end-use appliance gives a combined annual water use ranging from a maximum of almost 1 million m^3 if all appliances were of the most water intensive type, to a minimum of 0.4 million m^3 if all appliances were the most efficient type (see Appendix VII – Table 7.E). In other words, conversion of conventional to efficient appliances can save up to 0.6 million m^3 each year, and if water use by faucets and leaks were considered to make up a total of 30% of indoor use per household and were also made efficient, then a grand total of approximately 0.7 million m^3 can be saved annually. Of course, any actual water use reductions resulting from a systematic shift of water appliances are unlikely to result in this maximum savings due to the unlikelihood that all the households over the aquifer are still using the most inefficient types of appliances. This is because most of these appliances have a typical lifespan of approximately 10 years, and the most inefficient appliances tend to date back to the early 1990s or before, meaning that many of the old models are likely to have been replaced since. Granted that the replacement models may not be much more water efficient than their predecessors, but many economic and societal changes have occurred in recent years that have allowed more people to head towards being a more environmentally conscious consumer, and the incentives offered by municipalities (such as the Township of Langley's Waterwise program involving toilet rebates and residential water saver kits) are likely to have already started the trend towards increasing water use efficiency. Thus if the current annual residential water use from the aquifer already incorporates some of this increased efficiency, then this means that there would be a smaller total water use reduction that can be achieved from current water use amounts. Having said this, (Bronsro, Siu and DeOreo, 2005) found that only about 10% of the sampled residential properties in the GVRD had adopted efficient appliances, meaning that there is still likely to be a great potential for reducing indoor water use in the residential sector.

7.3.2 Outdoor Use

For residents of single-family homes, especially those that have a sizeable private yard or 'green space', outdoor water use can match that of indoor use. The major types of end-uses for outdoors include: garden/lawn irrigation, outdoor swimming pools, car washing and water-based playing/games. Out of all these end-uses, irrigation is generally considered the largest overall outdoor water use.

For residential properties over the aquifer, outdoor use is not known since the calculations in *Chapter 4* were based on total residential use. However, the estimates of indoor use can be used to infer average potential outdoor use. In *Chapter 4*, total residential water use over the aquifer was estimated to be 1.6 million m^3/yr. Indoor use is estimated to be between 0.9-1.2 million m^3/yr, depending on how extreme the dominance of the 'conventional' appliances are, and whether estimates for faucet use and leakage is added. This means that outdoor water use is likely to range from 0.3 to 0.6 million m^3/yr, or 22 to 44% of total residential use.

Ways to Increase Efficiency and Conservation

Without changing people's lifestyles and habits, the only method to reduce water use outdoors is to adopt efficient irrigation devices. Sprinklers are a common device used to water lawns and gardens, but different types of sprinklers have different levels of efficiency, as discussed in the Section 7.1. Generally though, with regards to outdoor use, conservation is harder to achieve without some changes to personal habits and gardening practices. As with agricultural irrigation, increasing the efficiency of the device means nothing if the amount of water needed by the plants are not matched to the amount of water provided by the watering system. If the homeowner is not educated about the needs and properties of their plants, the soil and the climate, there is a tendency to oversupply water most of the time, meaning that no water savings can be achieved. Thus education is one of the first principles of water use efficiency and conservation that need to be addressed. Coupled with this is the selection of the most appropriate irrigation device for that particular garden/lawn, in other words, the device that is able to best meet the needs of the plants while minimizing wastage. The amount of water that can be saved by adopting these techniques are highly site and condition-specific, making it difficult to determine an actual volume of water savings that can be achieved. Savings are also dependent on the efficiency of the original system, as traditionally well managed gardens are not going to see as great a potential reduction in the water use as habitually poorly-managed gardens.

Changing the irrigation system of the garden is only one way to increase efficiency and conservation. Another method that is more effective at providing long-term water use reductions is by xeriscaping. This is the same as that described with landscaping in Section 7.2. Studies and models in the U.S. have shown that xeriscaping can reduce outdoor water use by between 20 to 50% (Hunt, McDevitt and Hunt, 1998; Jacobs and Haarhoff, 2004; Sovocool and Morgan, 2005), however, more public education is needed to implement such a drastic change in the landscape of private gardens, and the water savings will take several years before they can be realized.

Both the methods involving changes in the irrigation and type of plants are based on reducing the water use for outdoors, but outdoor water use is only an issue because the water used is supplied from the drinking water system. If rainwater or greywater was used instead, this would represent a zero consumption in terms of the amount of water extracted from the drinking water system. In other words, there needs to be no changes in the method of watering and the types of plants if the water that is used to water these plants is not contributing to the annual water consumption of the residence. Greywater reuse requires a fair amount of re-plumbing in order to implement, and to retrofit individual households has limitations in terms of financial, health and practicality. Rainwater use however, is a fairly simple and easy to implement method that can be adopted by individual homes without a lot of effort. Rain barrels can come in different sizes and designs, and some municipalities have been promoting them as an easy method to supplement or replace outdoor water needs while making good use of rain falling on rooftops. Rain barrels can also be home-made, and are generally low maintenance, have few problems[2] and are easy to hook up to the downspout tube, thereby diverting rooftop rainwater and consequently, helping to reduce stormwater flow.

7.4 DM Potential

For each of the major land use categories, there are different ways in which water use efficiency and conservation can be optimized, and some of these methods overlap, such as efficient irrigation techniques for agriculture, commercial landscaping, and residential gardens, or the water use of toilets and faucets not just in homes but also at public places and work places. This means that many of the methods described can be applied to different land uses, demonstrating how interconnected DM strategies can be.

7.4.1 DM Potential for Residential

Of the three groups of land use categories, residential use is the most researched and subsequently, quantifiable. Using the current annual estimated water use by residential properties as determined in *Chapter 4*, and the water savings that can be achieved by switching to efficient appliances, Table 7.7 shows that total residential water use has the potential to drop by between 27 to 49%.

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[2] One innovative solution that was discussed in an online gardening forum to deal with potential mosquito and algae problems for rain barrels is to grow a goldfish in the barrel. In addition to eliminating all the insects and algae, they also fertilize the water!

Table 7.7 Water use reduction potential of residential properties given a switch to efficient technology by different proportions of the aquifer population.

	Switch to Efficiency	
Total Population	90%	50%
Consumption (m^3)		
Conventional	124,113	620,564
Efficient	503,155	279,531
Total Consumption	627,268	900,094
% Water Use Reduction	49	27

The lower value is based on the assumption that only 50% of the population can be converted to efficiency, while the higher value is based on the assumptions that 90% of the population can be converted to efficiency. Both estimates include an extra 30% added to the efficient water needs for indoor use to account for faucets and leakage, with the assumption of a 40% and 50% reduction in water use for efficient versions of these 'appliances' respectively. Neither value considers water savings due to reductions in outdoor use, which is harder to quantify. The results also do not consider the likely increase in development of residential properties over the next 10 years, which is basically why the reductions calculated here do not correspond with those suggested in the conservation scenario in *Chapter 6*. Given the 49% reduction in indoor residential consumption, and assuming that outdoor residential water use is zero (due to adoption of rain barrels and initiatives like xeriscaping), then the total water extraction from the aquifer can drop by almost 1 million m^3, meaning a 13% reduction in current total annual water extraction over the whole aquifer, just from residential conservation.

7.4.2 The Importance of Non-residential DM

Despite the significance of residential DM and the strong potential it has for reducing water use from the aquifer, residential use makes up only 23% of the total use over the aquifer according to current estimates, and given the projected rates of development, the conservation scenario in *Chapter 6* suggests a conservation reduction potential of only 1.3% by 2015. Conversely, the CIIO group currently makes up only 22% of total water use, yet has a future reduction potential of 26% (based on 1995 water use rates). As for agriculture, just trying to prevent any further increase in water use in 10 years time would require all the DM resources available. This means that focusing solely on residential water use reduction will not be sufficient. Too much of the water use over the aquifer is for agricultural and other non-residential purposes to allow a sustainable reduction in water extraction from the aquifer to be achieved unless considerable effort is put into DM strategies for these land uses. Since non-residential uses are much more economic and policy-driven than residential uses, it seems likely that significant reductions in water use cannot be achieved without expanding beyond voluntary DM measures and into the economic and legislation-based strategies that force compliance. Currently, groundwater extraction is largely unregulated in B.C. The main legislation relevant to groundwater in B.C. can be found in the *Water Act* (1996), the *Drinking Water Protection Act* (2001) and the Groundwater Protection Regulation (2004), which is still being introduced (MoE, 2006; MoH, 2006). However, these have mostly been concerned with water quality protection as opposed to water quantity regulation. Thus there are a lot of opportunities for improvements in the legislation area, both provincially and municipally. The Township of Langley is currently developing a Water Management Plan which aims to regulate and protect local groundwater resources, however the success of this Plan will depend on the ability to balance the needs of the aquifer-dependent system versus the needs of the users. One approach is to work collaboratively with all the water users over the aquifer. An example of this is the partnership between water utilities and the irrigation industry in the Pacific Northwest, where regular dialogue has facilitated the development of the Smart Water Application Technology (SWAT) Initiative (Hoyenga and Reaves, 2006). This initiative has subsequently led to the production of SWAT protocols and has generally allowed utilities and industry to see each others perspectives and share in the management of the water resource.

7.4.3 Problems with Quantifying DM Potential for the Aldergrove aquifer

The potential for DM to reduce water needs and therefore, water extraction from the aquifer, is highly dependent on what the current methods and uses for this water are. It is expected that adoption of best management practices and water conservation principles is currently limited, due partly to the low cost of water, the lack of political will and the reluctance of changing traditional methods to name a few, meaning that there is a significant potential for DM to reduce water use. However, the magnitude of reductions that can be achieved depends fundamentally on what is known about current water uses and potential efficiency/conservation methods. Of these two parameters, it is the knowledge of current water use that is most hampering DM adoption. Data is the foundation block for all decisions related to management of any system or resource. Without it, there is less basis on which to make decisions, other than that of subjective opinions. For the purpose of trying to determine how much potential DM has to reduce water use over the Aldergrove aquifer, the lack of data on specific end-uses (for outdoor residential use as well as all non-residential uses) makes it impossible to quantify the reductions that can be achieved, and hence the justification for the capital investments and efforts. It also reduces the ability to plan for water needs in the future. Lack of data is thus the main factor limiting the analysis of DM potential in this chapter.

Second to data availability is public perception of potential efficiency and conservation methods. Thus far, attempts to conceptualize and sometimes quantify DM potential has been based largely on the more established, accepted, and conventional approaches to water use reduction, which are more likely to pass the test of public acceptance, barring financial issues. These DM strategies however, are by no means the best available technologies (BAT) for reducing water use. Instead, these can actually be termed the best practical technologies (BPT) (Gleick, Haasz and Henges-Jeck, *et al.*, 2003). For example, the analysis for toilet water use reduction has been based simply on minimizing the amount of water needed to flush the largest load of waste down the toilet. Thus only the ultra-low flush toilet was considered, however, even this is not the BPT. Instead, dual-flush toilets, which have two buttons for large versus small flush loads, are one step higher on the ladder of efficiency, as a study in the U.S. has shown that due to the lesser water requirement for flushing liquid wastes, dual-flush toilets can save an additional 7.6-9.5 m^3 of water per household per year over the ultra-low (6 litre) flush toilet (Sullivan, Elliott and Hillman, *et al.*, 2001). So the dual-flush can be considered the BPT, but the BAT is actually the composting toilet, otherwise known as the 'waterless toilet'. These toilets also meet all the standards and requirements, and are commercially available, but require absolutely no water at all. Yet public acceptance is the main hindrance to widespread adoption of this technology. Most of the analyzed DM strategies are not the best available strategies, even just in terms of efficient technology, meaning that there is a huge 'true' potential for DM to reduce water use beyond current estimates, if efforts can be made to push the boundary of public acceptance towards the BATs.

7.5 Chapter Summary

This chapter has provided some analysis of the types of 'structural-operational' DM methods that can be adopted for the purpose of increasing the efficiency of water use, and it is clear that there are many barriers to implementing widespread adoption, even when most of these methods have no real disadvantage for the consumer. The lack of willingness to voluntarily adopt best management practices and BPT leads to a difficult situation for municipalities. Without cooperation from the community, municipalities will be faced with the dilemma of either increasing supply or forcing DM, both of which will be at the expense of the consumer, leading to discontent and issues of equity. To avert this potential predicament, municipalities need to increase their understanding of the needs of the community, in order to find ways to work together with the community. This links back to the issue of data and education. These two components are the foundations of any task aimed at alerting the public to the plight of water scarcity, and by addressing these two areas thoroughly, the community is much more likely to accept municipal decisions regarding their water supply.

Chapter 8 – Conclusions

This study of the Aldergrove aquifer has involved looking at many different aspects of water use and development management. This chapter will combine the analysis and results of all the individual chapters in order to concisely present the main points discussed for the whole study.

8.1 Main Points

A summary of the main results from each chapter are presented as follows:

- Recharge to the aquifer has historically been variable, but most of the recent studies suggest that the aquifer receives approximately 26 million m^3/yr, and there is a fair amount of correlation between the results derived using different methods.
- The storage capacity of the aquifer may be greater than 200 million m^3, but the actual water content in the aquifer is likely to be less than 70%, and this is strongly dependent on the magnitude of discharge.
- Consumption from the aquifer is approximately 7 million m^3/yr, and varies by location and land use type. Agriculture is the biggest water user over the aquifer, making up more than half of total current use, but lack of data (particularly on the water use of the CIIO group in Abbotsford) limits the confidence of estimates.
- Natural discharge is strongly dependent on consumption, and was inferred to range from 22 to 26 million m^3/yr.
- The climate of the region has remained largely constant over the decades despite large annual variation, however land use development has increased substantially in the past 10 years, and this is expected to have an impact on the aquifer.
- Consumption from the aquifer has increased by 31% in 10 years, and the current level of extraction is at least 2.8 million m^3 above the theoretical 'sustainable' withdrawal limit, assuming no substantial decrease in natural discharge.
- Depending on the change in development and water use in the next 10 years, consumption is projected to range from between 6 to 11 million m^3/yr by 2015.

- Many demand management strategies exist that can help control water use, with the potential for a 13% reduction in current consumption just by increasing residential water use efficiency.
- Lack of data is the main limitation to assessing demand management potential, while education is ultimately the foundation for effective demand management implementation.

8.2 Recommendations

Throughout the study, many limitations to analysis were apparent, which suggests that additional information would be desirable to fully understand the dynamics of the aquifer. The following is a list of recommendations that will help to supplement and improve the research and hopefully will facilitate the formation of a framework by which successful management of the aquifer can be achieved.

8.2.1 Aquifer Characterization (Recharge and Storage)

In terms of generating the data needed for better characterization of the physical and hydrogeological components of the aquifer, there is a need for:

- New, long-term observation wells with minimal influence by surrounding pumping wells.
- Comprehensive inventory of all public and private wells withdrawing water from the aquifer.
- Monitoring of streamflow and groundwater-surface water interactions.
- Quantifying the effect of impermeability on runoff generation and recharge loss.
- Additional analysis of the hydrological interaction between different aquifers and between aquifers and aquitards.

8.2.2 Consumption from the Aquifer

In terms of better managing demand from the aquifer, there is a need for:

- Collaboration with the Municipality of Abbotsford in order to address aquifer issues as a whole.

- Metering of private well owners (residential and agricultural) to better determine water use behaviours.
- In depth analysis of the individual uses for water within the industrial sector to better plan for water management approaches.
- Development of a program to address efficient water use in agriculture.
- Integration of community development plans with the actual supply potential of the aquifer.
- Investigation of the potential for political and economic demand management tools to further the objectives of sustainable aquifer management.
- Promotion of education as a means of conveying the issues to the public and getting acceptance of aquifer management strategies.

8.2.3 Alternatives

In terms of considering other options, it is recommended that:

- Full cost-benefit analysis be commissioned on all viable options for supply and demand. Examples of alternatives include;
  - Enhanced artificial recharge
  - Exploration and development of untapped aquifers
  - Full cost recovery of water
  - Water import from the GVRD
  - Changes in plumbing/building codes to reflect end-uses for water
  - Moratorium on development or additional abstraction from the aquifer
- A vision for the future be set and efforts be geared towards achieving that vision.

8.3 Concluding Remarks

The Aldergrove aquifer is a vital resource for communities both in Langley and Abbotsford, and the importance of careful planning, management and regulation cannot be overstressed, given the potential consequences of depletion. This study has employed a variety of techniques, tools and models to help construct a better understanding of the situation, making use of as much current and relevant data as is available, in order to help guide future planning and management. However, despite the broad scope and coverage of this study, many aspects of importance to water use could not be covered adequately, such as the importance of water quality and the hydrogeological aspects of groundwater flow both within the aquifer, between the surface and subsurface, as well as between geological units. These features are all important for a comprehensive understanding of the aquifer system in relation to water supply, and can perhaps be better addressed in future studies. As demand continues to increase, demand-based management becomes increasingly important, but it is worth noting that demand management does not have to be to the exclusion of supply management. Indeed, the key to a sustainable resource lies in taking proper account of both supply and demand, and as more new and innovative solutions become viable, such as enhanced artificial recharge, the ability to cleverly influence both sides of the water balance is what will ultimately determine the fate of the Aldergrove aquifer and the quality of life for those dependent upon the aquifer.

References

ALC. (2003). *Agricultural Land Commission Act.* Provincial Agricultural Land Commission. B.C., Canada. http://www.alc.gov.bc.ca/Legislation/Act/alca.htm

Alley, W.M. (1984). On the treatment of evapotranspiration, soil-moisture accounting, and aquifer recharge in monthly water-balance models. *Water Resources Research.* 20(8):1137-1149.

BCGGA. (2006). *personal communication.* B.C. Greenhouse Growers' Association. B.C., Canada.

BCGGA. (2006). *Quick facts.* B.C. Greenhouse Growers' Association. B.C., Canada. http://www.bcgreenhouse.ca/

BCMAFF. (2001). *Crop coefficients for use in irrigation scheduling.* Water Conservation Factsheet #577.100-5. B.C. Ministry of Agriculture, Food and Fisheries. B.C., Canada.

BCMAL. (2006). *Livestock watering requirements - quantity and quality.* Livestock Watering Factsheet #590.301-1. B.C. Ministry of Agriculture and Lands. B.C., Canada.

Beckie, R. (2006). *personal communication.* Associate Professor of Geotechnical Engineering. University of British Columbia, Canada.

Binley, A. (2001). *personal communication.* Professor of Hydrogeophysics. Lancaster University, U.K.

Black, T.A., Spittlehouse, D.L., Novak, M.D. and Price, D.T. (1989). *Estimation of areal evapotranspiration.* In: Spittlehouse, D.L. (eds.). Estimating evapotranspiration from land surfaces in B.C. IAHS Publication No. 177. pp245-256. IAHS Press. Oxfordshire.

Brandes, O.M. and Ferguson., K. (2003). *Flushing the future? Examining urban water use in Canada.* Polis project on Ecological Governance, University of Victoria. B.C., Canada.

Bredehoeft, J.D. (2002). The water budget myth revisited: Why hydrogeologists model. *Ground Water.* 40(4):340-345.

Bredehoeft, J.D. (1997). Safe yield and the water budget myth. *Ground Water.* 35(6):929.

Brocks, D.B. (2005). Beyond greater efficiency: the concept of water soft paths. *Canadian Water Resources Journal.* 30(1):83-92.

Brocks, D.B. and Peters., R. (1988). *Water: the potential for demand management in Canada.* Science Council of Canada. Ottawa, Canada.

Bronsro, A., Siu, A. and DeOreo, B. (2005). *Water usage by unmetered single-family households - direct measurements at last.* Presentation to the B.C. Water and Wastewater Association Conference. Kerr Wood Leidal Associates. B.C., Canada.

Burman, R. and Pochop, L.O. (1994). *Evaporation, evapotranspiration and climatic data.* pp98. Developments in Atmospheric Science, 22. Elsevier. Amsterdam.

Cantin, B., Shrubsole, D. and Ait-Ouyahia, M. (2005). Using economic instruments for water demand management: introduction. *Canadian Water Resources Journal.* 30(1):1-10.

Chieng, S. (2006). *personal communication.* Professor of Civil Engineering. University of British Columbia, Canada.

Chow, V.T. (1964). *Handbook of applied hydrology: a compendium of water resources technology.* pp13-14. McGraw-Hill Professional. New York.

Clemmens, A.J. and Dedrick, A.R. (1994). *Irrigation techniques and evaluations.* In: Tanji, K.K. and Yaron, B. (eds.). Management of water use in agriculture. pp64-103. Springer-Verlag. Berlin, Germany.

CoA. (2006). *Development services statistical report.* Department of Development Services. City of Abbotsford, B.C., Canada.

CoA. (2005). *Abbotsford water supply network.* Department of Engineering – Operations Yard. City of Abbotsford, B.C., Canada.
http://www.abbotsford.ca/AssetFactory.aspx?did=2691

De Loe, R., Moraru, L., Kreutzwiser, R., Schaefer, K. and Mills, B. (2001). Demand side management of water in Ontario municipalities: status, progress and opportunities. *Journal of American Water Resources Association.* 37(1):57-72.

DeOreo, W.B., Heaney, J.P. and Mayer, P.W. (1996). Flow trace analysis to assess water use. *Journal of the American Water Works Association.* 88:79-90.

Devlin, J.F. and Sophocleous, M. (2005). The persistence of the water budget myth and its relationship to sustainability. *Hydrogeology Journal.* 13(4):549-554.

Dingman, S.L. (2002). *Physical hydrology.* 2nd Ed. Prentice Hall. New Jersey.

Dixon-Warren, A. (2006). *personal communication.* Groundwater Specialist. Township of Langley, B.C., Canada.

Domenico, P.A. and Schwartz, F.W. (1998). *Physical and chemical hydrogeology.* John Wiley and Sons, Inc. New York.

EC. (2006a). *Climate data - Abbotsford.* Environment Canada. Canada.
http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

EC. (2006b). *Water conservation - every drop counts.* Environment Canada. Canada. http://www.ec.gc.ca/water/en/info/pubs/fs/e_fsa6.htm

EC. (2004). *Municipal water use: 2001 statistics.* Environment Canada. Canada. http://www.ec.gc.ca/water/en/info/pubs/sss/e_mun2001.pdf

EC. (1990). *Lake evaporation data – Vancouver UBC station.* Environment Canada. Canada. http://climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

Farmwest. (2006). *Evapotranspiration.* Ministry of Agriculture and Lands. B.C., Canada. http://farmwest.com/

Fleming, S.W. and Quilty, E.J. (2006). Aquifer responses to El-Nino-southern oscillation, Southwest British Columbia. *Ground Water.* 44(4):595-599.

Gleick, P.H. (2000). *The world's water: the biennial report on freshwater resources 2000-2001.* pp139-181. Island Press. Washington, D.C.

Gleick, P.H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Cushing K.K., and Mann. A. (2003). *Waste not, want not: the potential for urban water conservation in California.* Pacific Institute for Studies in Development, Environment, and Security. California, U.S.

Gleick, P.H., Haasz, D. and Wolff, G. (2004). *Urban water conservation: a case study of residential water use in California.* In: Gleick, P.H. (eds.). The world's water 2004-2005: The biennial report on freshwater resources. pp101-129. Island Press. Washington, D.C.

Gleick, P.H., Srinivasan, V., Henges-Jeck, C. and Wolff, G. (2004). *Urban water conservation: a case study of commercial and industrial water use in California.* In: Gleick, P.H. (eds.). The world's water 2004-2005: The biennial report on freshwater resources. pp131-156. Island Press. Washington, D.C.

Golder. (2005). *Comprehensive groundwater modeling assignment - A report to the Township of Langley.* Golder Associates Ltd. B.C., Canada.

GVRD. (2005). *Water conservation plan - in support of the GVWD Seymour-Capilano water filtration project.* Policy and Planning Department, Greater Vancouver Regional District. B.C., Canada.

GVWD. (2003). *Water consumption statistics.* Operations and Maintenance Department, Greater Vancouver Regional District. B.C., Canada.

Healy, R.W. and Cook, P.G. (2002). Using groundwater levels to estimate recharge. *Hydrogeology Journal.* 10(1):91-109.

Hiscock, K.M. (2005). *Hydrogeology - principles and practice.* Blackwell Publishing. Oxford, U.K.

Hogg, E.H. (1997). Temporal scaling of moisture and the forest-grassland boundary in western Canada. *Agricultural and Forest Meteorology.* 84(1-2):115-122.

Howard, K.W.F. and Lloyd, J.W. (1979). Sensitivity of Parameters in the Penman Evaporation Equations and Direct Recharge Balance. *Journal of Hydrology.* 41(3-4):329-344.

Howell, T. (2006). *Challenges in increasing water use efficiency in irrigated agriculture.* International Symposium on Water and Land Management for Sustainable Irrigated Agriculture. pp11-22. Cukurova University. Adana, Turkey.

Howitt, R. and Hanak, E. (2005). Incremental water market development: the California water sector. *Canadian Water Resources Journal.* 30(1):73-82.

Hoyenga, J. and Reaves, R. (2006). Smart application technology: a water utility/irrigation industry partnership. *Journal American Water Works Association.* 98(2):112-121.

Hudak, P.F. (2005). *Principles of hydrogeology.* 3rd Ed. CRC Press. Boca Raton, Florida.

Hudson, R. and Elwell, L. (2004). *Canadian poultry industry forum - avian influenza, lessons learned and moving forward.* Canadian Food Inspection Agency in conjunction with the BC Ministry of Agriculture and the BC Poultry Industry. B.C., Canada.

Hunt, J.B., McDevitt, W., and Hunt., G. (1998). *Water efficiency manual for commercial, industrial and institutional facilities.* A joint publication of the Division of Pollution Prevention and Environmental Assistance and Division of Water Resources of the North Carolina Department of Environment and Natural Resources, and Land-of-Sky Regional Council. North Carolina.

Irwin, R.W. and Hicks., W.J. (1979). *Farm water use - report on Ontario Ministry of Agriculture and Food Research Program.* Project A-39-716. University of Guelph. Ontario.

Jacobs, H.E. and Haarhoff, J. (2004). Application of a residential end-use model for estimating cold and hot water demand, wastewater flow and salinity. *Water SA.* 30(3):305-316.

Kassem, A.M. and Tate, D.M. (1994). *Water conservation data, statistics and modeling: a federal perspective.* In: Shrubsole, D. and Tate, D. (eds.). Every drop counts. pp183-200. Canadian Water Resources Association. Cambridge, Canada.

Keller, J. and Bliesner, R.D. (1990). *Sprinkler and Trickle Irrigation.* pp115. Van Nostrand Reinhold. New York.

Luttmerding, H.A. (1981). *Soils of the Langley-Vancouver map area.* RAB Bulletin 18. Ministry of Environment. B.C., Canada.

Maas, T. (2003). *What the experts think: understanding urban water demand management in Canada.* POLIS project on Ecological Governance, University of Victoria. B.C., Canada.

MacKinnon, G. (2006). *Economic development - population growth will slow.* Community Development Division. Township of Langley, B.C. Canada. http://www.tol.bc.ca/files/web_files/planning/13_-_Population_Growth_Will_Slow.pdf

Manning, J.C. (1987). *Applied principles of hydrology.* pp98. Merrill Publishing Company. Ohio, U.S.

Mayer, P.W., DeOreo, W.B., Opitz, E.M., Kiefer, J.C., Davis, W.Y., Dziegielewski, B. and Nelson, J.O. (1999). *Residential end uses of water - final report.* AWWA Research Foundation. Denver, Colorado.

MoE. (2006). *Legislation.* Ministry of Environment, B.C., Canada. http://www.env.gov.bc.ca/wsd/water_rights/legislation.html

MoH. (2006). *Drinking water protection act.* Ministry of Health, B.C., Canada. http://www.health.gov.bc.ca/protect/dwact.html

Morton, F.I. (1983). Operational Estimates of Areal Evapo-Transpiration and their Significance to the Science and Practice of Hydrology. *Journal of Hydrology.* 66(1-4):1-76.

MWLAP. (2005). *Water well application database.* Ministry of Water, Land and Air Protection. B.C., Canada. http://srmapps.gov.bc.ca/apps/wells/jsp/common/wellsreport1.jsp

Nosetto, M.D., Jobbagy, E.G. and Paruelo, J.M. (2005). Land-use change and water losses: the case of grassland afforestation across a soil textural gradient in central Argentina. *Global Change Biology.* 11(7):1101-1117.

Pereira, L.S. (2006). *Irrigated agriculture: facing environmental and water scarcity challenges.* Prepared for the International Symposium on "Water and Land Management for Sustainable Irrigated Agriculture". Cukurova University. Adana, Turkey.

Pereira, L.S., Cordery, I. and Iacovides, I. (2002). *Coping with water scarcity.* Prepared for the International Hydrological Program, UNESCO. Paris.

Piteau. (2005). *Construction and testing of production well no: 10.* A Report to the Township of Langley. Piteau Associates Ltd. B.C., Canada.

Piteau. (2004). *Construction and testing of production well no: 9 (PW-9) - Aldergrove, B.C.* A Report to the Township of Langley. Piteau Associates Ltd. B.C., Canada.

Piteau. (1997). *Hydrogeological assessment of the Aldergrove aquifer.* A Report to the Township of Langley. Piteau Associates Ltd. B.C., Canada.

Piteau. (1991). *Hydrogeological assessment of the Aldergrove aquifer.* A Report to the Township of Langley. Piteau Associates Ltd. B.C., Canada.

Plaut, Z. and Meiri, A. (1994). *Crop irrigation.* In: Tanji, K.K. and Yaron, B. (eds.). Management of water use in agriculture. pp48-63. Springer-Verlag. Berlin, Germany.

Renzetti, S. (2005). Economic instruments and Canadian industrial water use *Canadian Water Resources Journal.* 30(1):21-30.

Rushton, K.R. and Ward, C. (1979). Estimation of Groundwater Recharge. *Journal of Hydrology.* 41(3-4):345-361.

Ryder, J.M. (2006). *Soil landscapes of B.C., section 1.3 - geology, landforms and surficial materials.* Ministry of Sustainable Resource Management. B.C., Canada. http://srmwww.gov.bc.ca/soils/landscape/1.3geology.html

Sanford, W. (2002). Recharge and groundwater models: an overview. *Hydrogeology Journal.* 10(1):110-120.

Scanlon, B.R., Healy, R.W. and Cook, P.G. (2002). Choosing appropriate techniques for quantifying groundwater recharge. *Hydrogeology Journal.* 10(1):18-39.

Scharf, D., Burke, D.W., Villeneuve, M. and Leigh, L. (2002). *Industrial water use, 1996.* Published by the Authority of the Ministry of Environment. Canada.

Schneider, A.D. (2000). Efficiency and uniformity of the LEPA and spray sprinkler methods: A review. *Transactions of the ASAE.* 43(4):937-944.

Schreier, H. (2006). *personal communication.* Professor at the Institute for Resources, Environment and Sustainability. University of British Columbia.

Schwartz, F.W. and Zhang, H. (2004). *Fundamentals of ground water.* John Wiley and Sons, Inc. New York.

SCS. (1975). *Livestock water use.* Prepared by the Special Projects Division. Soil Conservation Service. U.S. Department of Agriculture.

SOE. (2001). *Urban water indicators: municipal water use and wastewater treatment bulletin.* State of the Environment, Government of Canada. Ottawa.

Sophocleous, M. (2005). Groundwater recharge and sustainability in the high plains aquifer in Kansas, USA. *Hydrogeology Journal.* 13(2):351-365.

Sophocleous, M. (2000). From safe yield to sustainable development of water resources - the Kansas experience. *Journal of Hydrology.* 235:27-43.

Sovocool, K.A. and Morgan, M. (2005). *Xeriscape conversion study final report.* Southern Nevada Water Authority. Las Vegas, Nevada.

Sprague, J.B. (2003). Myth of abundance. *Alternatives Journal.* 29(2):28.

StatsCan. (2001). *2001 Census of agriculture.* Statistics Canada. http://www.statcan.ca/english/agcensus2001/index.htm

Sullivan, G.P., Elliott, D.B., Hillman, T.C. and Hadley, A.R. (2001). *The save water and energy education program: SWEEP. Water and energy saving evaluation.* Prepared for the United States Department of Energy, Office of Building Technology State and Community Programs. Washington, D.C.

ToL. (2006a). *Langley's groundwater.* Township of Langley. B.C., Canada. http://www.tol.bc.ca/index.php?option=com_content&task=view&id=1064&Itemid=902

ToL. (2006b). *Stormwater, sewers and water supply.* Township of Langley. B.C. Canada. http://www.tol.bc.ca/index.php?option=com_content&task=view&id=1084&Itemid=949

ToL. (2006c). *Water conservation.* Township of Langley. B.C. Canada. http://www.tol.bc.ca/Engineering/Water_Wise_Community/Water_Conservation/

ToL. (2005). *Aldergrove statistical profile.* Community Development Division, Township of Langley. Langley, B.C.

ToL. (1995). *Langley waterworks regulation bylaw 1995 no:3482.* Township of Langley. B.C., Canada.

Twine, T.E., Kucharik, C.J. and Foley, J.A. (2004). Effects of land cover change on the energy and water balance of the Mississippi River basin. *Journal of Hydrometeorology.* 5(4):640-655.

Van der Gulik, T. (1999). *B.C. Trickle Irrigation Manual.* Prepared by the B.C. Ministry of Agriculture and Food Irrigation Industry Association. B.C., Canada.

Van der Gulik, T. (1988). *B.C. Sprinkler Irrigation Manual.* Prepared by the B.C. Ministry of Agriculture and Fisheries. Irrigation Industry Association. B.C., Canada.

Walton, W.C. (1970). *Groundwater resource evaluation.* pp33. McGraw-Hill Professional. New York.

Ward, A.D. and Trimble, S.W. (2004). *Environmental hydrology.* pp322. Lewis Publishers. Boca Raton, Florida.

Weight, W.D. and Sonderegger, J.L. (2001). *Manual of applied field hydrogeology.* pp94. McGraw-Hill Professional. New York.

Yamazaki, T., Yabuki, H., Ishii, Y., Ohta, T. and Ohata, T. (2004). Water and energy exchanges at forests and a grassland in eastern Siberia evaluated using a one-dimensional land surface model. *Journal of Hydrometeorology.* 5(3):504-515.

Zandbergen, P., Houston, J. and Schreier, H. (1999). *Comparative analysis of methodologies for measuring imperviousness of watersheds in the Georgia Basin.* Prepared for the Habitat and Enhancement Branch of Fisheries and Oceans Canada.

Appendix 1 – Study Site Maps

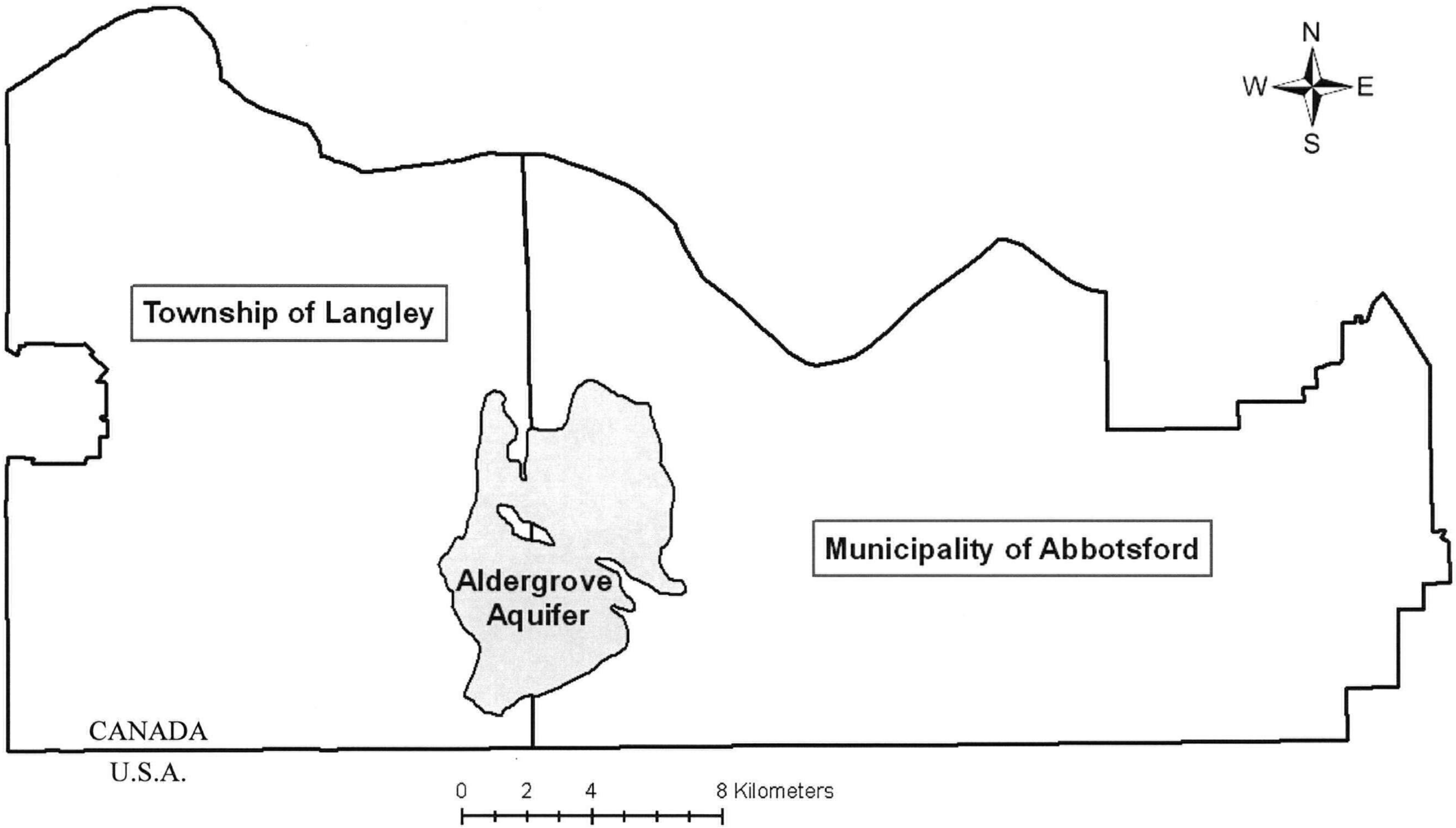

Figure 1.A – Map of aquifer location

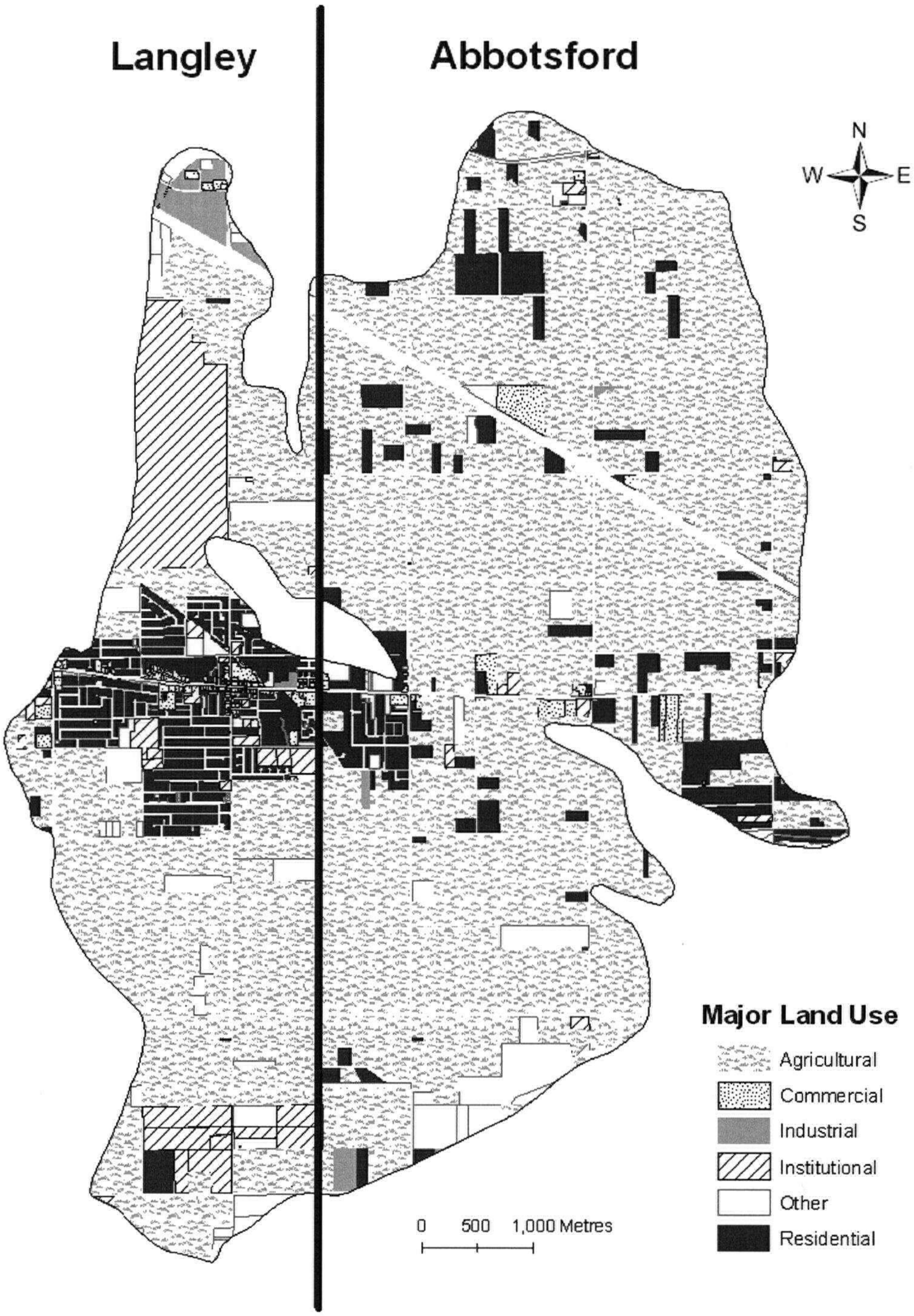

Figure 1.B – Map of major land uses over the aquifer

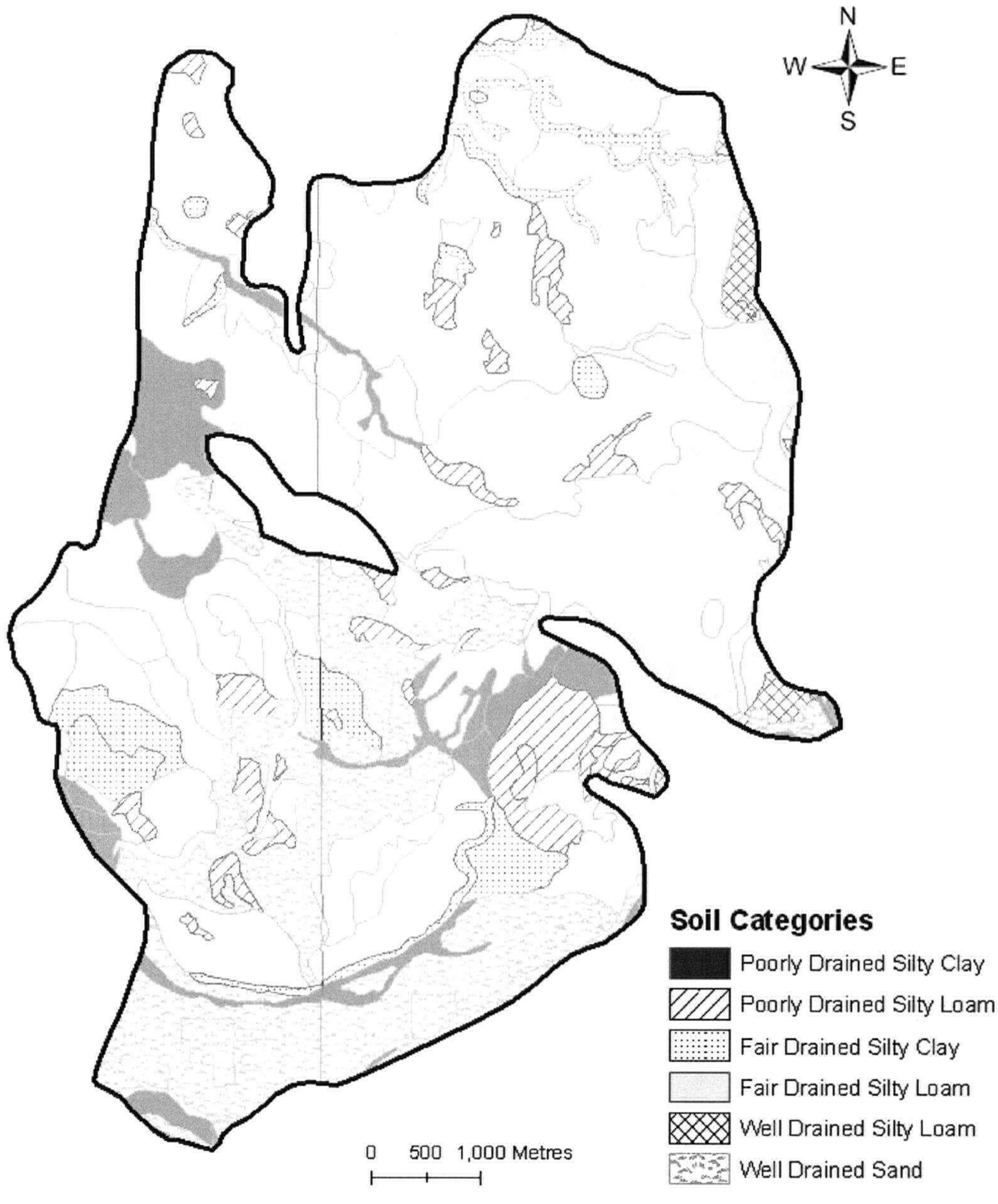

Figure 1.C – Map of the 6 major soil categories over the aquifer

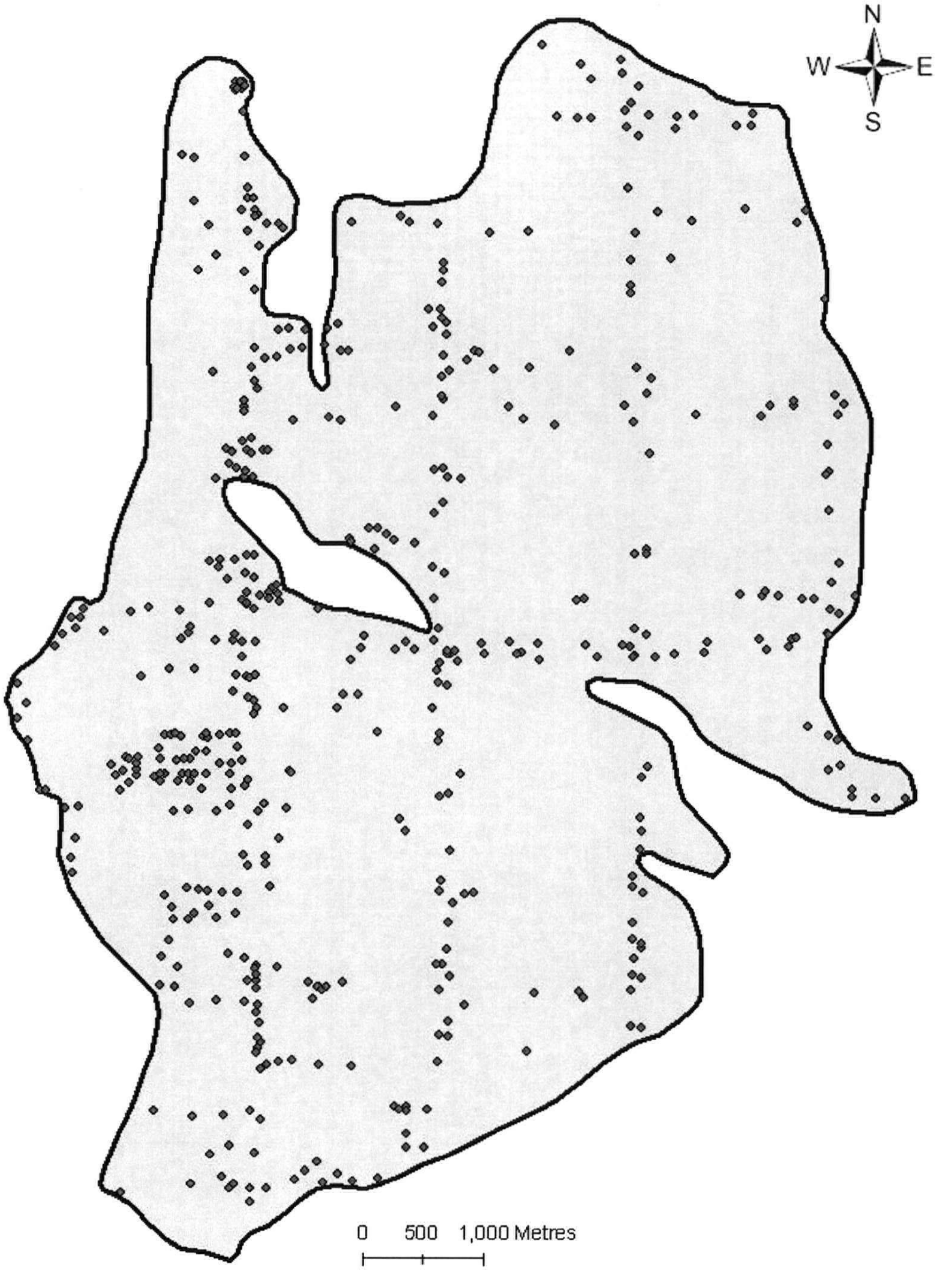

Figure 1.D – Registered well locations throughout the aquifer

Appendix 2 - Recharge

(Data for the Soil-Water Budget calculation and Streamflow can be found in the accompanying CD-ROM)

Table 2.A – Soil types and properties used to determine major soil categories

Soil Name	Texture	Drainage	Simplified Description	Designated Soil Category	% Field Moisture
Abbotsford	silty loam to gravelly sand	well to rapid	well drained silty loam	2	12.1
Albion	silty loam to silty clay loam	moderately poor to poor	poorly drained silty clay	6	32.4
Bose	loamy sand to gravelly sand	well to moderately well	well drained sand	1	13.8
Calkins	silty loam to silty clay loam	poor	poorly drained silty loam	5	-
Columbia	sandy loam	well to rapid	well drained sand	1	7.2
Defehr	loam to loam gravelly sand	imperfect	poorly drained silty loam	5	-
Glen Valley	organic mucky	very poor	poorly drained silty clay	6	-
Heron	fine sandy loam to sand	poor	poorly drained silty loam	5	-
Judson	organic mucky	very poor	poorly drained silty clay	6	-
Lehman	silty loam to loam sand	poor	poorly drained silty clay	6	-
Lynden	loamy sand	well to rapid	well drained sand	1	-
Nicholson	silty loam to silty clay loam	moderately well	fairly drained silty clay	4	36.9
Peardonville	silty loam to sandy loam	well	well drained silty loam	2	-
Ross	silty loam to silty clay loam	very poor	poorly drained silty clay	6	-
Ryder	silty loam to loam sand	well to moderately well	well drained silty loam	2	40.8
Scat	silty loam to silty clay	poor	poorly drained silty loam	5	-
Sunshine	sandy loam to sand	well to moderately well	well drained sand	1	29.9
Whatcom	silty loam	moderately well	fairly drained silty clay	3	18.3

Table 2.B – Surface conditions in relation to major soil categories

Soil Category	Average % Field Moisture	Volume of Saturation required (m^3/m^2)	Area over the Aldergrove aquifer (million m^3)			
			Forested	Pasture	Impermeable	Total
1	16.9	0.08	0.80	6.95	0.70	8.44
2	26.4	0.13	0.02	0.44	0.03	0.49
3	18.3	0.09	4.91	21.48	3.61	30.00
4	36.9	0.18	0.72	2.06	0.10	2.88
5	same as Soil Cat. 6	0.16	0.48	2.17	0.16	2.81
6	32.4	0.16	0.38	2.43	0.31	3.12
		Total	7.30	35.52	4.91	47.74

Table 2.C – Calculation of the hydrological discharge (recharge) based on flownets

Aquifer Thickness	**10 m**
K =	**7.40E-04 m/s**

Date	# streamtubes	dh	K.dh m^2/s	K.dh m^2/day	Discharge (Q) m^2/day	m^3/day	m^3/yr
winter 72	35	1	7.40E-04	6.39E+01	2,238	22,378	8,167,824
summer 73	21	5	3.70E-03	3.20E+02	6,713	67,133	24,503,472
winter 74	19.5	5	3.70E-03	3.20E+02	6,234	62,338	22,753,224
winter 76	22	5	3.70E-03	3.20E+02	7,033	70,330	25,670,304
summer 77	21	5	3.70E-03	3.20E+02	6,713	67,133	24,503,472
winter 77	18	5	3.70E-03	3.20E+02	5,754	57,542	21,002,976
winter 79	11.5	5	3.70E-03	3.20E+02	3,676	36,763	13,418,568

Appendix 3 - Storage

(Well data can be found in the accompanying CD-ROM)

Table 3.A – Total area consisting of different aquifer materials

Aquifer Composition	Area (m^2)	%
Gravel	7,756,291	16.3
Gravel and Sand Mix	18,427,451	38.6
Sand	21,538,839	45.1
Total	47,722,582	

GIS Aquifer Volume (hollow)	474,958,937m^3
Mean Aquifer Thickness	10m

Table 3.B – Volume estimate based on aquifer mean thickness

Aquifer Composition	Volume (m^3)
Gravel	77,562,913
Gravel and Sand Mix	184,274,514
Sand	215,388,390
Aquifer Volume (hollow)	477,225,817

Volume Discrepancy	0.48%

Table 3.C – Porosity values from literature and calculated aquifer storage capacities

	Gravel		Sand		Gravel and Sand	Silt	Clay
Literature	**coarse**	**fine**	**coarse**	**fine**			
Schwartz and Zhang, 2004	24 -36	25 - 38	31 - 46	26 - 53	-	34 - 61	34 - 60
Weight and Sonderegger, 2001	20 - 40		25 - 50		15 - 35	35 - 50	40 - 70
Domenico and Schwartz, 1990	24 -36	25 - 38	31 - 46	26 - 53	-	34 - 61	34 - 60
Walton, 1970	30 - 40		35 - 40		20 - 35	-	45 - 50
Chow, 1964	30 - 40		35 - 40	30 - 40	20 - 35	40 - 50	45 - 55
Lower Bound (%)	20		25		15		
Volume of Water (m^3)	15,512,583		53,847,097		27,641,177		
Total	97,000,857 (20.4%)						
Upper Bound (%)	40		53		35		
Volume of Water (m^3)	31,025,165		114,155,847		64,496,080		
Total	209,677,092 (44.2%)						

Table 3.D – Detailed results derived from the aquifer and water level layers analyzed by Surfer

Aq Vol (hollow) 492,973,932 m^3

		Winter 79	**%**	**Summer 79**	**%**	**Winter 77**	**%**
	Volume above aquifer base (m^3)	453,088,325		505,969,656		263,049,720	
	% of aquifer volume (above aquifer base)	92		103		53	
	Real aquifer volume (m^3)	276,225,972	**56.0**	347,628,619	**70.5**	198,891,536	**40.3**
	Volume (m^3)						
Aquifer Top	Above confined area	176,862,354		158,341,037		64,158,183	
	Below unconfined area	284,559,404		152,146,500		504,924,984	
Aquifer Base	Above base	453,088,325		505,969,656		263,049,720	
	Below base	67,811,444		6,801,187		210,842,588	
	Unsaturated volume in aquifer	216,747,960		145,345,313		294,082,395	
	Area (m^2)						
Aquifer Top	Confined	19,027,792	**41.1**	21,654,557	**46.7**	12,557,572	**27.1**
	Unconfined	27,304,230	**58.9**	24,677,145	**53.3**	33,774,672	**72.9**
Aquifer Base	Confined	31,055,955	**67.0**	42,434,850	**91.6**	23,526,621	**50.8**
	Unconfined	15,275,739	**33.0**	3,896,730	**8.4**	22,805,122	**49.2**

Table 3.D - continued

Summer 77	%	Winter 76	%	Winter 74	%	Summer 73	%	Winter 72	%
286,568,669		308,357,707		552,497,115		367,331,644		381,181,831	
58		63		112		75		77	
217,083,603	**44.0**	228,890,964	**46.4**	287,027,913	**58.2**	279,047,504	**56.6**	274,210,119	**55.6**
69,485,066		79,466,743		265,469,203		88,284,139		106,971,712	
481,898,581		418,286,539		319,945,506		296,635,698		257,429,045	
286,568,669		308,357,707		552,497,115		367,331,644		381,181,831	
206,008,251		154,203,571		113,999,486		82,709,270		38,665,232	
275,890,329		264,082,968		205,946,019		213,926,428		218,763,813	
12,967,888	**28.0**	14,304,380	**30.9**	23,335,483	**50.4**	19,737,358	**42.6**	17,736,282	**38.3**
33,364,286	**72.0**	32,027,640	**69.1**	22,997,307	**49.6**	26,594,473	**57.4**	28,595,357	**61.7**
24,683,167	**53.3**	27,993,786	**60.4**	32,862,675	**70.9**	32,385,413	**69.9**	33,485,236	**72.3**
21,648,677	**46.7**	18,337,879	**39.6**	13,469,685	**29.1**	13,945,964	**30.1**	12,846,213	**27.7**

Table 3.E – Calculation of residence times using different saturation

***Farmwest* Derived Recharge Total = 25,352,146m^3/yr**

Aquifer Volume (hollow)

Surfer 492,973,932 m^3

GIS 474,958,937 m^3

	% Aquifer Saturation	Volume (m^3)	Residence Time (yrs)	Discrepancy between models
Surfer	40%	197,189,573	7.8	0.3
GIS		189,983,575	7.5	
Surfer	70%	345,081,752	13.6	0.5
GIS		332,471,256	13.1	
Surfer	100%	492,973,932	19.4	0.7
GIS		474,958,937	18.7	

Appendix 4 - Discharge

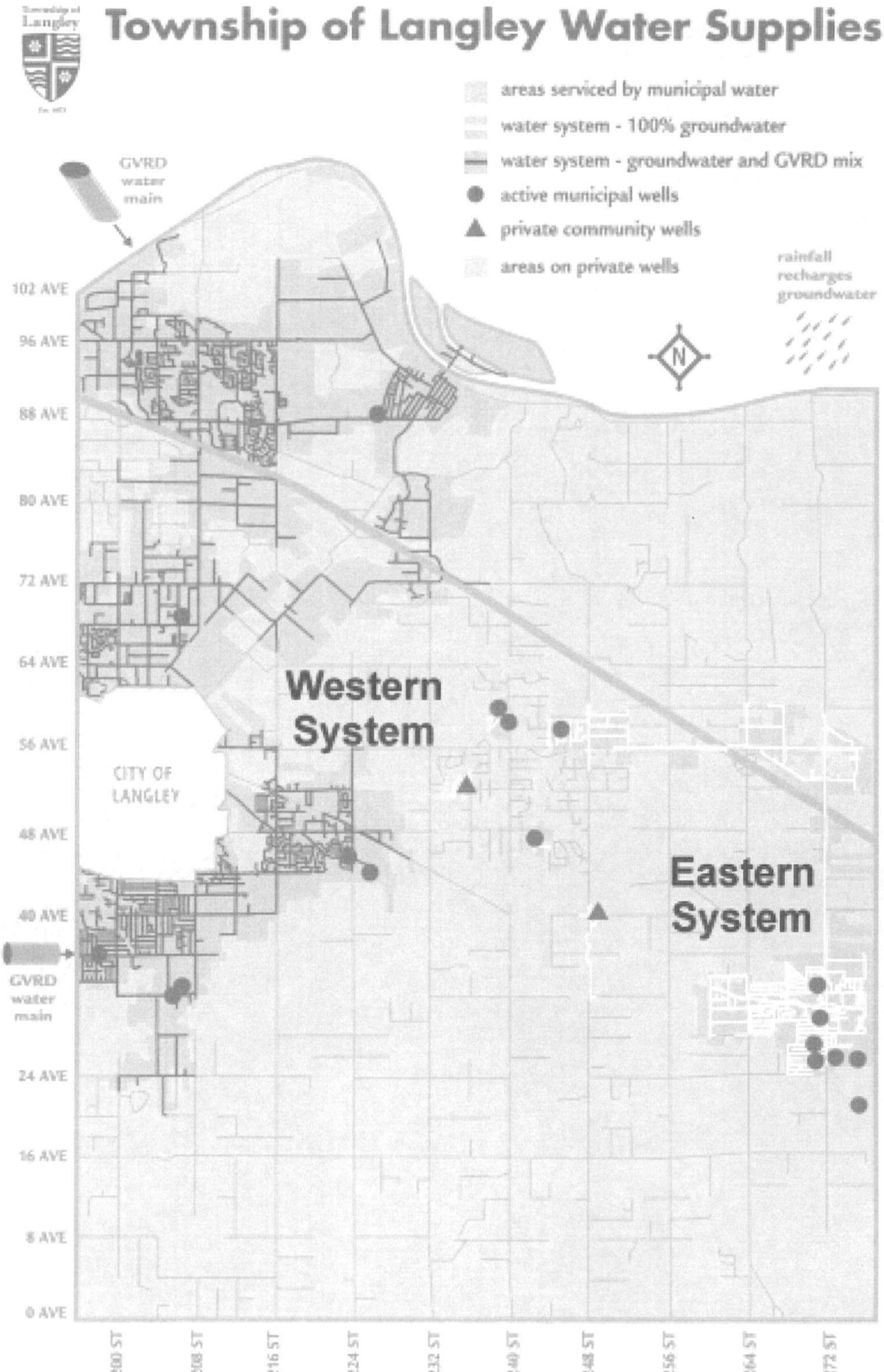

Figure 4.A – Map of the Township's water supply system. Source: ToL, (2006b)

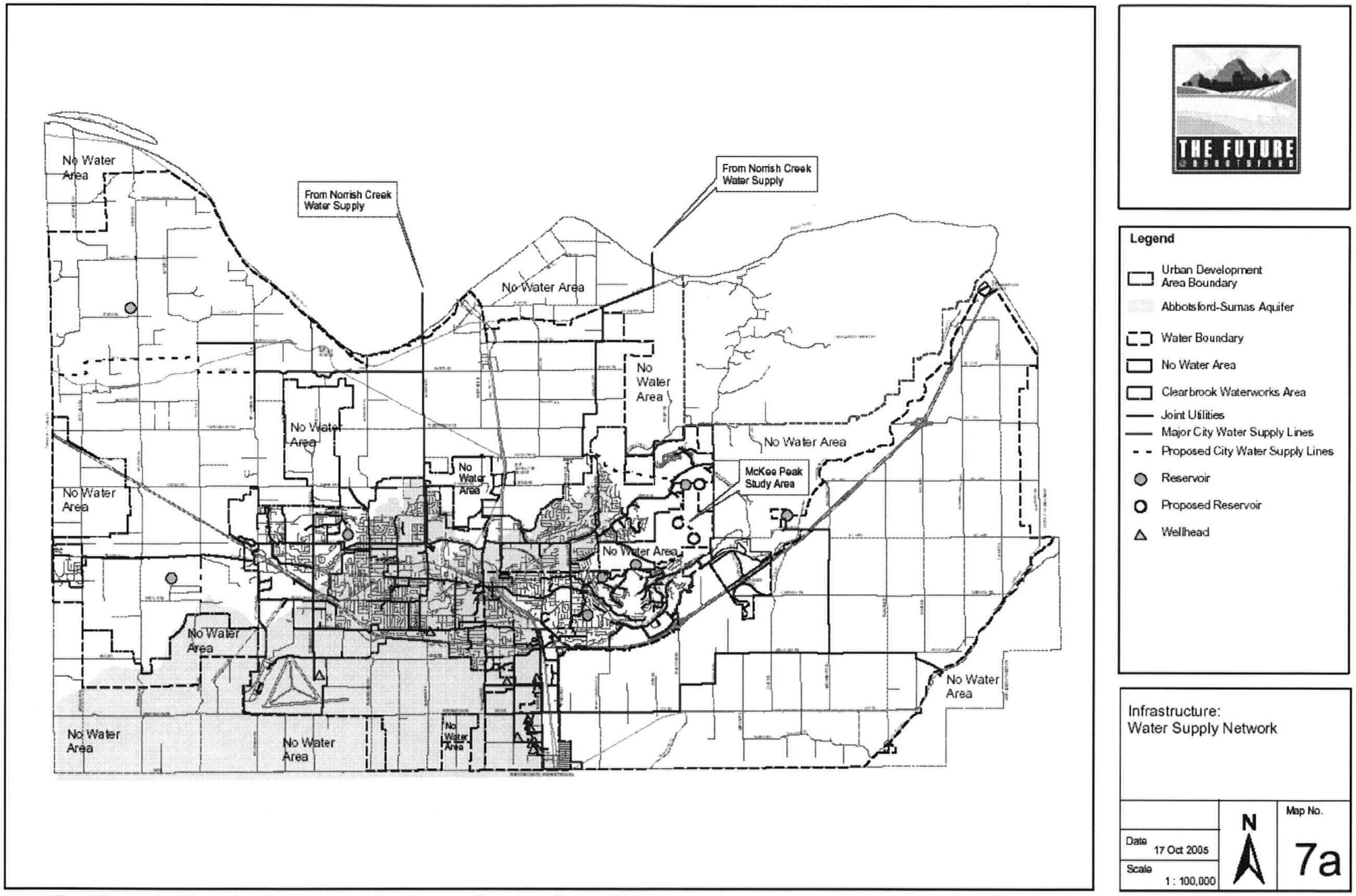

Figure 4.B – Map of Abbotsford water supply system. Source: CoA, (2005)

Table 4.A – Calculation of crop and pasture water consumption based on evapotranspiration

Source: Farmwest.com

	Daily Averages For ET (mm)					Crop Coefficients[2]		Estimated ET Losses			
Month	**2002**	**2003**	**2004**	**2005**	**Long-term Average**	**Berries[1]**	**Pasture**	**Berries (mm/day)**	**Berries (mm/month)**	**Pasture (mm/day)**	**Pasture (mm/month)**
May	2.9	3.1	3.2	3.4	3.2	0.4	n/a	1.3	39.0	-	-
June	4	4.1	4.2	3.4	3.9	1.04	1	4.1	122.5	3.9	117.8
July	4.2	4.5	4.7	4.2	4.4	1.04	1	4.6	141.9	4.4	136.4
August	3.7	4.1	3.7	4	3.9	0.68	1	2.7	81.7	3.9	120.1
September	2.7	2.9	2.1	2.6	2.6	0.68	n/a	1.8	52.5	-	-
								Total	437.6		374.3
								Total in m³	0.44		0.37
								Aquifer Total (m³)	2,373,667		858,233
								Abbotsford	1,602,166		631,637
								Langley	771,501		226,597

Table 4.B – Area occupied by crop and pastures

Area (m²)	Fruits Crop	Pasture	15% Pasture
Abbotsford	3,661,332	11,250,852	1,687,628
Langley	1,763,065	4,036,186	605,428
Total	5,424,397	15,287,038	2,293,056

[1] 'Berries' refers to the amalgamated average of blueberries, cranberries, raspberries and strawberries.

[2] Farmwest crop coefficients are grouped into periods of plant growth stages, (initial, mid, and end), thus the monthly coefficient is estimated by assuming May = initial, June/July = mid, and Aug/Sept = end of growth season.

Table 4.C – Calculations for greenhouse water consumption based on evapotranspiration

	Daily Average ET (mm)					Water Use Forecast		Water Use Estimate			
Month	**2002**	**2003**	**2004**	**2005**	**Average**	**L/m2 /day**	**m3/m2/ month**	**L/m² /month**	**Langley L/month**	**Abbotsford L/month**	**Total**
January	0.6	0.6	0.5	0.5	0.6	2.11	0.07	65.6	6,202,786	18,065,875	24,268,661
February	0.9	1	1	1.2	1.0	2.84	0.08	79.5	7,526,273	21,920,583	29,446,856
March	1.2	1.4	1.7	1.6	1.5	3.53	0.11	109.4	10,350,433	30,146,068	40,496,501
April	2.3	2.1	3.1	2.6	2.5	5.13	0.15	154.0	14,572,812	42,443,923	57,016,734
May	2.9	3.1	3.2	3.4	3.2	6.09	0.19	188.8	17,861,036	52,021,013	69,882,049
June	4	4.1	4.2	3.4	3.9	7.27	0.22	218.2	20,647,830	60,137,667	80,785,497
July	4.2	4.5	4.7	4.2	4.4	8.00	0.25	248.0	23,465,963	68,345,598	91,811,562
August	3.7	4.1	3.7	4	3.9	7.20	0.22	223.1	21,111,894	61,489,272	82,601,166
September	2.7	2.9	2.1	2.6	2.6	5.21	0.16	156.3	14,789,777	43,075,842	57,865,619
October	1.4	1.3	1.3	1.2	1.3	3.26	0.10	101.1	9,565,743	27,860,626	37,426,369
November	0.8	0.7	0.7	0.6	0.7	2.34	0.07	70.3	6,653,591	19,378,863	26,032,454
December	0.5	0.5	0.4	0.5	0.5	2.00	0.06	62.0	5,866,491	17,086,400	22,952,890
								Total	158,615	461,972	620,586
								2/3 Total	105,743	307,981	413,724

Table 4.D – Area of greenhouses

Area (m²)	**Greenhouses**
Abbotsford	275,587
Langley	94,621
Total	370,208

Table 4.E – Forecast Base[1]

	Average ET (mm)	**Water Use L/m²/day**
July	4.4	8
December	0.48	2

[1] Water use values obtained from BC Greenhouse Growers' Association

Table 4.F – Livestock water consumption based on drinking water needs

	Average Daily Water Needs[1]			Langley				Abbotsford				Total	
Livestock Type	US gallons	L/day	m^3/yr	# farms	Average # animals / farm[3]	Total # animals	C[4] (m^3/yr)	# farms	Average # animals / farm[3]	Total # animals	C[4] (m^3/yr)	# animals	C[4] (m^3/yr)
Beef	9	34.1	12.4	21	30	630	7,833	60	29	1,740	21,635	2,370	29,468
Dairy	36	136.3	49.7	4	76	304	15,119	4	85	340	16,910	644	32,029
Horse	12	45.4	16.6	46	9	414	6,863	84	4	336	5,570	750	12,434
Sheep/ Goat	2.5	9.5	3.5	6	28	168	580	12	45	540	1,865	708	2,445
Poultry	0.06	0.2	0.1	12	7,240	86,880	7,202	46	29,336	1,349,456	111,858	1,436,336	119,060
Exotics[2]	2	7.6	2.8	7	14	98	271	8	5	40	111	138	381
						Total	37,869				157,949		195,818

[1] Based on values taken from the B.C. Ministry of Agriculture and Lands

[2] Based on llama/alpaca values

[3] Based on data from the 2001 Census of Agriculture

[4] Denotes consumption

Table 4.G – Agricultural property statistics

	# Properties[1]		
Agricultural Type	**Langley**	**Abbotsford**	**Total**
Fruits/Crop	31	108	139
Pasture	107	247	354
Livestock	86	195	281
Greenhouses	8	15	23
Total	232	565	797
# Farms with Residential Units	223	453	676
# Hobby Farms	135	159	294
Total # Agricultural Properties	237	506	743
# Excluded Properties[2]	32	28	60
# Included Properties[3]	205	478	683
# Multi-Use Properties	27	87	114

[1] Each agricultural property can have more than one agricultural land use

[2] Properties that do not require water

[3] Properties that do require water

Table 4.H – Water consumption of the CIIO group

All properties over the Aldergrove aquifer

	Metered data				Langley-side				Abbotsford-side			Total	
Land Use Type	**# meters[1]**	**# addresses metered**	**2005 Total C (m^3)**	**Average C / property**	**Total # Properties**	**# External Metered[2]**	**# Excl.[3]**	**# Incl.[4]**	**Total # Properties**	**# Excl.**	**# Incl.**	**# Incl.**	**C (m^3)**
Commercial	145	121	275,319	2,275	243	21	0	264	23	2	21	285	648,479
Industrial	105	92	464,021	5,044	19	91	0	110	5	1	4	114	574,983
Institutional	28	26	50,850	1,956	48	5	1	52	16	2	14	66	129,081
Recreational /Other	9	6	40,699	6,783	115	3	84	34	44	37	7	41	278,110
												Total	1,631,652

C = Consumption

Table 4.I – Water consumption of the CIIO group excluding 'City Supplied' properties in Abbotsford

			Total	
		# Incl.	# Incl.	C (m^3)
Commercial	Same as Above	1	265	602,971
Industrial		3	113	569,939
Institutional		0	52	101,700
Recreational /Other		4	38	257,760
			Total	1,532,371

[1] Some properties have more than one water meter
[2] Properties that exist outside of the Aldergrove aquifer area, but still obtain their water supply from the Aldergrove municipal wells
[3] Properties that do not require a water supply
[4] Properties that do require a water supply

Table 4.J – Calculation of residential water consumption based on municipal data

Total Metered Consumption for 2005[1]	=	889,541	m^3
Total Volume of Flow through AWTP[2]	=	2,521,329	m^3

Total Consumption from Residential properties supplied by the Municipality
= 1,631,788 m^3/yr

Population over Aldergrove (excluding rural properties supplied by private wells)
= 11,819

# of Residences on the Municipal Supply
= 4044

Estimated Consumption

138	m^3/person/yr
404	m^3/house/yr

If 15% of AWTP is removed due to leakage, then

Total consumption	=	1,387,020	m^3/yr

Estimated Consumption

117	m^3/person/yr
343	m^3/house/yr

Average # People per Household

Abbotsford[3]	2.8
Langley	2.9

Source: Township of Langley

[1] Taken from the Aldergrove metered properties data from Sept '04 to Sept '05.

[2] Aldergrove Water Treatment Plant, flow data from Sept '04 to Sept '05.

[3] Sourced from Statistics Canada 2001 Census for Abbotsford

Table 4.K – Meter results from the privately metered residential properties, and the monthly average results

	Meter Readings from Private Residences (m^3)				
Date	**A**	**B**	**C**	**D**	**E**
1-Dec	17.6	17.16	-	-	-
2-Dec	-	-	22.1	-	-
5-Dec	-	-	-	-	50.78
8-Dec	-	-	-	23.53	-
22-Dec	28.91	-	-	30.26	-
15-Jan	43.56	37.56	47.97	-	103.96
15-Feb	59.77	51.75	67.33	55.15	144.64
15-Mar	76.3	64.59	89.07	69	-
15-Apr	96.85	78.08	110.39	84.8	-
23-Apr	-	-	-	-	227.56
15-May	-	-	132.15	98.82	-
15-Jun	127.85	-	175.36	115.57	-
17-Jun	-	102.62	-	-	-
15-Jul	-	118.36	255.67	-	-
17-Jul	-	-	-	133.39	-
7-Aug	-	-	-	-	397.39
14-Aug	-	-	332.52	-	-
15-Aug	158.85	133.92	-	155.15	-

	Average Consumption (m^3/day)				
Month	**A**	**B**	**C**	**D**	**E**
December	0.54	0.44	0.57	0.48	1.30
January	0.61	0.46	0.62	0.45	1.31
February	0.52	-	0.78	0.49	-
March	0.59	0.46	0.69	0.51	-
April	0.66	0.44	0.73	0.47	1.24
May	0.51	0.39	1.39	0.54	-
June	-	0.56	2.68	0.56	-
July	0.51	0.50	2.56	0.75	1.60
Average	0.56	0.46	1.25	0.53	1.36
# People	2	2	3	2	7
Average / person	0.28	0.23	0.42	0.27	0.19
	Overall Average (m^3/house/day)				0.79
	Consumption (m^3/house/yr)				288.92

Table 4.L – Calculation of annual residential consumption

Location	# Houses	# People	Consumption (House/yr) 100%	Consumption (House/yr) 85%	Consumption (House/yr) Conservative	Consumption (Person/yr) 100%	Consumption (Person/yr) 85%	Consumption (Person/yr) Conservative
Langley								
Suburban	4,044	11,728	1,631,788	1,387,020	1,168,393	1,619,169	1,376,294	1,191,308
Rural	33	96	13,316	11,318	9,534	13,213	11,231	9,721
Agricultural	223	647	89,982	76,485	64,429	89,287	75,894	65,693
Total	**4,300**	**12,470**	**1,735,086**	**1,474,823**	**1,242,357**	**1,721,668**	**1,463,418**	**1,266,722**
Abbotsford (All)								
Suburban	274	767	110,561	93,977	79,164	105,923	90,035	77,933
Rural	155	434	62,544	53,162	44,783	59,920	50,932	44,086
Agricultural	453	1,268	182,789	155,371	130,881	175,121	148,853	128,846
Total	**882**	**2,470**	**355,894**	**302,510**	**254,828**	**340,965**	**289,820**	**250,866**
Abbotsford (Select)[1]								
Suburban	0	0	0	0	0	0	0	0
Rural	32	90	12,912	10,975	9,245	12,371	10,515	9,102
Agricultural	296	829	119,438	101,523	85,520	114,428	97,264	84,191
Total	**328**	**918**	**132,351**	**112,498**	**94,766**	**126,799**	**107,779**	**93,293**
Grand Total								
All Aquifer	5,182	14,940	2,090,981	1,777,333	1,497,185	2,062,633	1,753,238	1,517,588
Select Aquifer	4,628	13,388	1,867,437	1,587,321	1,337,123	1,848,467	1,571,197	1,360,015

Table 4.M – Property statistics of the major land use categories over the aquifer

# Properties (water users)	Langley	Abbotsford	Total	%
Agricultural	256	478	734	15.5
Commercial	264	21	285	6.0
Industrial	110	4	114	2.4
Institutional	52	14	66	1.4
Recreational/Other	34	7	41	0.9
Residential	3078	417	3495	73.8
Total	3794	941	4735	100

Table 4.N – Meter readings from the sub-sampled properties on the municipal supply

	Meter Values Observed on the (Range of) Date(s) in m^3							
Category	Aug 30	Sept 6-7	Sept 13-14	Oct 4-5	Jan 16-17	Feb 23-24	Apr 25 - May 5	Aug 1 - 8
A1	4,326	4,329	4,332	4,341	4,386	4,404	4,432	-
A2	3,758	3,760	3,760	3,813	3,861	3,874	3,925	-
A3	7,731	7,750	7,772	7,818	8,140	8,224	8,353	-
A4	-	1,884	1,885	1,891	1,919	1,928	1,943	-
A5	108,205	108,595	108,900	109,710	113,480	115,525	117,050	-
A6	1,915	1,919	1,924	1,936	1,992	2,020	2,074	-
A7	1,060	1,090	1,115	1,225	1,485	1,485	1,485	-
A8	2,004	2,061	2,160	2,333	3,106	3,364	3,888	-
A9	3,438	3,532	3,602	3,855	4,484	4,503	-	4710
A10	20,092	20,114	20,140	20,219	20,537	20,642	21,236	-
A11	24,566	24,565	24,566	24,567	24,593	24,594	24,783	-
A12	5,178	5,179	5,184	5,197	5,277	5,305	5,358	-
A13	2,638	2,658	2,662	2,672	2,674	2,674	2,674	-
A14	7,759	7,780	7,808	7,855	8,180	8,210	8,271	-
A15	4,556	45,666	4,575	4,599	4,681	4,721	4,816	-
A16	1,787	1,805	1,807	1,817	1,830	1,834	1,841	-
A17	9,624	9,639	9,652	9,686	9,840	9,889	9,933	-
A18	8,542	8,599	8,653	8,735	8,998	9,123	9,376	-
A19	961	963	965	970	993	1,002	1,040	-
A20	4,656	4,690	4,721	4,817	5,203	5,343	5,576	-
A21	26,725	26,760	26,788	26,822	27,849	28,423	29,562	-
A22	4,680	4,691	4,705	4,724	4,826	4,848	4,892	-
A23	4,988	4,996	5,003	5,028	5,144	5,187	5,260	-
A24	1,892	1,895	1,896	1,906	1,935	1,943	1,956	-
A25	-	1,437	1,440	1,444	1,471	1,490	1,538	-
A26	15,135	15,187	15,250	15,329	15,371	15,393	15,483	-
A27	274	337	342	357	421	463	526	-
A28	49,337	49,451	49,603	50,046	51,887	52,541	53,421	-
A29	-	4,346	4,353	4,371	4,464	4,501	4,577	-
A30	6,022	6,030	6,038	6,062	6,215	6,279	6,447	-
A31	3,287	3,295	3,304	3,331	3,463	3,516	-	3746
A32	4,045	4,051	4,058	4,080	4,169	4,219	-	4438
A33	1,920	2,146	2,357	2,427	2,691	2,724	-	3904
A34	54,237	54,559	54,865	55,763	59,946	61,310	63,710	-
A35	13,769	13,772	13,782	13,805	13,893	13,929	-	-

	Meter Values Observed on the (Range of) Date(s) in m³							
Category	**Aug 30**	**Sept 6-7**	**Sept 13-14**	**Oct 4-5**	**Jan 16-17**	**Feb 23-24**	**Apr 25 - May 5**	**Aug 1 - 8**
A36	2,372	2,372	2,372	2,372	2,392	2,404	-	2440
A37	4,058	4,075	4,092	4,138	4,189	4,208	4,245	-
A38	1,450	1,457	1,471	1,492	1,569	1,588	-	1621
A39	329	333	337	349	436	472	534	-
A40	3,536	3,541	3,543	3,553	3,580	3,590	3,592	-
A41	3,860	3,863	3,866	3,876	3,919	3,938	3,965	-
A42	1,455	1,439	1,442	1,452	1,500	1,514	1,538	-
A43	3,089	3,099	3,108	3,137	3,279	3,331	3,426	-
A44	4,915	4,919	4,924	4,941	5,260	5,602	-	-
C1	197,656	198,017	198,388	199,522	204,540	206,456	210,020	-
C2	11,220	11,224	11,230	11,252	11,356	11,406	11,477	-
C3	2,949	2,953	2,956	2,963	3,004	3,020	3,042	-
C4	8,214	8,245	8,264	8,469	9,197	9,296	9,364	-
C5	-	38,016	38,100	38,338	39,256	39,536	40,139	-
C6	535	538	541	549	575	582	600	-
C7	-	969	982	1,022	1,189	1,241	1,328	-
C8	-	8,093	8,139	8,293	8,998	9,175	9,502	-
C9	-	9,678	9,681	9,698	9,779	9,814	9,921	-
C10	-	293,128	293,365	294,015	297,072	298,296	300,218	-
C11	-	6,278	6,295	6,322	6,438	6,491	6,566	-
ID1	1,328	1,329	1,331	1,339	1,361	1,366	1,385	-
ID2	95,420	95,490	95,723	96,105	98,510	99,451	101,175	-
ID3	1,602	1,604	1,607	1,616	1,654	1,671	1,698	-
ID4	347,949	349,050	350,564	355,100	379,092	389,180	405,877	-
ID5	1,640	1,642	1,645	1,652	1,684	1,699	1,723	-
ID6	-	-	-	-	3,041	3,058	3,354	-
ID7	-	-	-	-	88,674	88,710	88,773	-
ID8	-	-	-	-	11,430	11,497	11,535	-
ID9	-	-	-	-	26,142	26,389	28,111	-
ID10	-	-	-	-	19,373	19,482	19,746	-
ID11	-	-	-	-	3,036	3,607	5,136	-
ID12	-	-	-	-	1,975	2,006	2,023	-
IS1	5,206	5,208	5,212	5,225	5,259	5,274	5,310	-
IS2	-	-	-	-	43,755	43,960	44,293	-
IS3	-	-	-	-	31,087	31,272	77,100	-

	Meter Values Observed on the (Range of) Date(s) in m^3							
Category	**Aug 30**	**Sept 6-7**	**Sept 13-14**	**Oct 4-5**	**Jan 16-17**	**Feb 23-24**	**Apr 25 - May 5**	**Aug 1 - 8**
IS4	-	-	-	-	111,611	112,571	113,801	-

A = Agricultural/Hobby Farms

C = Commercial

ID = Industrial

IS = Institutional

Table 4.O – Calculations for the *dS* component of natural discharge

Aquifer Thickness	10	m
Aquifer Area	47,737,334	m^3
Average dh (head change)	0.3	m/yr

If the aquifer was completely saturated, then a 0.3m head drop means that the saturated thickness:

= 10m - 0.3m

= 9.7m

At 10m saturation, the volume of the aquifer =	477,373,340	m^3
At 9.7m saturation, the volume of the aquifer =	463,052,140	
Volumetric Difference =	14,321,200	

Porosity of the aquifer materials ranges from 20% to 44%

Therefore, *dS* =	20% of Volumetric difference =	**2,864,240**	m^3
	44% of Volumetric difference =	**6,301,328**	m^3

Appendix 5 – Changes over the Aquifer

Table 5.A – Impermeability over the Langley part of Aldergrove aquifer in 1995

Land Use	Total Area (m^2)	Impermeable Area (m^2)	%
Residential	2,232,815	766,190	34.3
Agricultural	8,677,639	224,216	2.6
Commercial	316,113	196,429	62.1
Industrial	326,642	14,686	4.5
Institutional	2,864,392	164,366	5.7
Other	1,295,710	28,363	2.2
Total	15,713,311	1,394,250	

Roads

Type	Width (m)	Length (m)	Estimated Imperviousness (m^2)
Highway	27	1,398	37,746
Large	15	16,137	242,059
Local	9	39,460	355,142
	Total	56,995	634,947

Residential

	Area (m^2)		Impermeable Area (m^2)		
Type (ID)	**Total**	**Sampled**	**Sampled**	**%**	**Estimated Total**
Block (1)	1,140,083	28,169	11,245	39.9	
		27,602	8,276	30.0	
		16,272	7,402	45.5	
			Average	38.5	438,509
Cul de Sac (2)	399,838	24,911	9,375	37.6	150,468
Enclosed (3)	282,702	29,752	16,557	55.7	157,326
Others (4)	410,192	410,192	19,887	4.8	19,887
				Total	766,190

Total Area (m^2)	Total Impervious Area (m^2)	Total Imperviousness %
16,348,258	2,029,198	12.4

Table 5.B – Impermeability over the Langley part of Aldergrove aquifer in 2005

Land Use	Total Area (m^2)	Impermeable Area (m^2)	%
Residential	2,291,957	833,626	36.4
Agricultural	8,677,639	262,524	3.0
Commercial	316,113	248,794	78.7
Industrial	326,642	205,348	62.9
Institutional	2,864,392	172,065	6.0
Other	1,236,569	53,756	4.4
Total	15,713,311	1,776,112	

Roads

Type	Width (m)	Length (m)	Estimated Imperviousness (m^2)
Highway	27	1,398	37,746
Large	15	17,525	262,877
Local	9	46,027	414,244
	Total	64,950	714,867

Table 5.B – continued

Residential

	Area (m^2)		Impermeable Area (m^2)		
Type (ID)	**Total**	**Sampled**	**Sampled**	**%**	**Estimated Total**
Block (1)	1,140,083	28,169	11,245	39.9	
		27,602	8,276	30.0	
		16,272	7,402	45.5	
			Average	38.5	438,509
New in 2005	84,745				
Total	**1,224,827**				**471,104**
Cul de Sac (2)	399,838	24,911	9,375	37.6	150,468
New in 2005	15,591				
Total	**415,429**				**156,335**
Enclosed (3)	281,695	29,752	161,870	57.5	161,870
Others (4)	370,005	370,005	44,317	12.0	44,317
				Total	833,626

Total Area (m^2)	**Total Impervious Area (m^2)**	**Total Imperviousness %**
16,428,179	2,490,980	15.2

Notes About Langley-Aldergrove Impermeability

All the land uses were determined from the 2004 parcel/landuse map, according to land use codes provided by the Township of Langley. Errors are likely to result from incompatability of the 1995/2004 land use with the 2005 aerial photos.

For residential, the grouping of this category into similar types involved manually creating polygons that cover each block/cul de sac/enclosement etc of houses, using the aerial photos as a guide. The impermeability was then determined by randomly selecting a sample of each type and using the impermeability of that sample to be representative of all the residential units of that type. This method will result in a possible error due to the representativeness of the selected sample, and the accuracy of delineated polygons.

The Type (ID) 4 properties were those that do not fit into any of the other 3 residential types (e.g. were stand alone units). These were manually delineated for impermeability.

Table 5.C – Impermeability over the Abbotsford part of Aldergrove aquifer in 1995

Land Use	Total Area (m^2)	Impervious Area (m^2)	% Impermeability
Agricultural	24,016,511	461,250	1.9
Commercial	424,214	67,374	15.9
Industrial	122,944	5,912	4.8
Institutional	168,433	16,148	9.6
Other	1,590,039	2,925	0.2
Residential	2,641,963	84,189	3.2
Total	28,964,103	637,798	

Roads

Type	Road Width (m)	Road Length (m)	Estimated Imperviousness (m^2)
Highway	27	5,014	135,370
10	10	36,958	369,583
8	8	1,204	9,630
7	7	4,901	34,305
6	6	11,460	68,762
4	4	18,873	75,491
Total		78,409	693,141

Total Area (m^2)	Total Impervious Area (m^2)	Total Imperviousness %
29,657,244	1,330,939	4.5

Table 5.D – Impermeability over the Abbotsford part of Aldergrove aquifer in 2005

Land Use	Total Area (m^2)	Impervious Area (m^2)	% Impermeability
Agricultural	24,016,511	782,173	3.3
Commercial	424,214	68,998	16.3
Industrial	122,944	6,276	5.1
Institutional	168,433	24,170	14.3
Other	1,391,798	7,241	0.5
Residential	2,840,204	144,949	5.1
Total	28,964,103	1,033,806	

Roads

Type	Road Width (m)	Road Length (m)	Estimated Imperviousness (m^2)
Highway	27	5,014	135,370
10	10	37,446	374,462
8	8	3,265	26,120
7	7	4,901	34,305
6	6	12,085	72,509
4	4	25,385	101,541
Total		88,096	744,308

Total Area (m^2)	Total Impervious Area (m^2)	Total Imperviousness %
29,708,411	1,778,114	6.0

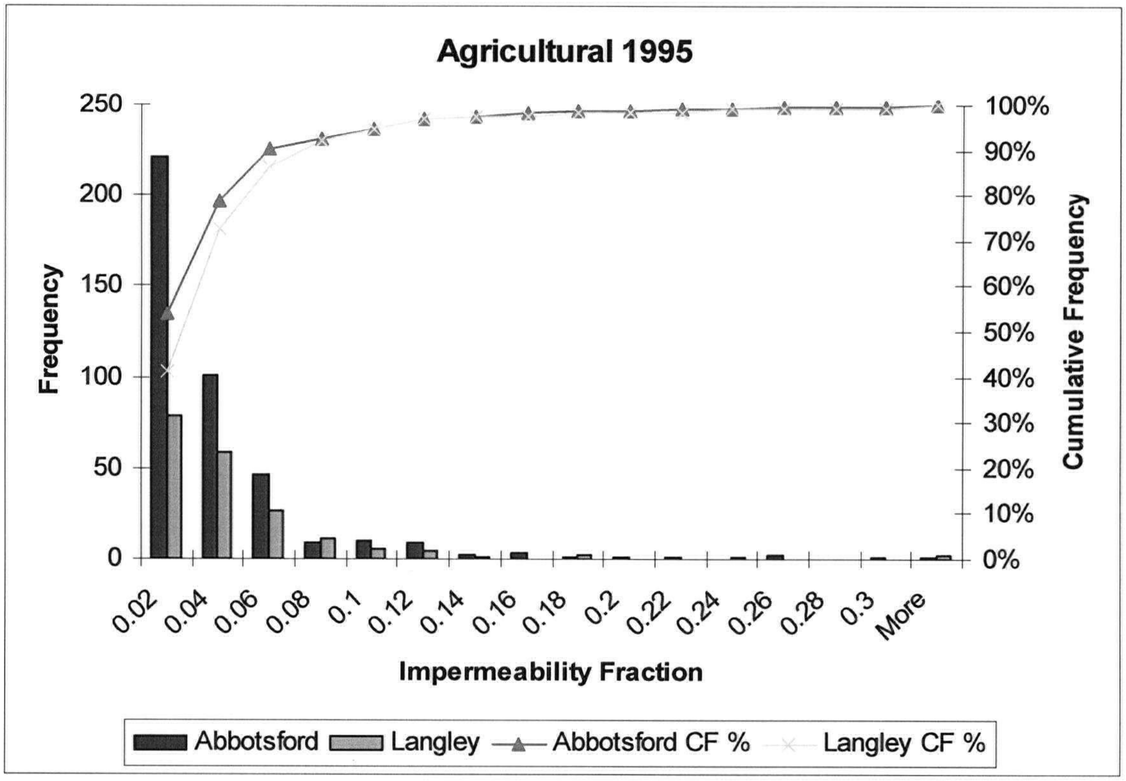

Figure 5.A - Impermeability distribution for agricultural properties in 1995

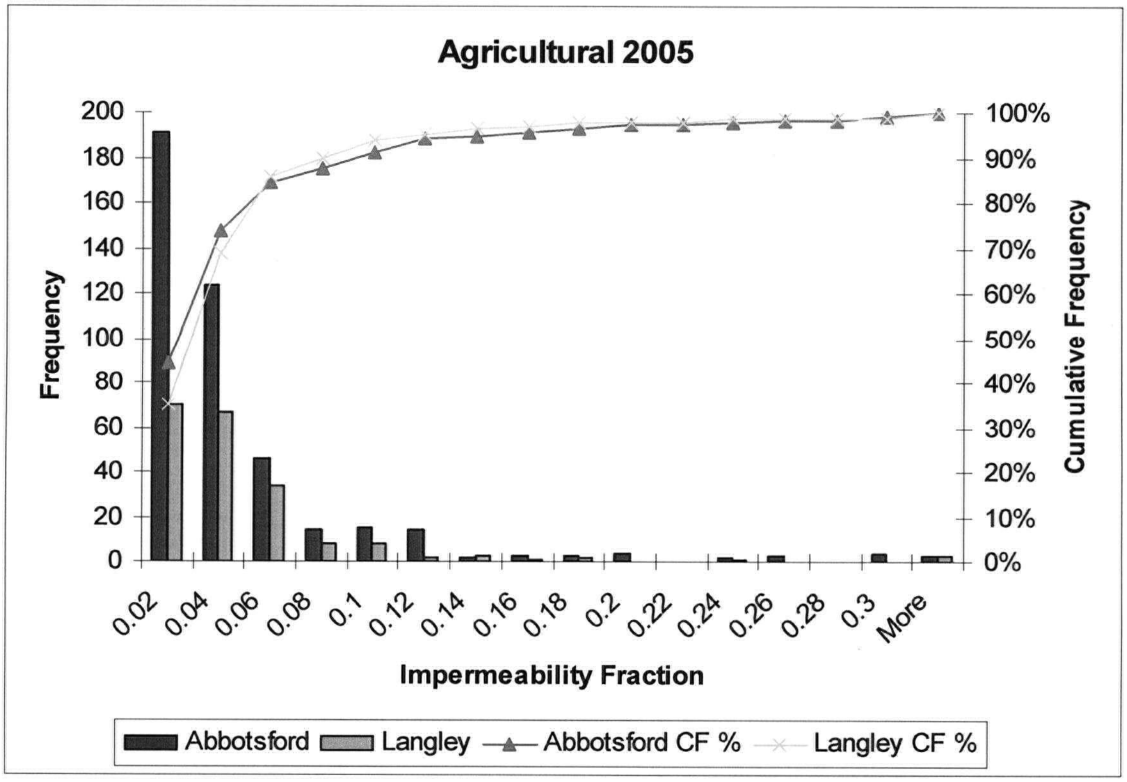

Figure 5.B – Impermeability distribution for agricultural properties in 2005

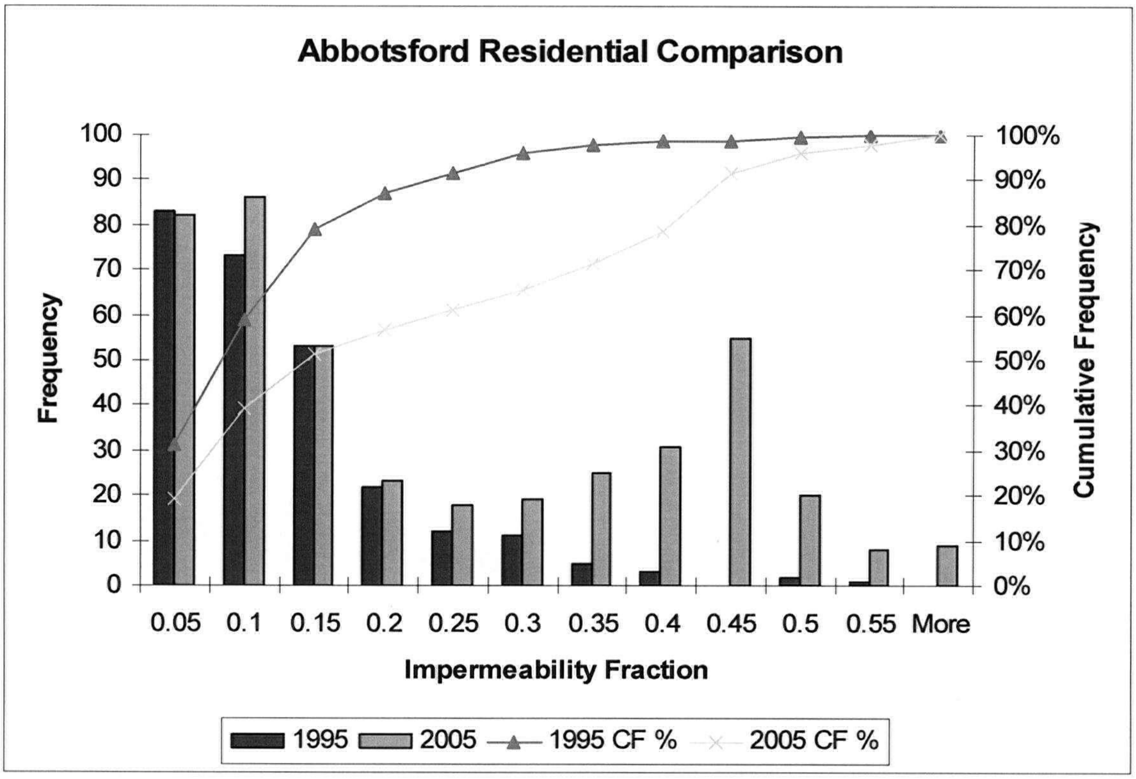

Figure 5.C – Impermeability distribution for Abbotsford residential properties for 1995 and 2005

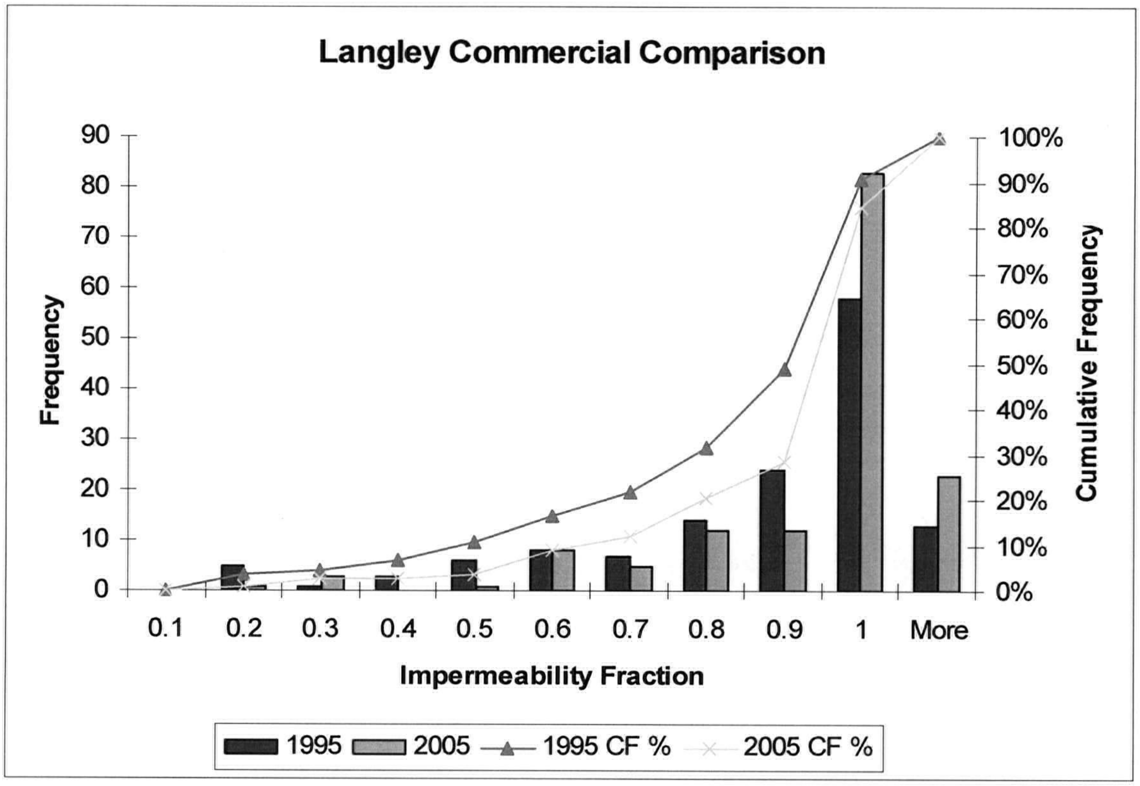

Figure 5.D – Impermeability distribution for Langley commercial properties in 1995 and 2005[4]

[4] Residential impermeability in Langley was estimated by sub-sampling, therefore cannot be presented as a distribution graph. None of the other land use types had sufficient number of properties to make a meaningful distribution graph.

Appendix 6 – Past, Present and Future Scenarios

Table 6.A– Calculations used to 'backcast' agricultural areas over the aquifer

Source: 1996/2001 Census of Agriculture

	South Langley			Aldergrove-Langley		
Type	Average area (m^2/farm)		Difference	2005 Area (m^2)	Backcast (m^2/farm)	
	1996	2001			2001	1996
Greenhouse	592.46	1,354.96	2.3	11,828	5,172	**2,261**
Fruits Crops	8.36	11.36	1.4	56,873	41,869	**30,823**
Pasture	3.99	4.49	1.1	37,721	33,523	**29,791**

	South Matsqui			Aldergrove-Abbotsford		
Type	Average area (m^2/farm)		Difference	2005 Area (m^2)	Backcast (m^2/farm)	
	1996	2001			2001	1996
Greenhouse	4,245.70	15,790.35	3.7	18,372	4,940	**1,328**
Fruits Crops	5.64	8.22	1.5	33,901	23,263	**15,963**
Pasture	3.89	11.01	2.8	45,550	16,098	**5,689**

Table 6.B – Agricultural areas in 2005

	Langley	Abbotsford
Greenhouses		
# Greenhouses	8	15
Total Area (m^2)	94,621	275,587
Average Area (m^2/farm)	**11,828**	**18,372**
Fruits Crops		
# Farms	31	108
Total Area (m^2)	1,763,065	3,661,332
Average Area (m^2/farm)	**56,873**	**33,901**
Pastures		
# Farms	107	247
Total Area (m^2)	4,036,186	11,250,852
Average Area (m^2/farm)	**37,721**	**45,550**

Table 6.C – Resulting 'backcasted' agricultural areas for 1996

	Langley	Abbotsford
Greenhouses		
# Greenhouses	8	15
Average Area (m^2/farm)	2,261	1,328
Total Area (m^2)	**18,090**	**19,924**
Fruits Crops		
# Farms	31	108
Average Area (m^2/farm)	30,823	15,963
Total Area (m^2)	**955,511**	**1,724,052**

Table 6.D - Crop and pasture water consumption in 1996 based on evapotranspiration requirements

Source: Farmwest.com

Month	Average ET in 1996 (mm/day)	Crop Coefficients[2]		Estimated ET Losses			
		Berries[1]	Pasture	Berries (mm/day)	Berries (mm/month)	Pasture (mm/day)	Pasture (mm/month)
May	**2.6**	0.4	not considered	1.04	32.24	-	-
June	**3.8**	1.04	1	3.95	118.56	3.80	114.00
July	**4.9**	1.04	1	5.10	157.98	4.90	151.90
August	**3.8**	0.68	1	2.58	80.10	3.80	117.80
September	**2.2**	0.68	not considered	1.50	44.88	-	-
				Total	433.76		383.70
				Total in m³	0.43		0.38
				Aquifer Total	**1,162,287**		**1,350,354**
				Abbotsford	747,825		880,151
				Langley	414,462		470,202

Table 6.E – Area based on 'backcasted' results

Area (m²)	**Fruits Crop**	**Pasture[3]**	**15% Pasture**
Abbotsford	1,724,052	15,292,355	2,293,853
Langley	955,511	8,169,618	1,225,443
Total	**2,679,563**	**23,461,973**	**3,519,296**

[1] 'Berries' refers to the amalgamated average of blueberries, cranberries, raspberries and strawberries.

[2] Farmwest crop coefficients are grouped into periods of plant growth stages, (initial, mid, and end), thus the monthly coefficient is estimated by assuming May = initial, June/July = mid, and Aug/Sept = end of growth season.

[3] The 'backcast' for fruits/crops and greenhouse area resulted in a reduction of the total agricultural area. Since the total agricultural land over the aquifer has not changed due to the existence of the ALR, the remaining agricultural land (after backcasting fruits/crops and greenhouse area) was designated as pasture area. Consequently, the area of pasture is much greater in 1996 than in 2005.

Table 6.F – Greenhouse water consumption in 1996 based on evapotranspiration requirements

		Water Use Forecast		Water Use Estimate			
Month	Average ET (mm/day)	L/m²/day	m³/m²/month	L/m²/month	Langley L/month	Abbotsford L/month	Total
January	**0.5**	2.1	0.07	66.1	1,196,352	1,317,641	2,513,993
February	**1**	2.8	0.08	78.4	1,418,256	1,562,042	2,980,298
March	**1.5**	3.5	0.11	107.5	1,944,072	2,141,166	4,085,238
April	**2.1**	4.3	0.13	128.0	2,315,520	2,550,272	4,865,792
May	**2.6**	4.9	0.15	152.9	2,766,564	3,047,044	5,813,608
June	**3.8**	6.5	0.20	196.0	3,545,640	3,905,104	7,450,744
July	**4.9**	8.0	0.25	248.0	4,486,320	4,941,152	9,427,472
August	**3.8**	6.5	0.20	202.5	3,663,828	4,035,274	7,699,102
September	**2.2**	4.4	0.13	132.0	2,387,880	2,629,968	5,017,848
October	**1.2**	3.1	0.10	95.1	1,719,756	1,894,108	3,613,864
November	**0.5**	2.1	0.06	64.0	1,157,760	1,275,136	2,432,896
December	**0.4**	2.0	0.06	62.0	1,121,580	1,235,288	2,356,868
				Total	**27,724**	**30,534**	**58,258**
				2/3 Total	**18,482**	**20,356**	**38,838**

Table 6.G – Area from 'backcasted' results

Area (m²)	Greenhouses
Abbotsford	19,924
Langley	18,090
Total	**38,014**

Table 6.H – Forecast Base[1]

	Average ET (mm)	Water Use L/m²/day
July	4.9	8
December	0.4	2

[1] Water use values obtained from BC Greenhouse Growers' Association

Table 6.I – Livestock water consumption in 1996 based on drinking water needs

	Average Daily Water Needs[1]			Langley				Abbotsford				Total	
Livestock Type	US gallons	L/day	m^3/yr	# farms	Average # animals / farm[3]	Total # animals	C (m^3/yr)	# farms	Average # animals / farm[3]	Total # animals	C (m^3/yr)	# animals	C (m^3/yr)
Beef	9	34.1	12.4	21	21	441	5,483	60	21	1,260	15,666	1,701	21,150
Dairy	36	136.3	49.7	4	50	200	9,947	4	33	132	6,565	332	16,512
Horse	12	45.4	16.6	46	8	368	6,101	84	4	336	5,570	704	11,671
Sheep/ Goat	2.5	9.5	3.5	6	30	180	622	12	43	516	1,782	696	2,404
Poultry	0.06	0.2	0.1	12	6,374	76,488	6,340	46	22,859	1,051,514	87,162	1,128,002	93,502
Exotics[2]	2	7.6	2.8	7	11	77	213	8	0	0	0	77	213
						Total	28,706				116,746		145,451

[1] Based on values taken from the B.C. Ministry of Agriculture and Lands
[2] Based on llama/alpaca values
[3] Based on data from the 1996 Census of Agriculture
C = Consumption

Table 6.J – Water consumption of the CIIO group in 1995

All properties over the Aldergrove aquifer

	Metered data				Langley-side				Abbotsford-side			Total	
Land Use Type	# meters[1]	# addresses metered	2005 Total C (m^3)	Average C / property	Total # Properties	# External Metered[2]	# Excl.[3]	# Incl.[4]	Total # Properties	# Excl.	# Incl.	# Incl.	C (m^3)
Commercial	95	85	192,922	2,270	235	21	0	**256**	23	2	**21**	277	628,699
Industrial	37	30	77,460	2,582	9	91	0	**100**	5	1	**4**	104	268,528
Institutional	13	13	35,587	2,737	48	5	1	**52**	16	2	**14**	66	180,672
Recreational /Other	5	3	21,977	7,326	96	3	84	**15**	44	37	7	22	161,165
												Total	1,239,064

C = Consumption

Table 6.K – Water consumption of the CIIO group excluding 'city-supplied' properties in Abbotsford in 1995

			Total	
		# Incl.	**# Incl.**	**C (m^3)**
Commercial	Same as Above	1	257	583,305
Industrial		3	103	265,946
Institutional		0	52	142,348
Recreational /Other		4	19	139,188
		Total		1,130,787

[1] Some properties have more than one water meter
[2] Properties that exist outside of the Aldergrove aquifer area, but still obtain their water supply from the Aldergrove municipal wells
[3] Properties that do not require a water supply
[4] Properties that do require a water supply
C = Consumption

Table 6.L – Residential units data for 1995

	# Units	
Residence Type	Langley	Abbotsford
Single-family suburban	2557	130
Multi-family suburban	973	0
Rural	256	155
Agricultural-residential	210	453
Total	3996	738

Average # people/unit

Abbotsford[1]	2.8
Langley	3.0

Note

Residential consumption calculations for 1995 are based on the assumption that per person/household demand is the same as in 2005

Source: Township of Langley and GIS data

[1] Sourced from Statistics Canada 1996 Census for Abbotsford

Table 6.M – Calculation for annual residential consumption in 1995

Location	# Houses	# People	Consumption (House/yr) 100%	Consumption (House/yr) 85%	Consumption (House/yr) Conservative	Consumption (Person/yr) 100%	Consumption (Person/yr) 85%	Consumption (Person/yr) Conservative
Langley								
Suburban	3,530	10,590	1,424,385	1,210,727	1,019,888	1,462,106	1,242,790	1,075,749
Rural	256	768	103,298	87,803	73,964	106,034	90,129	78,015
Agricultural	210	630	84,737	72,026	60,673	86,981	73,934	63,996
Total	**3,996**	**11,988**	**1,612,420**	**1,370,557**	**1,154,525**	**1,655,121**	**1,406,853**	**1,217,760**
Abbotsford (All)								
Suburban	130	364	52,456	44,588	37,560	50,256	42,717	36,976
Rural	155	434	62,544	53,162	44,783	59,920	50,932	44,086
Agricultural	453	1,268	182,789	155,371	130,881	175,121	148,853	128,846
Total	**738**	**2,066**	**297,789**	**253,121**	**213,223**	**285,297**	**242,503**	**209,908**
Abbotsford (Select)[1]								
Suburban	0	0	0	0	0	0	0	0
Rural	32	90	12,912	10,975	9,245	12,371	10,515	9,102
Agricultural	296	829	119,438	101,523	85,520	114,428	97,264	84,191
Total	**328**	**918**	**132,351**	**112,498**	**94,766**	**126,799**	**107,779**	**93,293**
Grand Total								
All Aquifer	4,734	14,054	1,910,209	1,623,677	1,367,748	1,940,418	1,649,355	1,427,668
Select Aquifer	4,324	12,906	1,744,770	1,483,055	1,249,291	1,781,920	1,514,632	1,311,053

[1] Excludes those residential properties that are supplied by water from the City of Abbotsford, which is not a groundwater source

Table 6.N – Calculations used to 'forecast' agricultural area over the aquifer

Source: 1996/2001 Census of Agriculture

	South Langley			Aldergrove-Langley	
Type	Average area (m^2/farm) 1996	2001	Difference	2005 Area (m^2)	Forecast (m^2/farm)
Greenhouse	592.46	1,354.96	2.3	11,828	**27,050**
Fruits Crops	8.36	11.36	1.4	56,873	**77,254**
Pasture	3.99	4.49	1.1	37,721	**42,446**

	South Matsqui			Aldergrove-Abbotsford	
Type	Average area (m^2/farm) 1996	2001	Difference	2005 Area (m^2)	Forecast (m^2/farm)
Greenhouse	4,245.70	15,790.35	3.7	18,372	**68,330**
Fruits Crops	5.64	8.22	1.5	33,901	**49,404**
Pasture	3.89	11.01	2.8	45,550	**128,889**

Table 6.O – Agricultural areas in 2005

	Langley	Abbotsford
Greenhouses # Greenhouses	8	15
Total Area (m^2)	94,621	275,587
Average Area (m^2/farm)	**11,828**	**18,372**
Fruits Crops # Farms	31	108
Total Area (m^2)	1,763,065	3,661,332
Average Area (m^2/farm)	**56,873**	**33,901**
Pastures # Farms	107	247
Total Area (m^2)	4,036,186	11,250,852
Average Area (m^2/farm)	**37,721**	**45,550**

Table 6.P – Resulting 'forecasted' agricultural areas for 2015

	Langley	Abbotsford
Greenhouses # Greenhouses	8	15
Average Area (m^2/farm)	27,050	68,330
Total Area (m^2)	**216,399**	**1,024,948**
Fruits Crops # Farms	31	108
Average Area (m^2/farm)	77,254	49,404
Total Area (m^2)	**2,394,884**	**5,335,603**

Table 6.Q - Crop and pasture water consumption projection for the 2015 'growth' scenario

Source: Farmwest.com

		Crop Coefficients[2]		Estimated ET Losses			
Month	Long-term Average ET (mm/day)	Berries[1]	Pasture	Berries (mm/day)	Berries (mm/month)	Pasture (mm/day)	Pasture (mm/month)
May	**3.2**	0.4	not considered	1.26	39.06	-	-
June	**3.9**	1.04	1	4.08	122.46	3.93	117.75
July	**4.4**	1.04	1	4.58	141.86	4.40	136.40
August	**3.9**	0.68	1	2.64	81.69	3.88	120.13
September	**2.6**	0.68	not considered	1.75	52.53	-	-
				Total	437.59		374.28
				Total in m³	0.44		0.37
				Aquifer Total	**3,382,792**		**708,214**
				Abbotsford	2,334,812		521,227
				Langley	1,047,980		186,988

Table 6.R – Area based on 'forecasted' results

Area (m²)	Fruits Crop	Pasture[3]	15% Pasture
Abbotsford	5,335,603	9,284,205	1,392,631
Langley	2,394,884	3,330,662	499,599
Total	**7,730,487**	**12,614,867**	**1,892,230**

[1] 'Berries' refers to the amalgamated average of blueberries, cranberries, raspberries and strawberries.

[2] Farmwest crop coefficients are grouped into periods of plant growth stages, (initial, mid, and end), thus the monthly coefficient is estimated by assuming May = initial, June/July = mid, and Aug/Sept = end of growth season.

[3] The 'forecast' for fruits/crops and greenhouse area resulted in an expansion of the total agricultural area. Since the total agricultural land over the aquifer is not likely to increase, the amount of agricultural land 'in excess' (after forecasting fruits/crops and greenhouse area) was matched by an equivalent reduction in pasture area. Consequently, the area of pasture is much lower in 2015 than in 2005.

Table 6.S – Greenhouse water consumption projection for the 2015 'growth' scenario

		Water Use Forecast		Water Use Estimate			
Month	Average ET (mm/day)	L/m²/day	m³/m²/month	L/m²/month	Langley L/month	Abbotsford L/month	Total
January	**0.6**	2.11	0.07	65.55	14,185,850	67,189,585	81,375,435
February	**1.0**	2.84	0.08	79.54	17,212,680	81,525,800	98,738,480
March	**1.5**	3.53	0.11	109.39	23,671,570	112,117,560	135,789,130
April	**2.5**	5.13	0.15	154.01	33,328,203	157,855,049	191,183,251
May	**3.2**	6.09	0.19	188.76	40,848,413	193,473,624	234,322,036
June	**3.9**	7.27	0.22	218.22	47,221,845	223,660,627	270,882,473
July	**4.4**	8.00	0.25	248.00	53,666,952	254,187,104	307,854,056
August	**3.9**	7.20	0.22	223.12	48,283,165	228,687,442	276,970,608
September	**2.6**	5.21	0.16	156.31	33,824,404	160,205,248	194,029,652
October	**1.3**	3.26	0.10	101.10	21,876,974	103,617,673	125,494,647
November	**0.7**	2.34	0.07	70.32	15,216,847	72,072,777	87,289,623
December	**0.5**	2.00	0.06	62.00	13,416,738	63,546,776	76,963,514
				Total	**362,754**	**1,718,139**	**2,080,893**
				2/3 Total	**241,836**	**1,145,426**	**1,387,262**

Table 6.T – Area from 'forecasted' results

Area (m²)	Greenhouses
Abbotsford	1,024,948
Langley	216,399
Total	**1,241,347**

Table 6.U – Forecast Base[1]

	Average ET (mm)	Water Use L/m²/day
July	4.4	8
December	0.5	2

[1] Water use values obtained from BC Greenhouse Growers' Association

Table 6.V – Livestock water consumption projection for the 2015 'growth' scenario

	Average Daily Water Needs[1]		Average # of Animals/Farm				2015 Projection for Langley		
Livestock Type	US gallons	m^3/yr	2005	1996[3]	Difference	Projection for 2015	# Farms	Total # Animals	Consumption (m^3)
Beef	9	12.4	30	21	9	39	21	819	10,183
Dairy	36	49.7	76	50	26	102	4	408	20,292
Horse	12	16.6	9	8	1	10	46	460	7,626
Sheep/Goat	2.5	3.5	28	30	-2	26	6	156	539
Poultry	0.06	0.1	7,240	6,374	866	8,106	12	97,272	8,063
Exotics[2]	2	2.8	14	11	3	17	7	122	337
							Total		47,039

	Average Daily Water Needs[1]		Average # of Animals/Farm				2015 Projection for Langley		
Livestock Type	US gallons	m^3/yr	2005	1996[3]	Difference	Projection for 2015	# Farms	Total # Animals	Consumption (m^3)
Beef	9	12.4	29	21	8	37	60	2,220	27,603
Dairy	36	49.7	85	33	52	137	4	548	27,255
Horse	12	16.6	4	4	0	4	84	370	6,127
Sheep/Goat	2.5	3.5	45	43	2	47	12	564	1,948
Poultry	0.06	0.1	29,336	22,859	6,478	35,814	46	1,647,421	136,557
Exotics[2]	2	2.8	5	0	5	10	8	80	221
							Total		199,711

[1] Based on values taken from the B.C. Ministry of Agriculture and Lands

[2] Based on llama/alpaca values

[3] Based on data from the 1996 Census of Agriculture

Table 6.W – Residential water consumption projection for the 2015 'growth' scenario

[1]Consumption per Person per year =117m^3
[2]Population of the Langley-side of the aquifer in 2005 = 918
[2]Population of the Abbotsford-side of the aquifer in 2005 = 12,470

Compounded Annual Growth Rate Calculation		
Population	Abbotsford	Langley-Aldergrove
2005	-	12,008
2001	147,370	11,190
1996	136,480	-
# years	5	5
CAGR	**0.0155**	**0.0142**
%	1.55	1.42

Population Change over the Aquifer		
Year	Langley	Abbotsford
2005	12,470	918
2006	12,647	933
2007	12,827	947
2008	13,009	962
2009	13,194	977
2010	13,382	992
2011	13,572	1,007
2012	13,765	1,023
2013	13,960	1,038
2014	14,159	1,054
2015	14,360	1,071
2015 Consumption	**1,685,193**	**125,665**

[1] Based on the result from 85% of AWTP water making up residential consumption as calculated in Chapter 4 - Discharge
[2] Taken from the estimate of population as part of the residential consumption calculation in Chapter 4 - Discharge

Residential consumption is determined by estimating population growth with the assumption that consumption per person stays the same as in 2005.

Population growth is estimated using the Compounded Annual Growth Rate, which is expressed as:

$$CAGR = [(final\ year/first\ year)^\wedge(1/number\ of\ years)]-1$$

The population over the aquifer is assumed to have the same CAGR as that of the municipality/region.

Appendix 7 – Demand Management

Table 7.A – Agricultural DM potential based on irrigation efficiency

	Abbotsford	Langley	
Total Area (m^2)			**Total**
Total Fruit/Crop area	3,661,332	1,763,065	5,424,397
Area of Potential MI	2,075,692	1,250,413	3,326,104
Normalized Area[1]			
Non-MI	0.43	0.29	
MI	0.57	0.71	
Weighted average (%)	85	88	
Consumption (m^3)			**Total**
Total Consumption Estimate	1,602,166	771,501	2,373,667
Water Use at 72% efficiency	2,225,230	1,071,530	3,296,760
Water Use at 82.2% efficiency	1,884,032	873,607	2,757,638
Difference in water use	341,199	197,923	539,122
Water Savings (%)	**15.3**	**18.5**	

Table 7.B – Indoor residential water use for ‘conventional’ versus ‘efficient’ toilets

Total Population = 13,388

	Population Age Range Distribution			Toilet Use Daily		Water Consumption (m^3)	
Age Range	Sample Population[1]	Ratio of Total	Aquifer Population[2]	# times/person	Aquifer Population	20l flush	6l flush
3 - 9	1,925	0.17	2,221	6	13,327	267	80
10 - 49	6,925	0.60	7,990	5	39,952	799	240
50 +	2,753	0.24	3,177	8	25,412	508	152
Total	11,603		13,388			1,574	472
						Daily Water Savings	
						70	%
						1,102	(m^3)

[1] Based on data from the Aldergrove Statistical Report 2004
[2] Assumed to be the same age distribution as the community of Aldergrove

Table 7.C – Indoor residential water use for 'conventional' versus 'efficient' showerheads

Total Population = 13,388
Length of showers = 7 minutes

Conventional		Efficient		Water Savings	
flow rate[1] (l/m)	water use (l)	flow rate[1] (l/m)	water use (l)	m^3	%
18.93	1,773,575	13.25	1,241,503	532	30
18.93	1,773,575	9.46	886,788	887	50
18.93	1,773,575	5.68	532,073	1,242	70
13.25	1,241,503	9.46	886,788	355	29
13.25	1,241,503	5.68	532,073	709	57
9.46	886,788	5.68	532,073	355	40

Table 7.D – Indoor residential water use for 'conventional' versus 'efficient' washing machines and dishwashers

Total # Housing Units = 4628

	Washing Machine	Dishwasher
% Prevalence in Households	100	56
# Housing Units	4,628	2,592
Weekly Use (# of times)	1	4
Machine Water Use[1] (l/load)		
Conventional	166.5	35.2
Efficient	91.6	17.0
Total Consumption (m^3)		
Conventional	770.8	364.9
Efficient	423.9	176.6
Water Savings (m^3)	346.8	188.3
%	45	52

[1] Based on values taken from Gleick, (2004).

Table 7.E – Summary of indoor residential water use and water savings

Best Estimate for Total Residential Consumption in 2005 = 1,587,321

In One Week

Appliance	Conventional	Efficient	Savings %
Toilet	11,017	3,305	70
Shower	6,208	3,725	40
Laundry	771	424	45
Dishes	365	177	52
Total	18,360	7,630	

Total Savings	
58	%
10,730	(m^3)