Groundwater Quality of the Oak Ridges Moraine

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COMMUNITY BASED EDUCATION PROJECT

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Abstract

Groundwater quality is a growing concern nationwide and protecting critical recharge areas such as the Oak Ridges Moraine is of utmost importance. In conjunction with the Ganaraska Region Conservation Authority (GRCA) and the Conservation Authorities Moraine Coalition (CAMC) this study examines the groundwater quality within the Ganaraska Region. Using groundwater quality reports from various sources, such as consultant reports and baseflow monitoring data collected by the GRCA, the quality of water in various aquifers underlying the region are discussed. Water quality within the Ganaraska Region was very good, only hardness constantly exceeded the Ontario Drinking Water Quality Standards which is expected based on the concentrations of calcium and magnesium. Chloride and sodium concentrations throughout the subsurface were reflected by the use of road salt in the region but pose no immediate threat to groundwater quality.

1.0 Introduction

Groundwater is the main source of potable water in the Ganaraska Region**,** but its quality is still widely unknown. This is a nationwide trend due to the abundance of clean drinking water and its underestimated value. Although currently under-appreciated this is likely to change as demand for potable water rises and land use activities continue to threaten water quality. An absence of groundwater quality information may be attributed to a lack of funding from government, but it is likely more simply due the perception of infiniteness of the resource. It is becoming increasingly important that the quality of groundwater and other sources are monitored to identify potential risks. Due to the popular use of wells in the rural Ganaraska Region (Sibul et al., 1977) there is a need for a water quality assessment.

Cherry et al. (1988) concluded that in the last fifty years groundwater and stratigraphic interpretation had heavily relied on the well logs of drillers. This issue was raised in 1993 by the Canadian Geoscience Council who determined that major advances in groundwater inventory, protection and research were required. Drillers' logs are a formidable source of information, although not as technically advanced as some other methods, their abundance and general content is very useful when determining the properties of the subsurface over a large area. Their usefulness was reinforced by Russell et al. (1998) who used these logs as a fundamental source of information for a variety of stratigraphic conclusions.

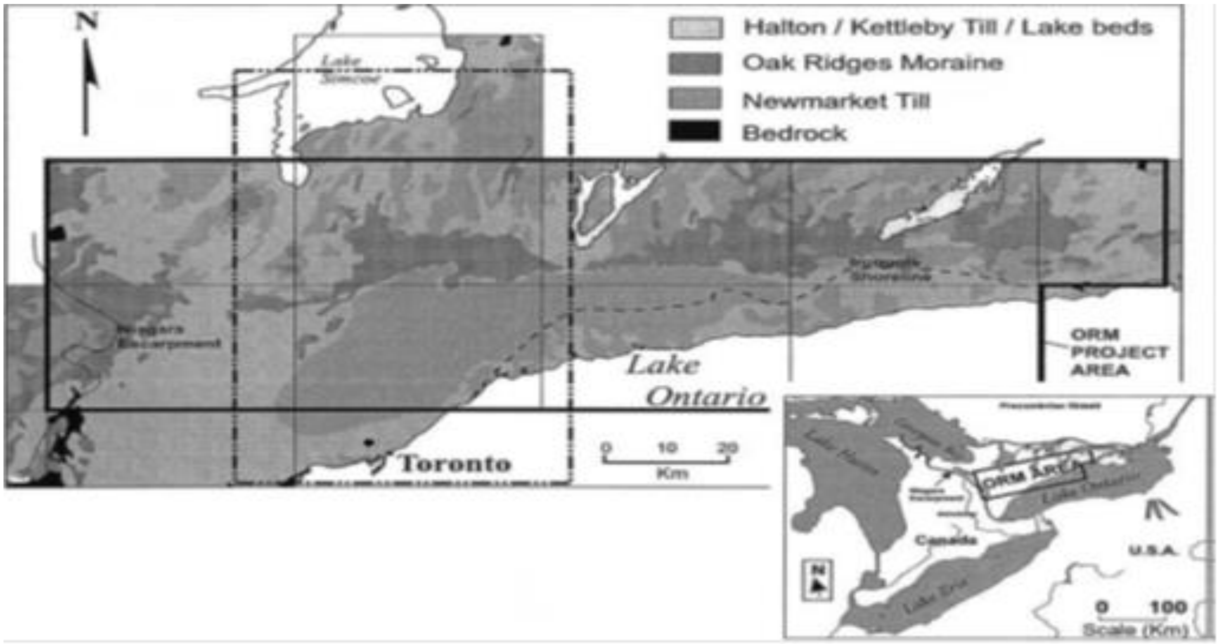

Figure 1 - Surficial geology of the Oak Ridges Moraine area (Desbarats et al., 2001).

The hydrogeological aspects of the Ganaraska Region are complex and still partially undefined, due to the intricacy of the Oak Ridges Moraine (ORM). The ORM is an area of varying subsurface materials that were deposited by the meltwater processes of receding glaciers at different times (Sharpe and Cowan, 1991). Its total area covers approximately 11,000 km^2 (bounded to the south by Lake Ontario extending north to the Canadian Shield.

Conservation Authorities in Ontario have historically disregarded groundwater quality initiatives. As explained by Ivey et al. (2002), financial and staffing restrictions, lack of public interest and an absence of regulatory authority to manage groundwater have often reduced the capacity to include groundwater in their areas of concentration. The Ganaraska Region Conservation Authority (GRCA) hopes to update this opinion and determine the quality of groundwater within their watershed area. In collaboration with the GRCA, Conservative Authorities Moraine Coalition (CAMC) and Trent University this study will summarize available data and determine the quality of groundwater within the aquifers of the Ganaraska Region.

2.0 Stratigraphy of the Ganaraska Region

As seen in Figure 2, there are a variety of sedimentary layers that make up the ORM, each with their own unique properties important to the flow and storage of water through the subsurface. Known as aquifers, these layers can be found at varying depths throughout most of Ganaraska Region and contain the cavities in which groundwater is stored. Water contained within aquifers is withdrawn by wells and used as a drinking water source for both private and municipal purposes. The differing properties of the subsurface determine groundwater movement and the volume of stored water.

As seen in Figure 2, the uppermost aquifer is the sands, silts and gravels that make up the ORM. This upper layer is very permeable and hydraulically conductive, a term used to describe the ability of a porous medium to transmit fluid which is dependent on both the properties of the fluid and the medium (Fetter, 2001). The ORM then has the unique ability to transmit water down through the subsurface to lower regions in the subsurface. Determined by Gerber and Howard (2000), the overlying ORM sediments act to recharge lower aquifers (the lower sediments) through fractures and eroded surfaces of the till.

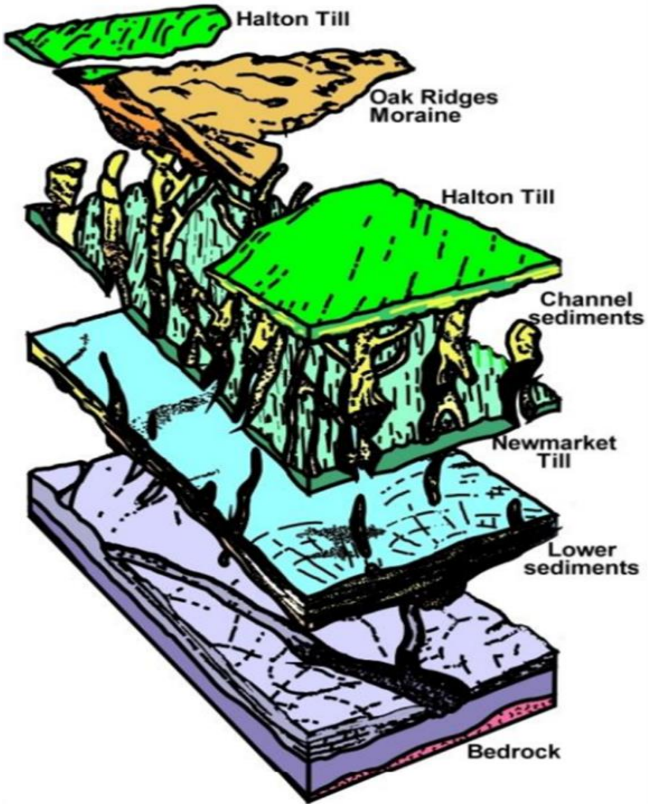

Figure 2 A 3D rendering of the ORM and the subsurface sedimentary layers. Confined within the porous spaces of these layers is the water that supplies private and municipal wells with water.

The ORM sediments and Lower Sediment aquifers are separated by the Newmarket Till, an area of reduced flow and low hydraulic conductivity (Barnett et al., 1998). Alternatively referred to as an aquitard, the Newmarket Till is present throughout the Ganaraska Region subsurface (Figure 3) and creates complex ground water flow patterns. As concluded by Gerber and Howard (2000) the Newmarket Till has a hydraulic conductivity ranging between 10^{-9} to 10^{-10}m s^{-1}. These values of hydraulic conductivity permit an assumed vertical flow rate through the aquifer of 30-40 mm/yr on a regional basis.

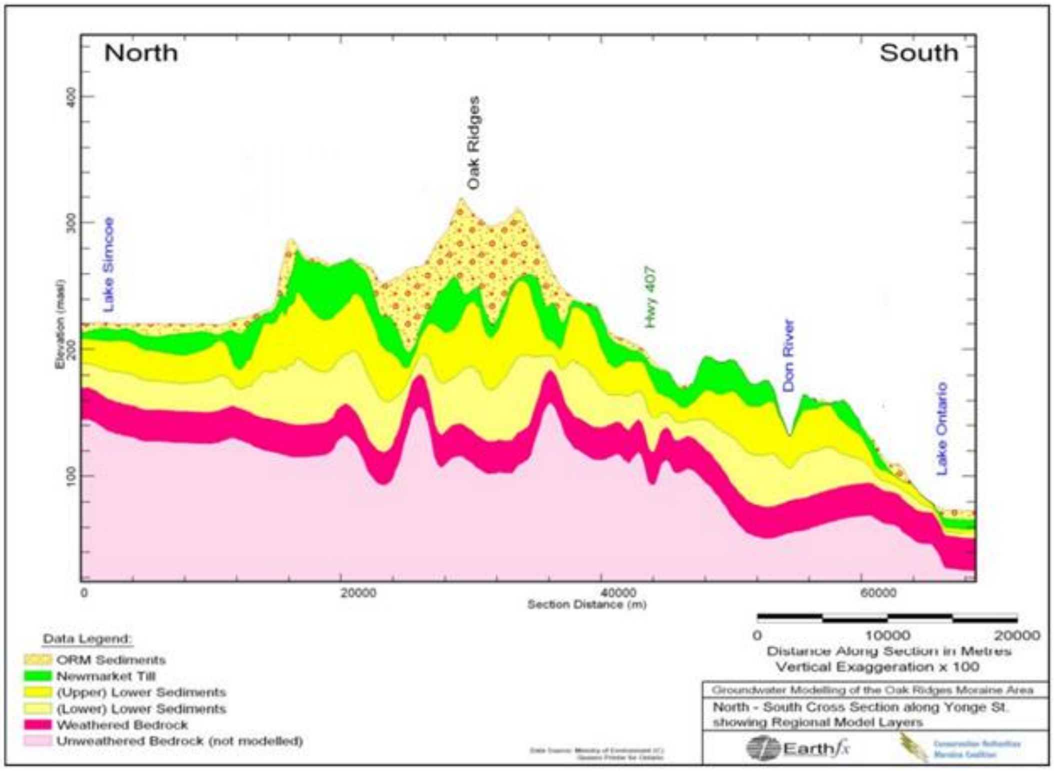

Figure 3 - CAMC's representation of the different aquifers present throughout the Oak Ridges Moraine. The more simplistic approach of this study merges the aquifers present in the (Upper) Lower and (Lower)

Understanding how aquifers connect and interact with the surrounding environment is crucial to protection from potential contamination (Fogg et al., 1998). This makes it increasingly important to determine how the lower sediment aquifer is recharged. Desbarats et al. (2001) concluded that breaches in the till were responsible for the recharge of the lower sediments, likely fractures or macropore-like structures. This was explained in detail by Sharpe et al. (2002) who found hydraulic 'windows' through the till that contributed higher recharge rates than originally predicted. In the Newmarket Till an irregular erosional surface has likely created these 'windows' allowing recharge into the lower sediments.

Channels within the Newmarket Till give water the ability to travel more freely in a horizontal direction (Figure 2). These channels have a deep 'U' shape that is filled with more highly conductive material than the surrounding till (Sharpe et al., 1996). Fenco-Mclaren (1994) estimated hydraulic conductivities in the channel ranged from 10^{-2} to 10^{-6}m s^{-1}, orders of magnitude greater than the conductivity of the surrounding till. Therefore, these channels have to potential to move water through the porous medium at a greater velocity. These hydraulically conductive areas within the till are likely to influence the interactions between the upper and lower aquifers as the channels can be long and move water great distances.

There have been connections within the ORM groundwater system that link areas of the Holland Marsh to Nobleton (Russell and Pulan, 1998). The distance of this channel is approximately 20 km and runs from an area of less urbanization to the outskirts of the GTA. Although outside of the Ganaraska Region, this feature exemplifies the range of potential contamination of groundwater within the ORM. Consequently, the results of this study could be affected by regions far outside of the study area including regions of the GTA.

Figure 3 illustrates the different aquifers present in the ORM throughout its entirety, cutting a cross section in the landscape between Georgian Bay and Lake Ontario. As seen, the ORM sediments overlie the Newmarket Till which superimposes the Upper and Lower Sediments below. The Ganaraska Region lies on the eastern side of the Oak Ridges and encompasses the peak of the ORM. The downward slope of the moraine has a North-South aspect which ends along the shores of Lake Ontario.

Toth (1962) determined the topology was the main influence of groundwater flow. Based on this conclusion the areas of greatest potentiometric head would lie on the highest region of the cross section seen in Figure 3 and decrease downwards. This coincides with Figure 4 which represents the ORM's potentiometric head across the region. The black lines overlain on the map indicate lines of equipotential (areas of equal hydraulic potential). Crossing these lines at ninety degrees from highest to lowest demonstrates direction of flow. Using Figure 4 it can then be determined that groundwater flow is generally flowing from north to south within the general Ganaraska Region.

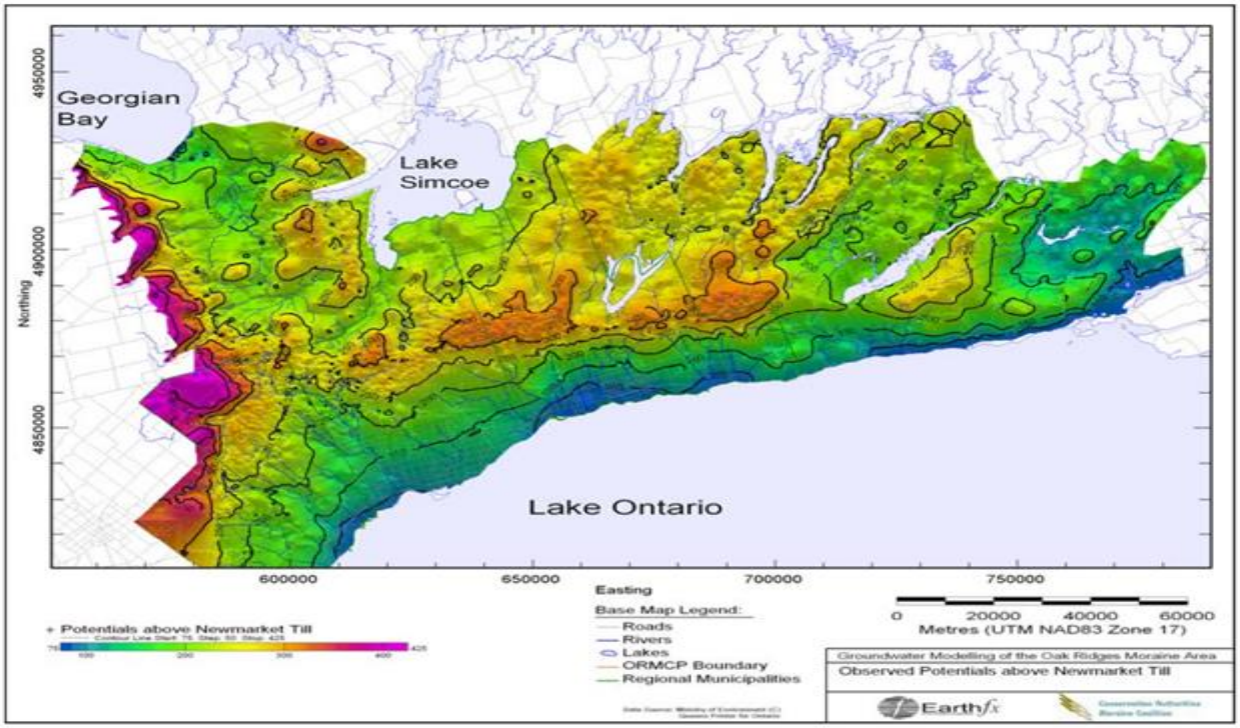

Figure 4 - The CAMC's representation of potentiometric head measured throughout the ORM. Areas of high potentiometric head (orange) represent the ORM and an area of high recharge. Water will flow in the direction of lower potentiometric head (blue).

The expansion of GTA is a risk to the quality of groundwater in the Ganaraska. As previously stated the intricacy of the ORM stratigraphy and potential for long groundwater pathways can affect the quality of water within the study region. To understand how water quality varies spatially the different sedimentary layers of the ORM and their properties must be understood first. This way contaminant flow and interact throughout the sedimentary layers can be better identified. Although it will not be possible to deduct exactly the subsurface processes affecting contamination an understanding of the parameters within the porous medium will improve our ability to draw conclusions.

A modified version of Heath's (1982) diagram representing the various flow paths of groundwater and their associated residency times can be seen in Figure 5. The local flows would be representative of the ORM aquifer in which water immediately infiltrates into the groundwater system. The flow path of this water is influenced by local topography as explained by Toth (1962). Deeper within the subsurface intermediate flow would occur within the Newmarket Till and upper regions of the lower sediments. This water can stay within the ground for a much longer period then local flows. Finally, regional flow would be represented by the Lower Sediments and Bedrock aquifers. This water can remain within the ground for very long periods of time and is subjected to the properties of the surrounding medium.

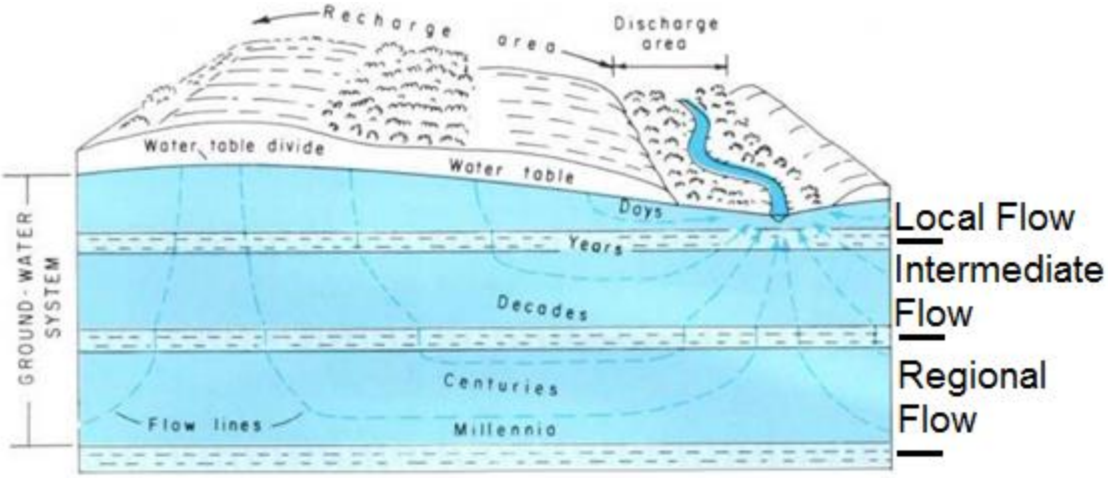

Figure 5 - Flow patterns of different aquifers at depth and the potential residency time of water.

3.0 Groundwater Contamination

There are many different ways that the contamination of groundwater can occur. It is important to understand these fundamental processes as they will be required to comprehend the further discussion. The complexities of groundwater movement coupled with the intricacies of the study area make it difficult to deduce exact developments throughout the region. This section of the study will describe the basic movements of contamination through the various aquifers and describe the different sources of pollutants.

Generally, deep regional aquifers have a decreased likelihood of being polluted due to their distance from potential areas of contamination and their greater capacity for dilution (Stigter et al., 2006). Therefore, the properties of the parent material will have a greater influence on water quality within regional flows (Pionke, 2006). Based on the usual depth of a regional aquifer most contaminants soluble in water have been bound to the surrounding medium before reaching their boundaries. This suggests that local aquifers are likely to have increased interactions with contaminants due to their relative distance from the source of pollution (Mackay et al., 1985).

In the Ganaraska region, point source contamination is of particular interest due to the number of single-family homes with septic systems. In the United States, the largest contributor to groundwater contamination was septic tanks which have been proved to be a complicated source of contamination as the effluent is rich in a variety of chemical constituents (Freeze, 1979). In rural regions septic systems employ the use of weeping beds which remove less harmful, liquid waste from the system into the surrounding soil. Removed effluent is high in organic constituents and if not properly filtered by soil can lead to groundwater contamination (Robertson et al., 1991). Furthermore, if effluent had the ability to escape from the solid waste containment via fractures or diffusion processes, potential groundwater infection would increase substantially.

Freeze and Cherry (1979) determined agricultural activities to be an additional source of groundwater contamination. Agriculture activity often involves fertilizers and pesticides to increase crop and livestock yield. In addition to this, when land is used for agriculture, increased runoff and sediment/nutrient losses have been determined based on soil compaction and overuse of chemicals (Skaggs, 1994). Freeze and Cherry (1979) emphasized that nitrate (NO_3^-) has the potential to contaminate shallow groundwater as a result of fertilizer leaching. In addition to this, the mobility of contaminants increases with concentration as exchange sites become saturated. As a result it is expected that local aquifers may suffer increased levels of agriculture related contaminants in the Ganaraska Region.

When considering the extensive transportation network that exists over the Ganaraska Region, the potential for contamination as a result of road salt is a major issue. Williams et al. (2000) examined how biological monitoring of benthic communities can be utilized to understand water degradation as a function of time. This study theorized that a large majority of salt applied will be removed by overland flow and not recharged into groundwater systems. Williams sampled 16 different springs that were representative of a variety of land use types. The sands and gravels that compose the ORM act as a catch basin for the fate of de-icing salts used to clear the road network. Buttle et al. (1996) found that the climatic conditions within the Peterborough region, in addition to the high levels of organic matter content and high cation exchange capacity created a situation where saline melt water was able to quickly travel through the unsaturated zone. Based on this conclusion, it is expected that shallow wells in proximity to road will show increased levels of chloride contamination.

4.0 Methodology

4.1 Data Entry

For the purposes of this study secondary information was used. Consultant reports and other forms of groundwater quality data were provided by the GRCA and input into the currently existing CAMC database. Due to the complexity of the database there was a strict process of data entry. The database uses Microsoft Access which had been previously coded by the CAMC to eliminate the possibility of missing data; the user cannot continue with data entry if there are mistakes within the previous columns and cells. This eliminates the likelihood of user caused errors but makes the entry process more difficult. Microsoft Excel was used to enter all of the GRCA data which then were transferred to the Access database. At this time the CAMC's coding alerted all of the users' mistakes which should be fixed to ensure seamless integration with the current database.

The database is used extensively by the CAMC to determine groundwater quality and flow patterns. The data contained within the database spans wells existing throughout the 11000 km^2 area of the Oak Ridges Moraine. Each well is identified using a LOC_ID, a number assigned by the CAMC which can then be subsequently used to link all newly entered data to that particular well. When entering new data for a well with a pre-existing LOC_ID the Ministry of Environment (MOE) well number found in drillers reports can be used to determine the LOC_ID. Other well properties that could be used to determine the LOC_ID were completion date, UTM coordinates, and depth. Once a LOC_ID has been identified, the water quality results from reports can be entered into the database. A well without a pre-assigned LOC_ID was be added to the collection of newly input data. Ultimately, the CAMC will assign these wells LOC_IDs, but for the purposes of this study they were not immediately defined.

The data provided by the CAMC spanned a large temporal scale. In order to decrease potential variability only wells that were tested from the year 1990 and forward were selected. This is due to the potential for older information to misrepresent the quality of water within the well, a trend recognized by Hirsch (1991). The year 1990 was chosen as it represented the majority of the tested wells without inducing a large variability in tests over time.

4.2 Determining Aquifer Quality

Once a LOC_ID was established for all of the available wells the CAMC will be able to determine which aquifer the well is drawing from. Wells will then be sorted based on the aquifer they are drawing from to establish the quality of water within each aquifer. There are several aquifers that underlie the Ganaraska Area so to increase the sample size of each subsurface region aquifers will be combined into larger categories. This approach was also used by Sharpe et al. (2002), in which four of the major areas of the subsurface were grouped together.

The ORM aquifer consists of wells drawing from the ORM, Halton and Kettleby Tills. This region encompasses the entirety of the uppermost saturated region. The Newmarket Till is composed of Inter, Upper and Lower Newmarket Sediments. This is the most complicated region of the subsurface and grouping these layers combined all of the properties of the Newmarket Till, including the eroded channel beds and the “windows” into the lower sediments. The Lower Sediments were a combination of the Thorncliffe, Sunnybrook, and Scarborough aquifers which are all fairly similar in properties. Finally, the lowest saturated zone of the Ganaraska Region was represented by the bedrock flow channels.

Upon completion of the data entry process the CAMC provided previously entered data from their existing database. This was combined with the newly entered data to increase the total number of wells were tested for water quality. Wells were sorted based on the aquifer they draw from then subdivided into the subsurface regions created for the purposes of this study. Once combined, the results of individual analyses were sorted. An average and standard deviation of each parameter was used to describe the quality of water within the aquifer.

If the maximum value of a parameter lies outside of one standard deviation from the mean, it was regarded as an outlying value. To determine the influence of that parameter Google Maps was used to determine land use activities in the area. This allowed for a better understanding of the parameter and was intrinsic to determining if land use affects the concentration of the parameter. In cases where values lied two or three standard deviations from the mean literature was consulted to determine if the concentration was a plausible value. If it was deemed to not be plausible then it was removed from the analysis to reduce variability.

To compare the different chemical parameters in the aquifers chemical species were divided based on the methods described in Fetter (2001). Physical parameters including: alkalinity, dissolved organic carbon (DOC), hardness, pH, total dissolved solids (TDS), and turbidity were divided based on average concentration. Any physical parameter above 100mg/L would be represented visually separate from values below 100mg/L. Cation species were divided into major and minor categories based on their varying concentrations. Anions were also represented separately but exclude bicarbonate which due to its significantly higher concentration is graphed on its own. This best displayed the graphical representation of the data given the variability of concentrations.

The concentration of nitrates in the results is represented by the test nitrate + nitrite. Although this test does encompass two tested parameters nitrite values in the results were extremely low and the frequency of this test was very high. Given that nitrite is unlikely to increase the total concentration of this test and nitrate will dominate in almost all cases it was chose to represent nitrate concentrations.

Quality of water within the aquifer will be compared to the Ontario Drinking Water Quality Standards (ODWQS) set in 2006. This will provide a benchmark to compare results of this study to an acceptable drinking water quality in the Province. The parameter concentrations of the ODWQS can be seen in Table (1) of the Appendix.

4.3 Baseflow Analysis

As defined in the GRCA River Report (2009) baseflow is stream discharge during periods when storm flow has ceased and stream flow consists entirely of delayed sources of flow (ie. groundwater discharge). Their collection process included simple surface water sampling techniques during periods of high evaporation and no precipitation. Baseflow quality results provided by the GRCA were used to determine which aquifer was supplying the baseflow discharge. This can be used to further quantify geochemical changes of the water throughout its residency within the aquifer.

Using the provided results, the different tested chemical constituents were sorted in Microsoft Excel from highest to lowest. It was then possible to deduce which streams had water quality results that matched the average quality of the underlying aquifers. If only there were less than three samples from a stream it was too difficult to determine average water quality of the baseflow and these results were omitted from the discussion.

5.0 Results

All of the combined data accounted for 131 wells spread throughout the Ganaraska Region (Figure 6). The most tested constituents within the Ganaraska Region can be seen in Figures 7 through 11 and in the Appendix Table 1. For the most part these parameters were tested in more than half of the wells per aquifer but the variation was still very high. The distribution of wells per aquifer can be seen in Figure 12. The bedrock aquifer was only represented by 6 wells however; the other three aquifers all had greater than 35 wells.

The average test date of the combined data was 2002. The most common chemical tests included the concentrations of chloride, sodium and DOC. Given the increasing significance of roadsalt use on the landscape testing for sodium and chloride is essential for developmental assessments, hence their dominance within the test. For the purposes of this study DOC is an important parameter as it is influenced by the presence of organic material which has important contaminant binding properties.

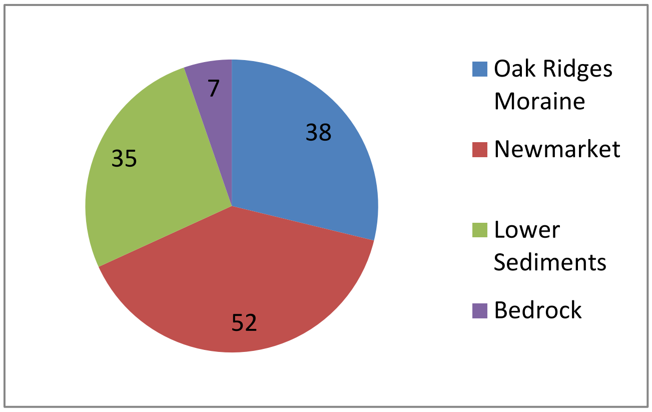

Figure 6 - Chart showing the breakdown of tested wells by stratigraphy formation (aquifer) in the Ganaraska Region. The most common formation in the area was the Newmarket Till.

5.1 Aquifer Quality

The quality of groundwater throughout the subsurface was very high with only few parameters overstepping the ODWQS. Some anomalies did occur but average data often fell within ODWQS range. One well in the Newmarket Till (LOC_ID 14880) aquifer was more prone to bacterial contamination, testing resulted in a very high coliform count of 14CFU/100ml which was accompanied with an outstandingly high TKN concentration of 7.6mg/L. When that well was tested again six months later the coliform level had dropped to 1CFU/100ml and 2.3mg/L TKN. Due to the major changes this well exhibited in a six month period it was removed from the dataset to ensure minimal variability.

Arsenic was only present in four total testing procedures and determined concentrations were an order of magnitude less than the ODWQS. All of the tested inorganic species were below the minimum threshold for good quality drinking water in Ontario. The only parameter that consistently tested on the high side of the standards was hardness. Between the four aquifers average hardness varied between 200-300mg/L, twice the provincial standard (Figure 7). Hardness is a water quality parameter that does not have direct health risks until much more concentrated, however it can affect some household plumbing fixtures such as hot water tanks.

All of the tested parameters in the ORM are well below the water quality standards, excluding hardness as mentioned above. The ORM aquifer had average calcium content

87.11mg/L, second highest only to the Newmarket Till aquifer which had an average 92.91mg/L (Figure 9). A standard deviation of 21.74mg/L signifies the variability of chemical concentrations within this uppermost aquifer. As seen in Figures 9 and 10, the ORM had the second highest concentrations of some cation species but concentrations of iron were substantially lower than the underlying aquifers, average 0.02mg/L with a standard deviation of only 0.01mg/L.

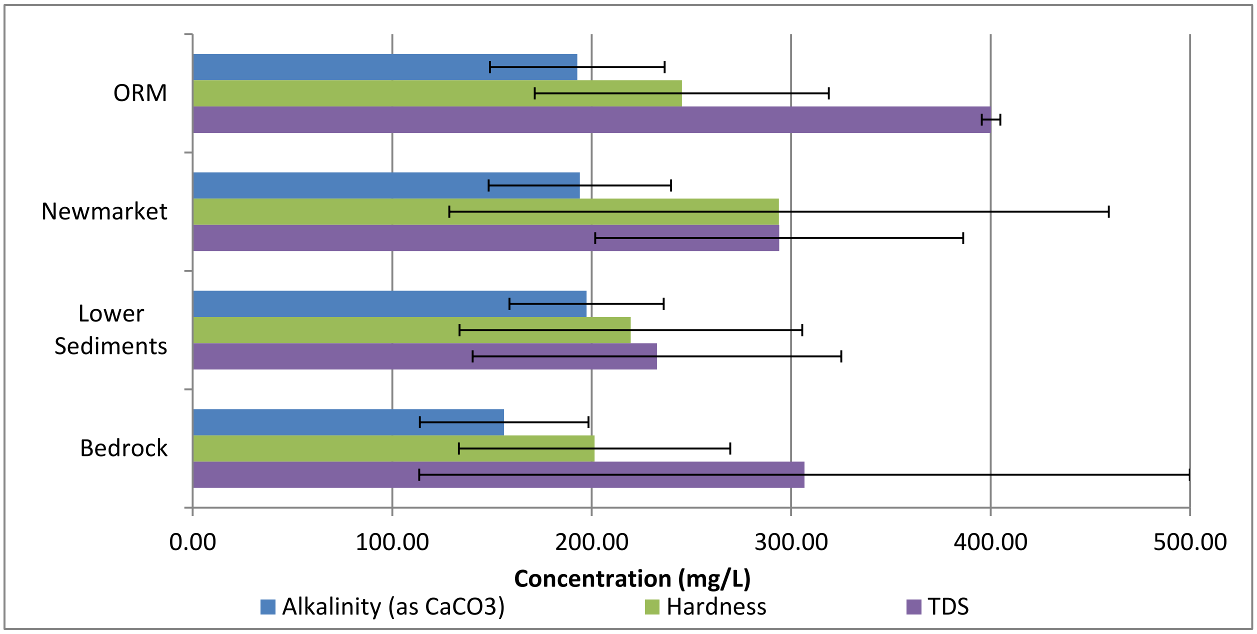

Figure 7 – Physical parameters of the four studied aquifers including: alkalinity, hardness, and total dissolved solids (TDS).

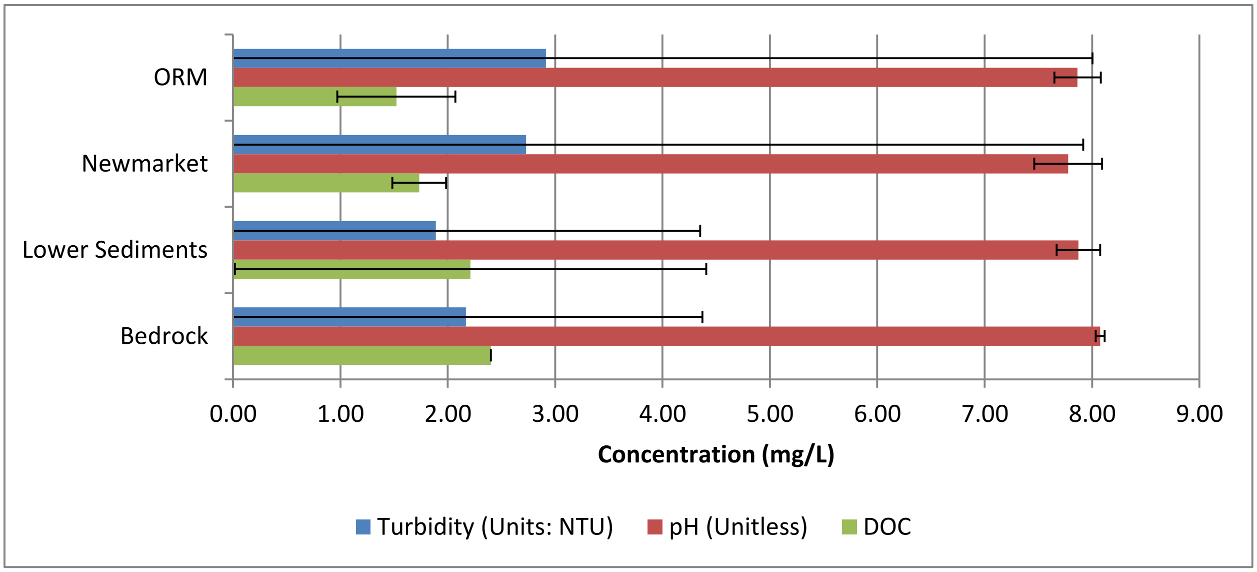

Figure 8 - Physical parameters of the four studied aquifers including: turbidity, pH, and dissolved organic carbon (DOC).

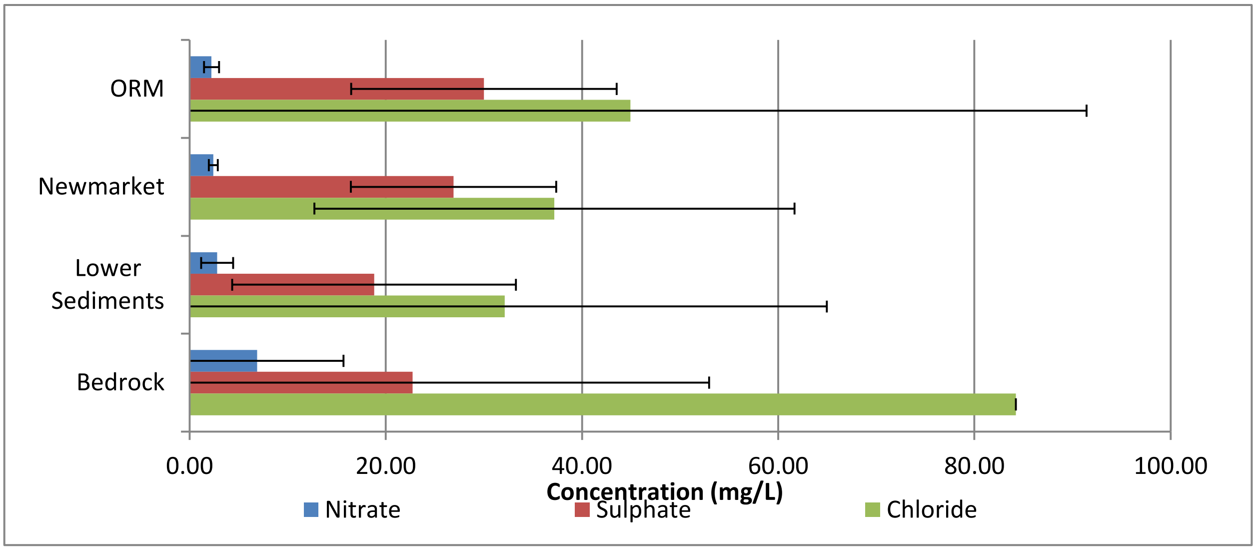

Figure 10 - Anion concentrations of the four studied aquifers including: nitrate, sulphate, and chloride.

As seen in figure 8, pH throughout the subsurface remained relatively equal. Turbidity seemed to decrease with depth while the concentration of DOC increased. The Newmarket till had the highest concentration of many of the physical parameters including the highest hardness (Figure 7 and 8). Bicarbonate concentration in each of the aquifers was variable but seemed to increase with depth into the Lower Sediments (Figure 9). Magnesium and calcium are two of the cation species that makeup total hardness and the Newmarket Till aquifer which had the greatest average concentration of both (Figure 10).

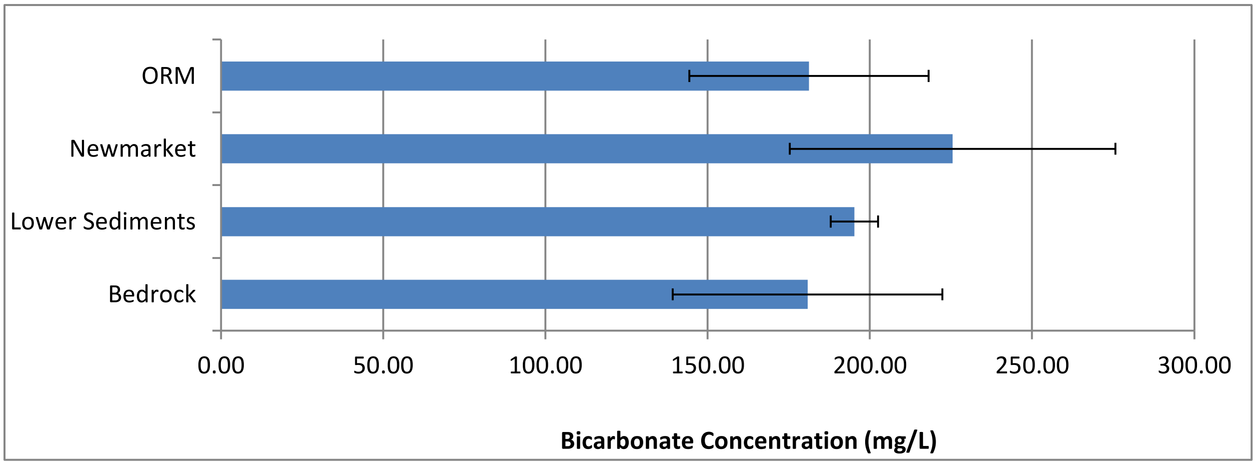

Figure 9 - Bicarbonate concentrations of the four studied aquifers.

The lower sediment aquifer had the most filtration potential which contrasted the lower average concentrations of cationic species (Figure 10 and 11). Nitrate concentrations were greatest in this region of the subsurface averaging 2.81mg/L (Figure 9). A high standard deviation of this parameter exposes potential for a direction point source of the organic species. A maximum value of 8.4mg/L highlights this overly concentrated parameter within the dataset.

The bedrock aquifer displayed the most variable results with very large standard deviations. Conductivity was highest within this region averaging 571.25us/cm but deviating by +/-225.57us/cm. Increased chloride and sodium concentrations are the responsible parameters for this result. The bedrock aquifer had the highest average concentration of chloride (84.23mg/L) and sodium (43.2mg/L) (Figures 9 and 10, respectively). Accompanied by these results are also very high deviations from the mean, 119.56mg/L and 57.99mg/L respectively.

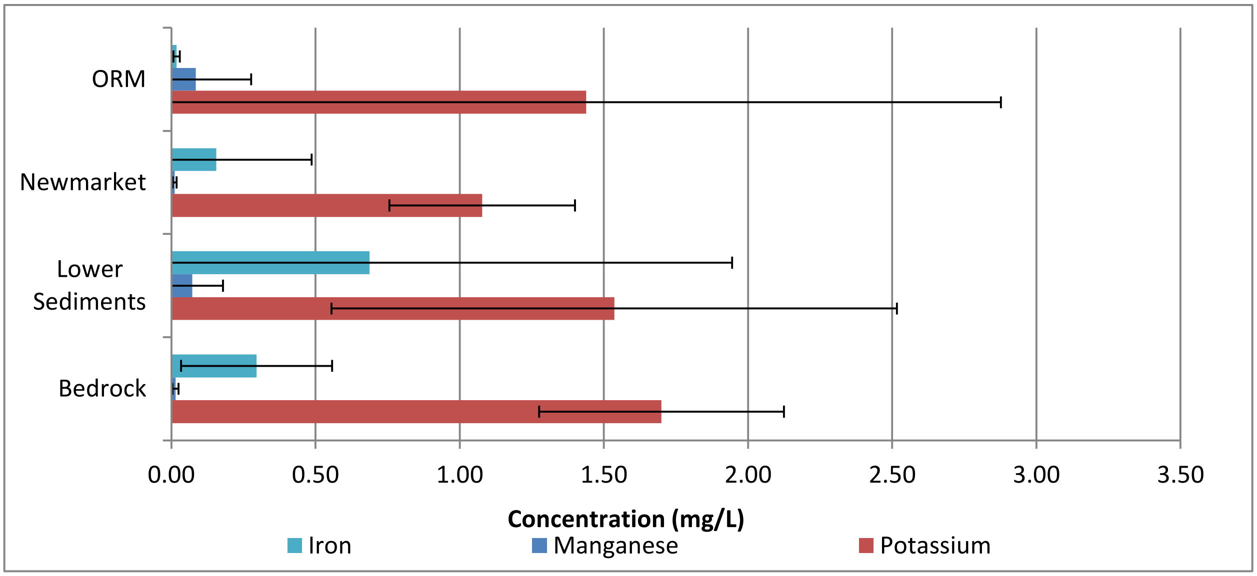

Figure 11 - Minor cations of the four studied aquifers including: iron, manganese, and potassium.

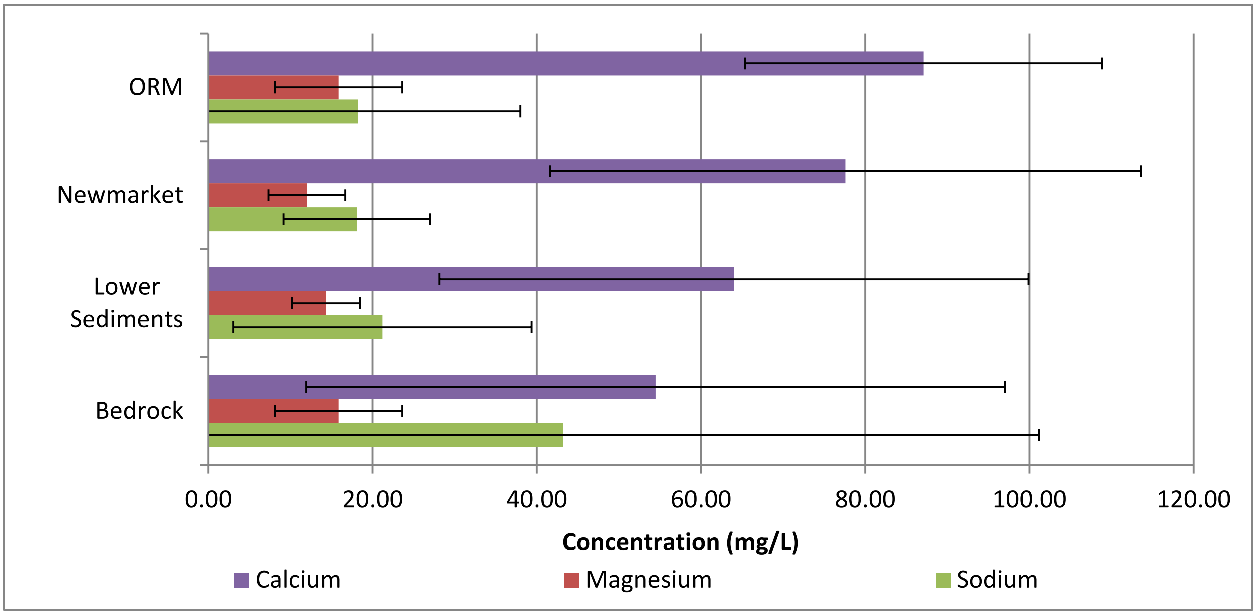

Figure 12 - Average concentrations of calcium, magnesium and sodium in each aquifer.

6.0 Discussion

Groundwater within the Ganaraska Region is suitable quality for consumption according to the parameters of the ODWQS. The quality of water within the aquifers does vary accordingly with depth and residency time. The properties of each aquifer had a significant effect on the quality of water contained in each. Although there was a high variation in some of the tested parameters this is a recognized problem with many water quality monitoring studies (Delhomme, 1979).

The process of creating an effective and accurate groundwater monitoring system is difficult and encompasses many fields of study (Mogheir and Singh, 2002). This study shows that simply combining groundwater quality data from a region creates a variety of limitations and errors including the large variability in observed chemical levels. However, due to time and data restrictions this is likely the most suitable method to determine total quality at present. Though not the best approach to groundwater quality the results have exposed the basic parameters of groundwater quality in the Ganaraska Region.

Following the general layout of the Ganaraska River Background Report (2009) the quality of water within individual aquifers is discussed below. Given that large variability between wells reduces the accuracy of some of the processes described; there are still patterns of quality within the Ganaraska Region that encompass hydrogeological thought.

6.1 Oak Ridges Moraine (ORM)

6.1.i Physical Parameters

The ORM had the highest concentration of total dissolved solids in all of the tested aquifers but this was only represented by two tests in the dataset. Average calculated TDS was significantly lower, only 261.5mg/L. As discussed by Toth (1985) TDS is likely to increase in water with greater residency time within the aquifer, which is better represented by average calculated TDS than measured. Given there were only two tests that contained measured TDS concentrations the average is likely not representative of the entire aquifer. However, combining both measured and calculated averages lowers the total concentration in the system to 330mg/L which would better suit the conclusions of Toth (1985). Calculated TDS is determined using the equation provided by Lloyd and Heathcote (1985). Atekwana (et al., 2004) concluded that the combination of both calculated and measured TDS in water samples is an appropriate method to increase total sample numbers and reduce variation.

Based on the average alkalinity of the aquifer there is a large potential within the ORM to dissociate acid and maintain pH. Alkalinity is very similar between the three porous aquifers, but the concentration of bicarbonate, the main species responsible for alkalinity, was lower in the ORM. Bicarbonate has the potential to neutralize incoming acids resulting in the formation of a salt (Stumm and Morgan, 1970). Given that the ORM is superimposed by the presence of anthropogenic activity it has the greatest potential to receive incoming acids. These acids would be neutralized by HCO_3^-, in turn reducing its concentration as it forms salts and other constituents.

6.1.ii Anions

Both sulfate and chloride have high concentrations within the ORM. Chloride concentrations likely reflect the use of road salt on the surface of the Ganaraska Region. As previously described by Williams et al. (2000) road salts are likely to be swept away via runoff flow but some does infiltrate the groundwater in solution. Being within the uppermost region of the Ganaraska Region the ORM would be the most influenced aquifer from this process.

Sulphate can form some highly soluble salts with a variety of chemical constituents including magnesium and potassium (Stumm and Morgan, 1970). Moncaster et al. (2000) describes two major sources of sulphates in groundwater: acid rain and agrochemicals. Given the average concentration of 29.98mg/L it is more likely that agricultural activities are increasing the concentration within the area. Four wells in the ORM had concentrations of sulphate greater than 40mg/L; one of which measured 69mg/L (LOC_ID 105880). This well sits within a region with industrial activity, including what resembles a junkyard or automotive depository. Moncaster et al. (2000) tested near landfill and residential areas which also resulted in an increased sulphate concentration, supporting that this well may be affected by runoff from this location.

6.1.iii Cations

The ORM aquifer has high concentrations of both calcium and magnesium (Figure 10). This is a further reflection chemical processes occurring with the material of the substrate. Concentrations of both magnesium and calcium are dictated by the presence of carbonate species in the aquifer. Again, bicarbonate concentrations within this layer of the ORM are slightly less than the underlying aquifers but could be the result of reactions with calcium and magnesium where hydrogen is replaced with either of these chemicals to create a salt (Hem, 1988). Calcium is likely to be more affected by bicarbonate presence as it can form a very stable calcite CaCO3 which is water soluble and mobile in groundwater systems.

Both calcium and magnesium are affected further by the presence of sulphate to produce salts. Magnesium can react with sulfate to form a complex with similar chemical properties to CaCo3 making it very stable and mobile in the environment (Hem, 1988). It is unlikely that reactions with sulphate are important as reactions with carbonate species given the lower concentration of sulphate. Bicarbonate species are likely to increase competition of these reactions within the groundwater system to a point where reactions with sulphate are negligible but important for magnesium.

Potassium concentrations in the ORM were also high among the four tested aquifers. Due to its participation within vegetation and soil, potassium is an important chemical constituent in agricultural fertilizers. This would likely reflect the ORM’s higher concentration of potassium given its proximity to agricultural practices. This result was seen in a Dutch study completed by Griffioen (2001) in which potassium did not infiltrate the soil as deep as more conservative behaving chemicals such as chloride. In one of the tested wells potassium concentration was 6mg/L which was 5mg/L greater than the next closest recorded value. This well (LOC_ID 4937) was drilled in the early 1960’s and is located next to a large agricultural operation. The age of the well increases the likelihood of direct contamination due to runoff from the surrounding practices assuming that its seal may have degraded over time.

6.2 Newmarket Till

The quality of water within the Newmarket aquifer largely reflects the different properties of its composition compared to the ORM. Composed primarily of dense silts the surface area of the substrate is much greater increasing the potential for cationic exchange with water. Given that the hydraulic conductivity in this region is also much lower there is a greater amount of time for chemical reactions to take place. This would be described as a kinetically favourable region of the subsurface as water is in contact with the same region of soil particles for greater periods of time.

6.2.i Physical Parameters

The physical parameters measured in the Newmarket were similar to that or the ORM. Average pH of the sampled wells within the Newmarket till was 7.74, alkalinity was slightly higher than the ORM but given the variability this is a negligible difference, the ability to buffer pH will be very similar. Major differences in physical parameters between the Newmarket and ORM are TDS and water hardness. Hardness in this region of the subsurface was highest of the four aquifers, however average TDS was much less than the ORM. However, these constituents also had high variability, hardness varied by +/-165 mg/L and TDS by +/-92.21 mg/L. Given, it is likely that average TDS could be slightly higher to support the high average hardness. Even considering the high variability the Newmarket Till still had a significantly lower concentration of TDS.

This result can stem from a variety of situations pertaining to both the quality of collected data and the ability of this aquifer to filter cations. Hardness and TDS are related parameters, generally with higher TDS water hardness is greater. Thus, the results of these parameters within this aquifer are not consistent with the conclusions of the literature when compared to the ORM (Hem, 1985). It is possible that due to a greater cation exchange capacity within the Newmarket, given the increased surface area of soil and the slow movement of water, cations are being removed from solution. This process would remove dissolved solids and reduce total hardness, which given the high variability could create a trend in reducing TDS and hardness with depth among the aquifers.

6.2.ii Anions

The average sulphate concentration recorded in the Newmarket till was 26.9mg/L. This supports the trend of reduced concentrations of sulphate with depth in the top three aquifers. Of the 52 wells examined in the Newmarket, 12 contained data for sulphate concentrations. One well in particular (LOC_ID 1172403190) had an abnormally high level of sulphate (310mg/L). This well is not drilled anywhere near any potential sources of sulphate yet it far exceeds any available value from the literature, even those known to be contaminated (Einsiedl and Mayer, 2005). Removing this anomalous value reduces the variation within the data set to a more realistic and comparable concentration.

The concentration of nitrate was relatively consistent across the three top aquifers. It is understood that nitrate levels are found in higher concentrations in groundwater than in surface water (Ham, 1985) but it is not expected that surface contamination would impact this unit due to its low permeability and overall depth. A study regarding the concentration of nitrate in rural groundwater determined that drilled wells at depths greater than 30m are generally regarded as safe (Johnson and Burton, 2007). Sodium concentrations in this region are very similar to the ORM (18.06mg/L).

6.2.iii Cations

As discussed above, the Newmarket Till aquifer contains high concentrations of both calcium and magnesium. It is assumed that the cation exchange capacity within this region of the subsurface is greatest given its high soil surface are of silts. The pH of the aquifer (7.78) supports that this is an alkaline environment suitable for increased cation exchange capacity. Potassium was slightly less concentrated in the Newmarket (1.08mg/L), but this is an expected result given the conclusions of Griffioen (2001). Both iron and manganese are slightly more concentrated in the Newmarket however their concentrations are still far too low to be of concern (ODWQS, 2006).

6.3 Lower Sediments

The aquifers that make up the lower sediments vary in composition but at this depth within the subsurface water is older and less likely to be affected by an acute event. As seen in these deeper regional aquifers can have residency times of decades. This supports the idea that these aquifers will be much less likely to represent chemical patterns of the upper sedimentary aquifers. Separated from the surface by the Newmarket Till, which offers an added layer of protection given the higher likelihood of cation exchange, water within the Lower Sediments should remain unscathed by most anthropogenic activity.

6.3.i Physical Parameters

Alkalinity within the lower sediments is very similar to the upper sediments both in terms of concentration (197.84mg/L) and variation (38.63mg/L). This result supports the potential for this aquifer to be slightly alkaline pH (7.87) and dissociate acids. The lower concentration of hardness and TDS is accompanied by less variation in both parameters, likely representative of a decreasing calcium concentration through the aquifers (Figure 10).

Turbidity within the Lower Sediments decreases significantly (1.89NTU) compared to the overlying aquifers. Given that turbidity is a representation of clarity or cloudiness of the water. This could be a representation of the decreasing total suspended sediments; however, given that these tests may occur during the pumping analysis of wells it is a very difficult term to quantify. If a turbidity test was carried out during a pumping analysis within hours of the well-being completed then there is a high chance that the result would not be representative of the aquifer. This makes turbidity a difficult parameter to draw conclusions from given that knowledge of the testing procedure is lacking.

A steady increase in DOC content through these aquifers becomes apparent within the lower sediments (2.11mg/L) as cation species seem to be more concentrated. However, high variability (2.19mg/L) is accompanied with this increase which reduces the ability to definitively determine that there is an increase. As discussed by Amrheln et al. (1992) sodium has the ability to increase the mobilization of DOC which is increasing with distance from the surface.

6.3.ii Anions

Nitrate concentrations in the lower sediments increase only slightly (2.81mg/L) from the Newmarket but there is a trend represented in Figure 9 showing a steady increase in nitrate concentration with distance from the surface. Given that the Lower Sediments contain the highest concentration of iron (0.69mg/L) and nitrate the conclusions of Burow et al. (1992) support the presence of increased DOC within this region.

As described below in the “Cations” subsection, the presence of DOC suggests that high cation concentrations within this aquifer are due to the presence of electrically favourable organic material. It is possible that nitrogenous material could also be present within this organic material which is mobilized by the presence of sodium. This would aid the conclusion that nitrates are accumulating within this aquifer due to an increase in DOC. This description of nitrate movement through the aquifer seems implausible but based on the averages presented could be an explanation.

Figure 9 displays a pattern of decreasing concentration for both sulphate and chloride. This is an expected result given that these values are generally represented by anthropogenic practices that are not reflected at this depth. As described by McGuire (et al. 2002) as water travels through a groundwater system, oxygen concentrations begin to deplete. Dissolved oxygen has the potential to react with surrounding species which reduces solubility of certain cations like iron (Vikesland et al., 2003) . The depletion of oxygen allows iron and other cations to become more soluble, thus the increased concentration of these species as proximity from the surface increases.

6.3.iii Cations

The Lower Sediments had high concentrations of iron (0.69mg/L), manganese (0.07mg/L), potassium (1.54mg/L) and magnesium (14.32mg/L) relative to the other aquifers. As described by Amrheln et al. (1992) sodium has the potential to mobilize organic matter within the subsurface which has cationic species bound to its surface. Organic matter is negatively charged, increasing the potential to bind with cationic species. This results in an increasing concentration with depth as the concentration of sodium also increases. Sodium is present in approximately 20 mg/L through the uppermost 3 aquifers, thus it is plausible that it is increasing mobility of organic matter.

The presence of organic matter within the Lower sediments is represented by DOC which has a higher concentration in the Lower Sediments then superimposing aquifers. As seen in Figure 10 there is a pattern of decreasing calcium with depth. This result is due to calcium binding with soil particles in higher regions of the subsurface due to its greater affinity for cationic exchange (Hem, 1985).

The increased concentration of cation species within this region of the subsurface could also be attributed to a lack of oxygen. At this depth oxygen within the water is likely more depeleted within the subsurface. Although dissolved oxygen was not a readily tested parameter of the data it is assumed that at his depth

6.4 Bedrock

The bedrock aquifer displayed the greatest variability of the four aquifers. Being so deep the well drillers generally find suitable amounts of water high within the subsurface. This reduces the total number of wells to represent the bedrock water and increases the potential for variability. In this aquifer water had a much greater opportunity to reflect the properties of the environment given water within bedrock is generally very old and has the potential to develop chemical parameters based on the parent material.

A well (LOC_ID #) drawing water from this aquifer tested very high concentrations of chemical constituents. This has resulted in a high variability and overly large concentrations of some of the parameters. It is likely that this test was improperly collected or that the well is affected by an improperly installed/cracked seal. However, based on the low amount of total tested wells it remained a part of the analysis. Although skewing the data this result does illustrate the effect that a contaminated well can have on a population and how if improperly sealed how a well can become easily contaminated.

6.4.i Physical Parameters

TDS in the bedrock aquifer are greater than within the Lower Sediments likely due to the weathering and reactions of limestone and water movement. Limestone is a carbonate rich surface that dissolves easily in water; this would increase the likelihood of solids dissolving into the passing water flows. This is reinforced by the conclusions of Aeschbach-Hertig et al. (2005)

who determined that older waters within bedrock fractured aquifers generally displayed a higher concentration of TDS.

The bedrock also had the highest concentration of DOC (2.4mg/L) of the aquifers which is likely described again by the high sodium content which is increasing mobility of organic matter. DOC was only measured by one test, thus this value may not be representative of the aquifer as a whole. It is possible that this DOC concentration misrepresents total DOC values but the trends seen in Figure 7 would suggest that DOC is increasing with depth from the surface.

6.4.ii Anions

Bedrock had the highest concentration of both nitrates and sulphates. One well resulted in both of these high concentrations. It is uncharacteristic of an aquifer this low to portray these values as the filtering processes of soil should have absorbed or degraded these concentrations to a much lesser concentration. With a range of 12.46mg/L the maximum recorded nitrate concentration was 13.1mg/L and the minimum 0.64mg/L. The latter value would best represent average nitrate values at this depth represented in the literature by Clewages and Vowinkel (1996).

Similarly the sulphate values at this depth are not consistent with the conclusions of Einsiedl and Mayer (2005) and the lack of wells drilled to this depth reduce the potential to balance this large variability. Based on values from the literature and the averages it is unlikely that the bedrock aquifer portrays these concentrations throughout the Ganaraska Region. It would be a safe to believe this result is due to some erroneous sampling or a poorly sealed well. This is a result that will be discussed further in the limitations to the study. There simply aren’t enough representative wells within the bedrock aquifer for this result to be deemed accurate.

6.4.iii Cations

Decreasing calcium concentrations within the subsurface are once again reflected in the bedrock aquifer. This result has been discussed in length above. Although variable the bedrock aquifer did have a very high concentration of sodium 43.20mg/L. This result could be due to the high water residency time within the argillaceous limestone described by Buttle (1994), but it is difficult to reinforce due to the high chloride content. Only one well tested chloride content so this reduces the possibility of describing this trend throughout the bedrock. High sodium and chloride concentration is a display of road salt contamination (Williams et al., 2000) but at this depth this is unlikely.

Potassium was unusually high in the bedrock aquifer, averaging 1.7mg/L with a standard deviation of only 0.42mg/L. As described by Stumm and Morgan (1970) this could be a reflection of sulphate based salts and their high solubility but at this depth is unlikely. As described the lack of wells within the bedrock reduces our potential to draw accurate conclusions. Wells tested at this depth seem to have large deviations from the mean that are caused extremely high and low values and a lack of wells to balance this result.

6.5 Bacterial Contamination

The presence of coliforms and E. Coli bacteria are a highly regarded parameter of groundwater quality testing following the events of Walkerton Ontario in 2000. These biologic contaminants have the potential to cause gastrointestinal infection and in serious cases can lead to death (Hrudey et al., 2003). Due to the intensive agricultural activity spread throughout the ORM the presence of coliform and E. Coli in the groundwater supply is an important parameter to investigate. As discussed in the results, one well was tested with 14 total coliforms per 100 ml. Although a test 6 months later revealed a coliform concentration of only 1CFU/100 ml this initial result is still frightening.

The well with high concentrations of coliform is located within the borders of an agricultural establishment and viewing the farm via Google Earth reveals that there may be some open storage of manure. As concluded by Gagliardi and Karns (2000) manure increases the habitability of E. Coli and coliform bacteria in the soil due to increasing concentrations of nitrogen. TKN concentrations in the contaminated sample were 7.6 mg/L, which would increase the likelihood of bacterial transport through the subsurface. The well is pulling water from the lower Newmarket, 17 m below the surface. Coliform has the potential to travel approximately 500 m through soil which resembles the distance between well location and open pit storage or manure (Gerba et al., 1975).

Although a coliform count above 1CFU/100ml was only discovered in a single test it represents the potential threat of agricultural practices on the ORM. The test 6 months later revealed that there may have been an error with the initial results but this still demonstrates the dangers of fecal contamination. Although bacterial contaminants do not travel as far in the soils as inorganic contaminants, their potential to infect humans is very high and should be regarded as a threat to the quality of groundwater in the region.

6.6 Baseflow

Based on the deviations from the mean in the observed results it was very difficult to draw conclusive results about …. There was simply too much variability within the aquifers. Some patterns that were seen throughout the subsurface of the Ganaraska Region that could aid in determining baseflow origins are the decrease in calcium concentration with depth, increasing iron and minor cation concentration with depth, increasing sodium concentration with depth and decreasing chloride concentration with depth (excluding bedrock).

Wilmot and Brand Creek flows both had an abnormally high concentration of chloride present in their flows. One result tested in brand displayed a very high concentration of almost all of the tested constituents. It is likely that this test was contaminated by some other source of chemicals which skewed the results. However, it could also be that the Brand flow is being fed by shallow subsurface flows that are directly affected by the overlying land use activities. With both high sulphate (34 mg/L) and nitrate (6.8 mg/L) it could be an indication of agricultural effluent.

Plainville and Port Granby Creek flows were also high in both nitrates and sulphates, but their other parameters were average compared to the other tests. This could be the result of some agriculture sources that are leaching into the stream either via direct contact such as livestock or the spreading of fertilizer close to the banks (Poor and McDonnell, 2007). Given that there were not many tests completed on these water bodies it is more difficult to gauge their interaction with groundwater outflow.

The Cobourg Creek and Ganaraska River flows had low concentrations of chloride, sodium and magnesium. This result would suggest that these flows are being fed by lower sediments and bedrock aquifers. Both of these flows also had low concentrations of nitrates, which is another supporting result of deeper groundwater discharge.

Flows that contained fewer tests were more difficult to determine because with only few data points trends could not be found. Gages tested high magnesium concentrations which could suggest that it's being fed by aquifers binding well with cationic species. In the results of this study this was best represented by the Newmarket Till. Calcium was not a tested parameter in the baseflow results which would have helped support this conclusion given that it was most concentrated in the Newmarket Till.

Although we can make assumptions based on the results of this study as to where the water in this stream originates it is too difficult to determine if water is changing geochemically. Resident time does affect the constituents of water but with so much variability in our results there isn't the accuracy required. This is a method that may be more advantageous for future research.

7.0 Errors and Limitations

The drilling process inevitably creates a disturbance within the aquifer. Proper sampling procedures dictate that after a well installation, purging must occur before sampling. A study examining the long-term disturbance after well installation found that for certain mediums, the time required to reach equilibrium was longer than previously thought (Kim, 2003). Combining the results of so many different well tests is bound to include some results that were skewed by poorly followed sampling methods. Furthermore, some of the wells that were tested could have been improperly sealed, had a cracked case or been subjected to some sort of damage throughout its lifespan (Christman et al., 2002). Any of these instances provides the necessary opening for contaminants to directly affect the quality within the well.

As was seen in some of the raw data there were values that created large deviations in the data. These values are thought to represent this occurrence of an improperly sealed well. Other factors may also influence the presence of high contaminant levels. As was the case in Walkerton, Ontario when high precipitation events paired with improperly sealed wells infected the entire population of a small urban town (Hrudey et al., 2003). Without a thorough understanding of the used sampling techniques, recent meteorological events, and the condition of the well there could be a multitude of wrongdoings that skew data.

In addition, this study did not examine the effect of seasonal climate on water quality. Water testing dates were collected, but not analyzed. It could be expected that water chemistry might be impacted seasonally, although this would most likely only affect the uppermost sediments (ORM and Halton Till). As described by Simmons et al. (1992) nitrate levels in surface groundwater flows is reduced in the summer months when plant productivity is high. Although this is only a very small portion, considering the limited tests used in this study it could have an effect.

As was stated earlier the average year that these results were collected was 2002. Even in the time between now and then the minimum detectable limits and testing procedures have increased immensely. Technology now is much more accurate and reliable then it was when some of these tests were conducted. This is likely to only have a small effect on the total result but is still an important aspect to consider. Recent research has also provoked the need to include more tests in our water quality research.

The largest limitation this study faced may have been a lack of total data, 132 wells to represent all of the Ganaraska Region is not enough points of data to determine water wuality change spatially. The large variation calculated in some of the tested parameters may have been reduced given there was a large sample size more representative of the tested region. More wells would have better represented the area and been able to better illustrate some of the patterns of water quality within the subsurface. However, the collection of data represented in this study is likely the majority of the data that could possibly be gathered. The CAMC operates for the sole purpose of maintaining accurate groundwater monitoring systems and this encompassed all their available data for the area. In 2013, the Ontario Geological Survey collected and begun processing data to study ground water between Peterborough and Kingston. If possible, further studies should include this data, as it would help provide a complete and up to date summary of water quality within the region.

8.0 Overall Conclusions

Recent research has indicated that growth and development within the Greater Toronto Area (GTA) has degraded water quality in shallow aquifers (Howard and Maier, 2006). Since the Ganaraka region lies outside of the GTA, this study was able to draw conclusions on both the rural and urban impacts on groundwater. The results of this study do accurately describe the ORM’s connection to the Lower Sediments and describes the chemical changes along the waters flow path. The ORM should be regarded as the upmost important aquifer in the Ganaraska Region as there is some provided evidence that land use activities are directly affecting the quality of water within this aquifer. Being an area of recharge for the underlying aquifers protecting this region of the subsurface will have a positive effect on water flowing downward.

With the expansion of the GTA and the urban fringe pushing further into rural boundaries every year it will become important to monitor the quality of water throughout the ORM. A monitoring network with proper sampling frequencies and distribution through the landscape would enhance the ability to track groundwater quality as a there is no currently employed system to track any groundwater change. The CAMC is a coalition dedicated to the protection of groundwater within the region and although their current understanding of flow and contamination is unparalleled they have no method of determining quality within a recent timeframe.

Groundwater is a resource that is utilized by both rural and urban inhabitants that is directly affected by anthropogenic activities. Sensitive areas such as the ORM are often underappreciated as the land use activities that occur are not always suitable for the delicate water storage system that it sits upon. If the GTA continues to expand into the rural area then the appropriate measures must be taken to protect the underlying resources. As a community it must be realized that actions have consequences and groundwater must be protected because once contaminated it is very difficult to remediate.

The Ganaraska Region is fortunate to have a bountiful supply of fresh water that is of very high quality. Meeting almost every aspect of the ODWQS this quality must be protected from activities that could degrade its superiority. The Ganaraska Region relies on potable drinking water to sustain its population. Perceived as infinite in supply, the quality of groundwater can degrade and land use activities in the region are threatening the current quality of water. Future generations and studies must lend attention to these details and determine best practices to protect this important resource.

9.0 Recommendations for Further Research

The initial objective of this report was to identify water quality issues over a geographical scale. This goal is still very much achievable as additional data is entered into the CAMC database. It might also be beneficial to examine ground water quality in a temporal sense. That is, examine how water quality may have changed since data collection began. As stated this study only used the most recent results of the tested wells, in some cases there were as many as 10 different sampling dates. This currently unused data could represent some changes in groundwater quality over time.

In addition to this, it would be beneficial for other conservation authorities along the Oak Ridges Moraine to undertake similar studies. Issues that arise within the Ganaraska Region are not unique to this region. The subsequent regions along the length of the Oak Ridges Moraine would benefit from having a well-linked database to map and help explain groundwater flow and quality across much of this 11,000 km^2 feature. The CAMC is spread throughout the ORM and does not have the manpower to facilitate a study of this magnitude in every region. With the help of the individual conservation authorities is may be possible to better describe groundwater quality throughout the aquifers, similar to this study.

A modelling project could help determine the flow of aquifers if the number of tested wells increased. Programs like MODFLOW which is capable of determining these flow paths could be used in conjunction with the CAMC and GRCA to more accurate describe the flow of chemicals through the subsurface. MODFLOW is a very complicated modelling package that requires lots of background knowledge on both the underlying substrate and the mathematical parameters of groundwater flow. This study could act as a stepping stone helping with a basic depiction of chemical movement which could be compared to the other final project.

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11.0 Appendix

	ORM Physical Parameters					
	Alkalinity	DOC	Hardness	pH	TDS	Turbidity
Average	192.84	1.52	245.19	7.87	400.30	2.91
St. Dev. (S)	43.83	0.55	73.76	0.22	4.67	5.09
	Newmarket Till Physical Parameters					
	Alkalinity	DOC	Hardness	pH	TDS	Turbidity
Average	194.08	1.73	293.95	7.78	294.00	2.73
St. Dev. (S)	45.71	0.25	165.39	0.32	92.21	5.19
	Lower Sediments Physical Parameters					
	Alkalinity	DOC	Hardness	pH	TDS	Turbidity
Average	197.42	2.21	219.67	7.87	232.75	1.89
St. Dev. (S)	38.63	2.19	85.95	0.20	92.43	2.46
	Bedrock Physical Parameters					
	Alkalinity	DOC	Hardness	pH	TDS	Turbidity
Average	156.10	2.40	201.43	8.08	306.67	2.17
St. Dev. (S)	42.29	0.00	68.01	0.04	193.18	2.20
ODWQS						
	ORM Anions					
	Bicarbonate	Chloride	Nitrate	Sulphate		
Average	181.27	44.92	2.23	29.99		
St. Dev. (S)	36.87	46.51	0.76	13.53		
	Newmarket Till Anions					
	Bicarbonate	Chloride	Nitrate	Sulphate		
Average	225.50	37.19	2.41	26.92		
St. Dev. (S)	50.20	24.47	0.45	10.47		
	Lower Sediments Anions					
	Bicarbonate	Chloride	Nitrate	Sulphate		
Average	195.25	32.12	2.81	18.82		
St. Dev. (S)	7.27	32.83	1.63	14.46		
	Bedrock Anions					
	Bicarbonate	Chloride	Nitrate	Sulphate		
Average	180.83	84.23	6.87	22.73		
St. Dev. (S)	41.57	119.56	8.81	30.25		
ODWQS						
	ORM Cations					
	Calcium	Iron	Magnesium	Manganese	Potassium	Sodium
Average	87.11	0.02	15.87	0.08	1.44	18.18
St. Dev. (S)	21.74	0.01	7.75	0.19	1.44	19.82
	Newmarket Till Cations					

	Calcium	Iron	Magnesium	Manganese	Potassium	Sodium
Average	77.60	0.16	12.00	0.01	1.08	18.06
St. Dev. (S)	36.01	0.33	4.67	0.01	0.32	8.93
	Lower Sediment Cations					
	Calcium	Iron	Magnesium	Manganese	Potassium	Sodium
Average	64.02	0.69	14.32	0.07	1.54	21.20
St. Dev. (S)	35.89	1.26	4.15	0.11	0.98	18.16
	Bedrock Cations					
	Calcium	Iron	Magnesium	Manganese	Potassium	Sodium
Average	54.47	0.30	15.87	0.01	1.70	43.20
St. Dev. (S)	42.56	0.26	7.75	0.01	0.42	57.99
ODWQS						