PRELIMINARY HYDROGEOLOGICAL CHARACTERIZATION OF THE ANNAPOLIS VALLEY, NOVA SCOTIA

Christine Rivard, Martin Ross and Yves Michaud, Geological Survey of Canada, Québec, Qc, Canada
Tony Hamblin, Geological Survey of Canada, Calgary, AB, Canada
John Drage, Nova Scotia Environment and Labour, Halifax, NS, Canada
Amanda Blackmore and Timothy Webster, Centre of Geographic Sciences (COGS), Middleton, NS, Canada
Claudio Paniconi, INRS - Eau, Terre et Environnement, Québec, Qc, Canada
Christine Deblonde, Geological Survey of Canada, Québec, Qc, Canada

ABSTRACT
A regional hydrogeological study in the Annapolis-Cornwallis Valley, Nova Scotia, is being undertaken within the framework of the Geological Survey of Canada Groundwater Program. The overall objective of this project is to characterize and quantify the groundwater resource within granular and fractured aquifers of this region (2100 km^2). A comprehensive inventory of existing data led to the creation of databases. Preliminary analysis of these data allowed the development of a first 3D geological model, and the mapping of hydraulic properties and hydraulic heads. The main regional aquifer resides in the Wolfville Formation, which underlies most of the Valley floor. The overlying Quaternary sediments mostly consist of till, ice-contact glaciofluvial and sandy proglacial sediments, whose thickness vary from 0 to 50 m. Reported transmissivities generally range from 10^{-5} to 10^{-2} m^2/s, indicating that a good aquifer potential is available. The regional groundwater flow appears to be mostly controlled by the topography.

RÉSUMÉ
Une étude hydrogéologique régionale dans la Vallée d'Annapolis-Cornwallis en Nouvelle-Écosse a été entreprise dans le cadre du programme sur les eaux souterraines de la Commission géologique du Canada. L'objectif général de ce projet consiste à caractériser et à quantifier l'eau des aquifères granulaires et fracturés de cette région (2100 km^2). Un inventaire complet des données existantes a mené à la création de banques de données. L'analyse préliminaire de ces données a permis le développement d'un premier modèle géologique 3D et la cartographie des propriétés et charges hydrauliques. La principale formation aquifère est la formation géologique de Wolfville, qui tapisse le fond de la vallée. Les dépôts quaternaires sont principalement composés de till, de sédiments fluvioglaciaires et de sables proglaciaires, dont l'épaisseur varie de 0 à 50 m. Les transmissivités varient généralement entre 10^{-5} to 10^{-2} m^2/s, indiquant la présence d'un bon potentiel aquifère. L'écoulement régional de l'eau souterraine semble surtout contrôlé par la topographie.

1. INTRODUCTION

The Annapolis-Cornwallis Valley is a long narrow lowland extending from the Minas to the Annapolis basins along the south shore of the Bay of Fundy in Nova Scotia. The Valley is about 100 km long and 10 to 15 km wide, and lies within the North and South mountains. The rich and fertile soils, as well as its micro-climate, make the Annapolis-Cornwallis Valley one of the three key regions in Canada for commercial fruit production, along with the Okanagan Valley and the Niagara Peninsula.

Population growth, intensive farming, changes in land use, and recent droughts have put high pressure on water resources in the Valley. Limited surface water supplies and its poor quality have made groundwater increasingly appealing. Little is known, however, about the groundwater resource and its properties. The only significant regional hydrogeologic report for the Valley was published more than 35 years ago (Trescott, 1968).

The current Annapolis-Cornwallis Valley Aquifer Study has been undertaken within the "Assessment of Regional Aquifers: Towards a National Inventory" framework of the Geological Survey of Canada Groundwater Program. The overall objective of this project is to characterize and quantify the groundwater resource within granular and fractured aquifers. This project will assess aquifer properties, hydrodynamic conditions, and groundwater characteristics, so as to provide valuable information to support management programs.

2. CHARACTERISTICS OF THE STUDY AREA

2.1 Physiography and hydrography

The Annapolis-Cornwallis Valley is flanked to the south by the granite rocks of the South Mountain and to the north by the basaltic North Mountain cuesta. It comprises 6 primary watersheds: Annapolis, Cornwallis, Habitant, Canard, Pereaux and Gaspereau. The Annapolis River drains almost 1600 km^2, while the other 5 rivers drain about 1070 km^2. The Gaspereau watershed is not included in this study, since its population is small and few environmental problems have been reported. Figure 1 shows the location of the study area. The small watersheds of Habitant, Canard and Pereaux (totalling 125 km^2), all located at the north-eastern extremity of Kings County, have been included in the Cornwallis watershed in this figure. These sub-watersheds are separated from each other by low ridges.

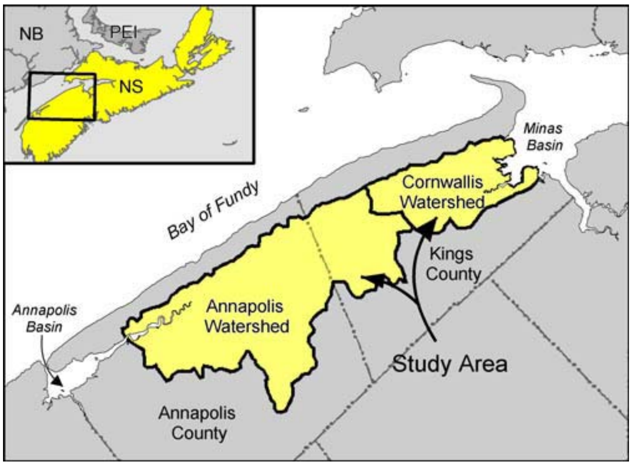

Figure 1: Location of the study area

Elevations of the South and North Mountains rarely exceed 250 m asl, and river banks heights in the Valley vary from 0 near the basins to 40 m at the watershed divide. Because of the topography, only a small portion of the North Mountain is included in the study area while a very large portion of the South Mountain is encompassed in the studied watersheds.

Although the study area comprises an impressive 1682 km of rivers, the Valley is not very well drained and contains 157 small to moderate lakes and reservoirs (covering 68 km^2). Wetlands throughout the Valley, especially along the main rivers (i.e. Annapolis and Cornwallis Rivers) and the coast of the Minas Basin have been extensively altered by dyking and infilling. It is estimated that 80% of the original salt marshes have been dyked or filled to create agricultural lands (KCEDA, 2000). Even so, numerous bogs, ponds and marshes are still present and provide excellent habitats for wildlife. Wetlands currently represent 3% of the study area.

2.2. Climate

The Valley's topography plays a major role in the climate conditions, with the North and South Mountains funnelling winds through the Valley and protecting it from weather blowing in directly off the Bay of Fundy and the Atlantic Ocean (Timmer, 2003). Local climatic conditions within the Valley are heavily influenced by proximity to the Annapolis and Minas basins and by topographic elevations.

Sixteen weather stations, which data span over 3 to 96 years, provide annual precipitation varying from 1127 to 1400 mm, with an average of 1200 mm within the Valley proper. Between 15 and 25% of this precipitation falls as snow on average. Monthly average temperatures generally range from –5 to +19^{o}C, with more than 200 frost-free days. Precipitation in the Valley falls mostly during the fall and winter, with precipitation levels peaking in December and January. The driest months are June and August. Surface runoff likely represents a significant component of the hydrologic budget. Indeed, runoff waters include a collection of waters from the abrupt side of the North Mountain cuesta, the Valley itself and a large part of the South Mountain. This water is drained to the bottom of the Valley, and is mainly evacuated either through the Annapolis River to the Annapolis Basin or through the Cornwallis River to the Minas Basin. Both basins connect to the Bay of Fundy.

2.3 Population and land use

The Valley is rural, with towns and villages concentrated predominantly along the rivers. The eastern end of the Valley is the most urbanized. From the 2001 population census, a total of 84 183 residents lived within the borders of Kings and Annapolis Counties (Nova Scotia Statistics Division, 2004), representing 8.9% of the province's population. Kings County had one of the highest population growths in Nova Scotia over the last years (7.8% over the 1991-2001 period), while the population in Annapolis County declined (6.7% for the same period; Timmer, 2003).

The region's economic base includes agriculture, fishing, tourism, and technology. One third of the provincial income from agriculture comes from Kings County (KCEDA, 1998). Major products include: orchard fruits (mostly apples), cranberries, blueberries, chickens, vegetables and potatoes, turkeys, and hogs.

3. DATABASES AND DATA DISSEMINATION

Over a hundred documents including reports, maps, scientific papers, and theses were compiled (and often digitized) and structured into databases. Databases from two Nova Scotia Departments, Environment and Labour (NSEL) and Natural Resources (NSDNR), have also been obtained. Targeted information primarily consisted in well log descriptions, well characteristics (depth, yield, static water level, etc.), weather and hydrological data, water chemistry data, as well as pump test results and data related to monitoring wells. Geotechnical and well data have also been obtained from National Defence (Greenwood military base). Five dataloggers have been installed to complement the provincial monitoring program so as to record daily groundwater levels.

A web site (http://www.cgcq.rncan.gc.ca/annapolis/) was created to provide data access to all stakeholders. Through the web, participants can enter new observations and can also access, query, visualise, and edit existing data. The information can further be integrated into a GIS (Geographical Information System) for statistical and spatial analysis and map representation. The information gathered so far is divided into four categories: 1) Project information (contact information and publications), 2) Field data (field data collected during the summer campaigns), 3) Compiled data (metadata and databases), and 4) Maps.

4. GEOLOGICAL CONTEXT

4.1 Bedrock

The Triassic/Jurassic rocks of onshore Atlantic Canada are related to the early stages of rifting and drifting that led to the opening of the proto-Atlantic Ocean. They unconformably overlie a variety of Paleozoic rocks which themselves relate to earlier collisional and extensional phases (Greenough, 1995; Wade *et al*., 1996).

Paleozoic

Paleozoic rocks form the South Mountain highland and the basement beneath Triassic rocks in the Valley. These include the Meguma and the Horton groups, encountered directly under surficial deposits in some areas of the Valley. The Meguma Group's youngest unit, the Halifax Formation (Lower Ordovician), covers a large region in the south-eastern part of the study area and is composed of interbedded slate, siltstone and quartzite (Trescott, 1968). In the eastern part of the valley, the Meguma Group is unconformably overlain by the Horton Group, which consists in its upper part of shale with interbedded grits and sandstones. Strata are lenticular and cross-bedded, typical of the Carboniferous Maritimes Basin units. Middle-Late Devonian granitic and metasedimentary rocks are dominant in the South Mountain highland.

Mesozoic

The Mesozoic rocks of the Valley include the Triassic Fundy Group, underlying the Valley proper and forming the North Mountain. In Nova Scotia, the Fundy Group comprises, in ascending order: the Wolfville, Blomidon, North Mountain, Scots Bay, and McCoy Brook formations, deposited in a half-graben fault-bounded basin. The Scots Bay and McCoy Brook formations however are not found in the study area and are therefore not described here. In the Annapolis-Cornwallis Valley, rocks of the Fundy Group outcrop along the North Mountain and near the Minas Basin.

The Wolfville Formation represents the most important bedrock aquifer of the Annapolis-Cornwallis Valley. This formation, which underlies most of the Valley floor, comprises reddish thickly bedded medium to coarse grained arenitic to subarkosic sandstone, with subordinate pebbly and conglomeratic beds whose clasts are derived from the adjacent metamorphic and granitic highlands. The Wolfville Formation is remarkable for its heterogeneity. It is an interbedded and intertonguing complex of crudely-stratified rocks of continental origin, typically in lenticular beds (Crosby, 1962; Taylor, 1969). Large-scale cross bedding is present in some locations. Consequently, its composition may vary widely from place to place.

Deposition occurred in alluvial fan, fluvial, and aeolian environments, and an overall fining-upward succession is evident (Tanner, 2000). It unconformably overlies the Lower and Upper Paleozoic rocks which form the deformed basement in the area and thicknesses up to 833 m have been reported (Crosby, 1962; Taylor, 1969). Wolfville rocks are assigned a Late Triassic age. The strata generally dip 5-10^{o} NW towards the Bay of Fundy. Offsets of a few metres have been reported along numerous NE/SW and steeply dipping normal faults and joints, although there is no evidence for a large, basin-bounding fault on the south side of the Fundy Rift. (Crosby, 1962; Smitheringale, 1973; Wade et al., 1996).

The Blomidon Formation, present along the length of the Valley on the northern side, forms the flank of North Mountain. This formation is remarkably homogeneous, comprising evenly bedded red siltstone and mudstone, with minor fine sandstone. It could be classified as a "variable" or poor aquifer. There is again evidence of an overall fining-upward trend. Deposition occurred in an arid mudflat/playa setting. It conformably overlies the Wolfville Formation and conformably underlies the North Mountain Formation. Thicknesses up to 363 m are known and the strata dip 5^{o}NW (Crosby, 1962; Smitheringale, 1973). The Blomidon Formation is assigned a Late Triassic age.

The North Mountain Formation corresponds to a series of tholeiitic basalt flows, whose number varies from seven near Middleton to sixteen near the Minas Basin (Trescott, 1968). Columnar jointing is very well developed in many areas. Zeolites and various forms of quartz are common. Coastal outcrops are generally good. Thicknesses up to 427 m are recorded and the strata dip 3-5^{o}NW (Crosby, 1962). Radiometric dates indicate an Early Jurassic age.

4.2 Quaternary

The Quaternary geology and geomorphology of the Annapolis Valley present a high degree of diversity involving the major depositional systems of glacial settings. Their interactions often result in a series of genetically-related contemporaneous or time-transgressive deposits partly overlying other deposits of different origin and age. Surficial sediments of the Annapolis-Cornwallis Valley were mapped to a 1:500 000 scale (Stea *et al.*, 1992) and to a 1:63 360 scale (1 mile: 1 inch, Trescott, 1968).

Glacial dynamics

The Annapolis Valley records evidence of complex Wisconsinian glacial dynamics and deglacial history. Stea and Mott (1998) presented a glacial dynamics model consisting of four ice flow phases. The earliest ice flow was towards the southeast (Caledonia Phase), and was followed by a southward ice flow (Escuminac Phase). Later, the development of an ice divide over southern mainland Nova Scotia (Scotian Ice Divide) resulted in northwestward ice flow over much of the Valley (Scotian Phase). A late westward ice flow event is also recorded in the Valley and represents another significant glacial dynamics shift or a readvance from an ice lobe in the eastern part of the Valley (Chignecto Phase). A few striation sites indicating the age relationships between the different phases are found mainly in the North Mountain and South Mountain. In the lowland, outcrops are very rare but the study of landforms and sediment characteristics provide a mean to analyse the impact and, in some cases, the extent of the different phases.

Sediment distribution and composition

Available data and analysis of previous work as well as limited recent investigations suggest the presence of west-trending glaciofluvial morphosequences consisting of ice-contact and proglacial deposits. Across the Valley and starting from the east end, kames and eskers, and perhaps kame terraces, grade into and are partly overlain by outwash plain and outwash fan sediments which are linked, in a possible interfingering fashion, to more distal and thus fine-grained glaciolacustrine/glaciomarine sediments in the Bridgetown area. The morphosequences of ice-contact and outwash sediments imply that the late glacial westward ice flow phase (Chignecto Phase) extended to the area of Middleton.

Till and glaciofluvial deposits, as well as fluvial deposits, cover most of the valley. Till is the most widespread glacial deposit, but the largest mass of glacial materials may be of glaciofluvial origin (Trescott, 1968). The till composition is the result of the different ice flow phases briefly described above and is also related to the underlying bedrock lithology. Deposits are thinner in the upland areas (rarely exceeding 10 m), and thicker in the valley (up to 20 m). They can however reach 60 m in some bedrock depressions. Most of the surficial sediments were deposited during the last glacial/deglacial episode.

In particular, the middle and eastern portion of the Valley is generally covered by ice proximal/ice contact sandy sediments, but some varved clays were observed during a field trip. Their extent must be determined. Ice contact deposits are also present along secondary depressions near the Minas Basin, in many of the tributary valleys along South Mountain and scattered along North Mountain (Trescott, 1968). In general, the sediments are sandier and better sorted in the centre of the valley, whereas gravel and boulders are found along the flank of the South Mountain (Trescott, 1968). An extensive outwash plain occupies much of the central part of the valley between Berwick and Lawrencetown. West from Wilmot, outwash commonly overlie estuarine deposits of silt and clay (Trescott, 1968). Outwash sediments usually consist of well stratified and cross-bedded fine to coarse sand. Clay-covered areas are relatively large west of Middleton. The ends of the valley are dominated by intertidal sediments.

As is often the case, eskers appear to be controlled by depressions in the bedrock. Available data indicate that till is frequently lacking along these depressions, suggesting that melt water activity eroded most of the pre-existing glacial sediments along these narrow conduits. Kames and other ice-contact deposits are closely associated spatially with eskers, forming complex and sometimes large and continuous glaciofluvial ridges in the eastern part of the valley. This likely implies controlled deposition, reflecting former subglacial, englacial, and supraglacial debris concentrations, crevasse patterns and/or drainage systems. Glaciolacustrine rhythmites have recently been found near Coldbrook but their extent and paleogeographic significance are still poorly understood. It could be related to a local ice-dammed lake or a more extensive lake that covered part of the eastern side of the Valley. Available data tend to indicate a limited extent.

4.3 Geological model

A preliminary 3D geological model was developed, integrating map information from Trescott (1968), and constrained by borehole data and interpretation.

The thickness map of Quaternary sediments is presented in Figure 2. Three potential buried NE-trending valleys have been identified between Berwick and the Minas Basin, with depths varying from 15 to 60 m. However, the subsurface distribution and thickness of surficial deposits is poorly known at this stage and the thickness is likely underestimated due to low borehole density, especially in the western portion of the Valley. These depressions should contain sand and gravel, and could hence represent a non negligible aquifer potential.

The bedrock model was constructed using outcrops and borehole data (137) from Trescott's report (1968) as well as lithologic logs (100) from precisely described wells from the NSEL database. Some of these wells were located with fair precision using information contained in the original reports. A DEM of the surface topography was used as a soft constraint. The preliminary 3D model is shown in Figure 3.

Triassic units of the 3D model are dipping towards northwest at an angle generally ranging from 3 to 7 degrees, which is within the reported range for these units (see above). However, internal dip and structures are not modelled in the Horton Group and Lower Paleozoic rocks are undivided. The modeled vertical thickness of the Wolfville Formation range from 0 to about 1150 meters under the North Mountain. However, the geometry is mainly inferred and extrapolated and is affected by the preliminary modeling process itself. For example, the modeled thickness of the Wolfville Formation is controlled by a set of constraints and by the geometry of the underlying units which are subject to modifications in future versions of the model. Folds and faults are not yet represented.

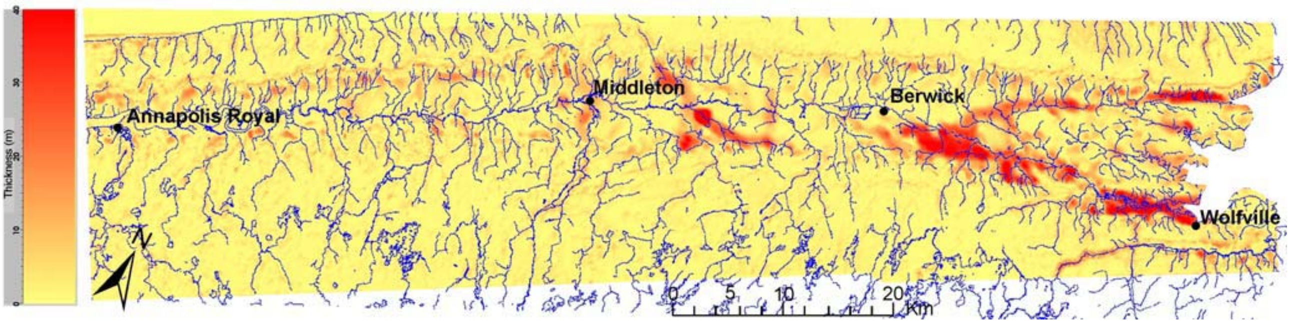

Figure 2: Quaternary sediment thickness distribution

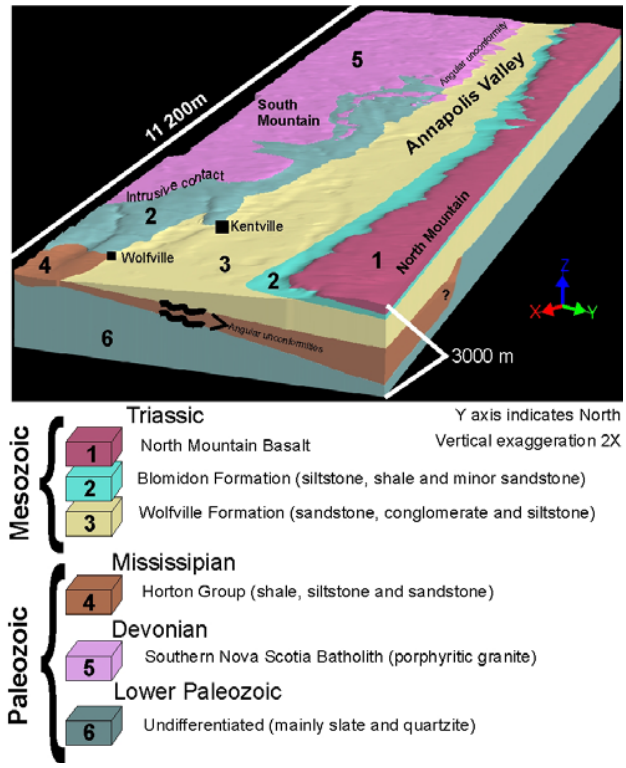

Figure 3: Preliminary 3D geological model

5. HYDROGEOLOGICAL CONTEXT

5.1 Hydrostratigraphic units of most interest

The main bedrock aquifers occur in the Wolfville Formation and, to a lesser extent, in the Blomidon Formation. Other geological formations, such as the North Mountain and those of the Horton Group, can provide good yields only on a local basis, depending on their fracturing, jointing, and weathering, but are not considered good aquifers. They are thus not described in this section. Sand and gravel deposits can constitute good aquifers in some areas of the Valley, depending on their saturated thickness. Tills cannot provide significant yields. However, they have a key role in this hydrogeological system, as they allow aquifers to recharge.

Triassic bedrock

Due to the gentle northward dip of 5-10^{o} of all Fundy Group strata in the Bay of Fundy area, all stratigraphic intervals represented in the Triassic occur at surface somewhere in the study area. In the Wolfville Formation, good water-bearing sandstones and/or conglomerates may be penetrated almost anywhere within the boundaries of the formation (Trescott, 1968). Nevertheless, the heterogeneity of the rock of these formation, resulting from the regional dip, lateral discontinuity of the sub-units, and variable lithologies, control the circulation of groundwater through the Triassic rocks. In addition, movement of the water is often limited by the poorly sorted sediments and cementation of the grains by secondary minerals (Trescott, 1968). Therefore, variable aquifer quality and conditions are encountered throughout the study area. According to Trescott (1968), water is primarily circulating trough intergranular pores spaces and only secondarily through joints. This hypothesis is still to be verified.

The Blomidon Formation, composed predominantly of fine-grained rocks (siltstone and claystone), can usually only yield small amounts of water, primarily through joints (Trescott, 1968). Occasionally, thin, interbedded sandstones and/or more frequent fractures are encountered, which will yield more water to drilled wells. However, this formation can act, regionally, as a thick sealing aquitard for the multiple aquifers of the Wolfville Formation.

Quaternary sediments

Glacial sediments of the Valley appear to be generally made of sand and gravel, but they tend to have a wide range of particle sizes due to highly variable meltwater flow conditions associated with glaciers. Outwash plain sediments are usually better sorted than in ice-contact deposits. Tills present different facies due to changes in glacial dynamics during deposition, but the nature of the underlying bedrock lithology is usually the predominant controlling parameter. Since sandstone is the most widespread rock over the valley, the till may be generally sandy.

The porosity and permeability of these deposits can thus be highly variable because of internal heterogeneity. Nevertheless, these deposits frequently contribute significantly to the recharge and may also locally constitute good aquifers. The major limiting factor is the limited saturated thickness. The largest granular aquifers should be found in buried bedrock valleys in the eastern portion of the Valley (see Figure 2). These aquifer units are probably connected to underlying glaciofluvial and fractured rock aquifers.

5.2 Hydraulic properties

To draw a preliminary portrayal of the hydraulic properties of the Valley, 92 transmissivity values and 18 storage coefficient values are currently available. Wells were initially located using the grid system of the Province (precision of 1 km^{2}). Some well locations were improved, although approximately 20% still have duplicate coordinates. The great majority of these productive (high capacity) wells are located in the bedrock. Their depths are highly variable, with an average of 55 ± 35 m. Only 20% are less deep than 20 m.

Hydraulic properties exhibit large variations, as is to be expected in fractured rocks. Figure 4 shows that transmissivities generally range from 10^{-5} to 10^{-2} m^{2}/s, indicating that a relatively good hydraulic capacity is available in the Valley. Reported storage coefficients are usually smaller than 10^{-3}. The transmissivity data have shown no correlation, most likely because not enough data pairs are available for a given range. Storage coefficients are too scattered over the region to allow the building of a variogram.

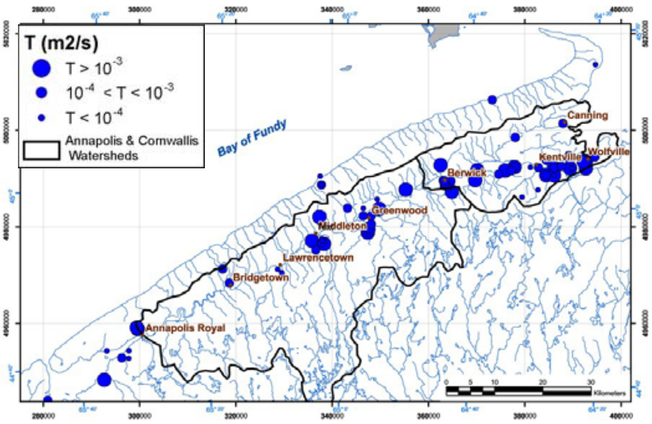

Figure 4: Spatial distribution of the transmissivities. Values are classified into three ranges. A circle may represent either a single value or a geometrical mean of several values located in a close area (within 1 km).

The bedrock aquifers appear to be generally confined or semi-confined, due to overlying fine-grained rock strata and sediments such as glaciomarine and intertidal deposits. Nevertheless, aquifers of the bedrock and granular units appear to be hydraulically connected at the regional scale. Further investigations still have to be performed to study the surface water and groundwater interactions.

5.3 Groundwater levels

The preliminary piezometric map was obtained using all data (9500 wells covering many years and seasons), assuming that the granular and the bedrock aquifers are hydraulically connected and that a similar uncertainty can be attributed to each data source. This map, presented in Figure 5, was produced through kriging, using a spherical variogram with a correlation length of 25 km. The water levels measured in wells located in the study area vary from artesian flowing conditions to depths that can reach more than 50 m. The groundwater level depth (from the surface) is on average (median) 4.6 m. The regional groundwater flow is mostly controlled by the topography.

5.4 Hydrologic budget: water use and recharge

Groundwater is the primary source of drinking water for municipal and rural residents. Indeed, 99% of the Valley residents obtain their drinking water from groundwater (KCEDA, 2000). The move to reliance on groundwater is a relatively new phenomenon, with several towns and villages switching from surface water to groundwater sources within the last decade.

The largest water use sector during the growing season is agriculture. However, the great majority of irrigation demands are supplied by surface water. It is estimated that 80% of stream water is taken every summer for irrigation (KCEDA, 2000). Since the demand for irrigation peaks during the months with the lowest streamflows, it can have a significant impact on water resources. Year round management of water allocation thus poses challenges for municipal and provincial authorities. According to AGRA Earth and Environmental Limited (2000), demands exceed supply in the Canard River watershed, and 25%, 40% and 95% of the sustainable supply are used in the Annapolis, Cornwallis, and Pereaux watersheds, respectively. In many areas, residents are experiencing dry wells (KCEDA, 2000).

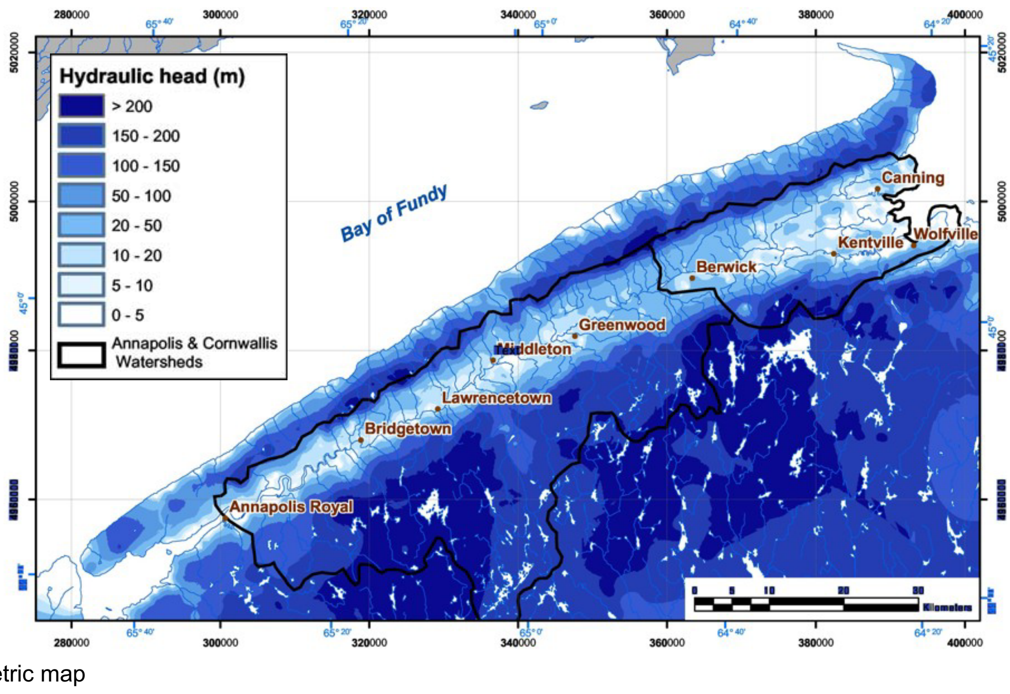

Figure 5: Piezometric map

The available information on well yields has allowed us to establish an approximate picture of the groundwater usage within the Valley. Only the high capacity wells are likely to provide an accurate yield since a long-duration pump test was usually performed in these wells. As a result, this map simply provides an indication of the hydraulic capacity of the various geological formations. The spatial distribution shows that most productive wells are found in the eastern part of the Valley, where most industries, schools, and large farms are located. The yields in Figure 6 were classified into three categories, according to their values. The average yield reported in the database (median for 9600 wells) is 0.61 l/s. Most wells (75%) have a yield smaller than 1.1 l/s. Only 4.1% have a yield larger than 3 l/s, which is considered the upper limit for residential wells.

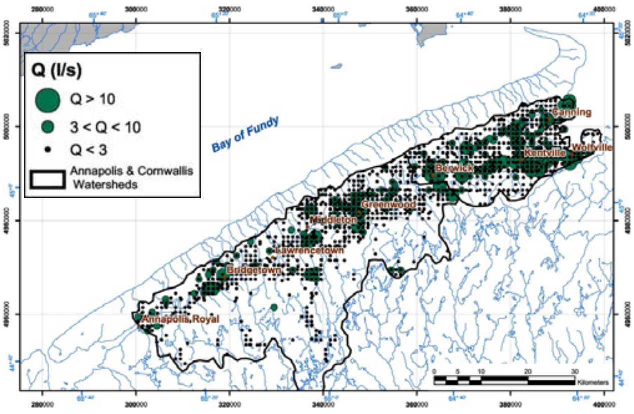

Figure 6: Spatial distribution of groundwater yields

An indication of the hydraulic capacity can also be obtained using cumulative frequency graphs of the specific capacity values (*Q/s*, where *Q* is the pumping rate and *s* is the total drawdown). However, less than a hundred values are available for the Valley, because the NSEL well log database does not include this parameter. The average specific capacity was found to be 0.25 l/s/m, with 8% of the wells having a value larger than 5 l/s/m and 4.5% larger than 10 l/s/m.

A water use survey of the Valley (MacPherson, 2004) has indicated, using available data from 4 recent reports (2000-2003), that the total groundwater demand for the study area was comprised between 31 000 and 404 000 m^3/d, depending on the method of calculation used. These numbers are based on the fact that most groundwater demands come from domestic, institutional, and municipal, as well as industrial and commercial sectors. These numbers therefore exclude irrigation demands. The pie chart of Figure 7 illustrates the maximum groundwater demand distribution (in m^3/d) as a function of the sub-watershed.

Preliminary base flow calculations using 5 gauging stations have shown that recharge should be on the order of 385 mm/y. Recharge would then represent approximately 30% of the precipitation. Using the aforementioned groundwater demand range, the regional budget does not indicate overall water shortages (1 to 18% of the calculated aquifer recharge). However, local, or at least sub-watershed, studies should be performed to have a better idea of the actual situation.

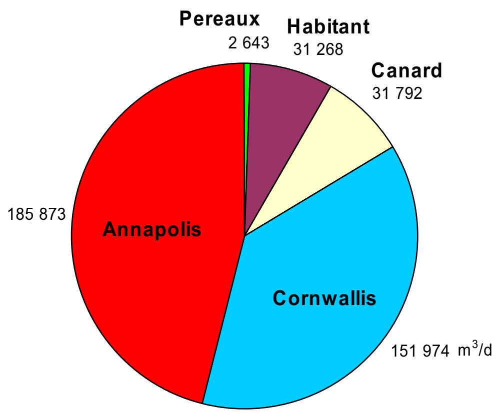

Figure 7: Pie chart of groundwater demands for each sub-watershed (in m^3/d)

5.5 Water quality

In the Annapolis-Cornwallis Valley, water pollution is of great concern, especially for nitrates, bacteria, and pesticides, as a large part of the land is devoted to agriculture. Besides farming related activities, concerns are mostly related to: poorly constructed or maintained septic systems, removal of riparian vegetation by agricultural and forestry operations, and a lack or malfunction of municipal sewage treatment plants (Timmer, 2003). Levels of nitrogen and fecal coliform in rivers that exceed limits for drinking, irrigation, and even recreational activities are commonly reported throughout the Valley (Timmer, 2003). Currently, the town of Wolfville and other small harbour towns discharge raw sewage into the Minas Basin (KCEDA, 2000).

Some groundwater quality problems (mostly nitrates) have also begun to occur and will likely increase in the following years. However, current conditions indicate that groundwater within the bedrock is generally of good quality. This water is mainly of the calcium bicarbonate type and slightly alkaline. Natural occurrence of some elements (such as iron and manganese) may be a problem in some areas. Groundwater in bedrock has usually a higher mineral content, alkalinity and hardness than the water from surficial deposits.

6. FUTURE WORK

Field work will be carried out to verify the consistency of the glaciofluvial morphosequence interpretation. The nature of the transition and/or stratigraphic architectural relationships between the permeable glaciofluvial sequence and the more impermeable glaciolacustrine/glaciomarine sediments will also be investigated, especially at both ends of the Valley. These fine-grained sediments can indeed play a significant role in the regional hydrogeology, by impeding recharge and protecting aquifers from surface contamination. In addition, areas with significant thickness of sand such as buried valleys and depressions will be further studied.

The possibility of a connection between surficial sediments and fractured rocks and, perhaps, fault systems, along certain depressions, will also be examined. If fault systems are present on both sides of the valley it would significantly change the bedrock conceptual model.

Further analyses and additional data will also allow the 1) estimation of the aquifer recharge with various methods, 2) improvement of the understanding of the hydrodynamics within the Valley, 3) completion of the geological and hydrogeological maps, 4) development of conceptual and numerical models and 5) analysis of geochemistry data.

7. CONCLUSION

With the rapid economic development of the Annapolis-Cornwallis Valley, water allocation and water quality maintenance are posing challenges to municipal and provincial authorities. Since surface water supplies have become insufficient within the Valley in the past years, groundwater has become the major source of water supply. The most important aquifers are found within the Wolfville Formation, which covers almost all the Valley floor. The Triassic rocks consist of a sequence of interbedding of coarse and fine grained lithologies. Water quality and yields may therefore vary over short distances, both stratigraphically and geographically.

This study will shed light on some of the important water issues of the Valley and will seek to further our understanding of groundwater / surface water interactions, the hydrologic budget, hydraulic properties, and Quaternary sediment deposition history in an effort to better support water resources management in the Annapolis-Cornwallis Valley.

ACKNOWLEDGMENTS

The authors wish to thank all the project collaborators for their availability and continued support. They are: the Nova Scotia Department of Environment and Labour, The Centre of Geographical Sciences, the Nova Scotia Agricultural College, the Acadia University, Environment Canada, Agriculture and Agri-Food Canada, National Defence, the Clean Annapolis River Project and the Friends of the Cornwallis River associations and finally, T. Hennigar who has acted as an advisor. We also wish to thank Dr. Rivera for his valuable comments. This paper is a GSC contribution no 2004037.

REFERENCES

AGRA Earth and Environmental Limited. 2000. Water Resources Needs of the Agricultural Industry in the Annapolis Valley, Nova Scotia. Final Report. Halifax, Nova Scotia: AGRA Earth and Environmental Limited.

Crosby, D.G. 1962. Wolfville map-area, Nova Scotia (21 H 1). Geological Survey of Canada, Memoir 325, 67 pages.

Greenough, J.D. 1995. Mesozoic Rocks. *In* H. Williams (ed.), Geology of the Appalachian-Caledonian Orogen in Canada and Greenland. Geological Survey of Canada, Geology of Canada, no. 6, pp. 567-600.

KCEDA. 2000. A study and review of sustainability indicators, Quality of the Environment report for Kings County. Nova Scotia. Kings Community Development Agency, 32 pages.

KCEDA. 1998. A survey of perceptions and issues. Quality of the Environment report for Kings County. Nova Scotia. Kings Community Development Agency, 57 pages.

MacPherson, S. 2004. Kings County and Annapolis County groundwater survey, Nova Scotia Department of Agriculture and Fisheries, internal report, 18 pages

Nova Scotia Statistics Division. 2004. http://www.gov.ns.ca/finance/statistics/agency/index.asp.

Smitheringale, W.G. 1973. Geology of parts of Digby, Bridgetown and Gasperau Lake map-areas, Nova Scotia (21A/12, East Half; 21A/14, East Half; 21A/15, West Half). Geological Survey of Canada, Memoir 375, 78 pages.

Stea, R.R. and Mott, R.J. 1998. Deglaciation of Nova Scotia: Stratigraphy and chronology of lake sediment cores and buried organic sections. Géographie physique et quaternaire, vol. 52, no 1, pp. 3-21, 11 fig., 1 table.

Stea, R.R., Conley, H and Brown, Y. 1992. Surficial geology of the province of Nova Scotia. Nova Scotia Department of Natural Resources, Map 92-3, 1:500,000.

Tanner, L.H. and Brown, D.E. 1999. The Upper Triassic Chedabucto Formation, Guysborough County, Nova Scotia: depositional and tectonic context. Atlantic Geology, v. 35, pp. 129-138.

Taylor, F.C. 1969. Geology of the Annapolis-St. Marys Bay map-area, Nova Scotia (21A, 21B East Half). Geological Survey of Canada, Memoir 358, 65 pages.

Timmer, D. 2003. Watershed characterization project. Guelph Water Management Group, University of Guelph, http://www.uoguelph.ca/gwmg/wcp_home/index.htm

Trescott, P.C. 1968. Groundwater resources and hydrogeology of the Annapolis-Cornwallis Valley, Nova Scotia. Department of Mines, Memoir 6, 159 pages.

Wade, J.A., Brown, D.E., Traverse, A. and Fensome, R.A. 1996. The Triassic-Jurassic Fundy Basin, eastern Canada: regional setting, stratigraphy and hydrocarbon potential. Atlantic Geology, v. 32, pp.189-231.