Groundwater Use in the Annapolis Valley

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ABSTRACT
A database was prepared to aid efforts to manage groundwater use in the Annapolis Valley of Nova Scotia. The database provided a record for each known user together with map coordinates and an estimate of average daily water use. Records of actual water use, facility information, and standard rates of consumption were used to generate a water use estimate for each record. The database contained 562 records upon completion, with public utilities accounting for 23%, domestic use for up to 20%, industrial users for 27%, and farms for just 12% of water withdrawn from Valley aquifers. The database provided an estimated demand of 71 412 m^3/day.

RÉSUMÉ
Une base de données fut préparée pour assister à la gestion des nappes phréatiques dans la vallée d'Annapolis en Nouvelle Ecosse. La base de données contient une entrée pour chaque usager avec les coordonnées géographiques et les moyennes journalières de consommation. Les enregistrements de consommation réelle, les informations sur les usagers et les taux de consommation courante furent utilisés pour estimer la consommation pour chaque entrée. Le base de données maintenant complète compte 562 entrées dont 23% de services publiques, 20% d'usagers domestiques, 27% d'usagers industriels et seulement 12% de fermes agricoles en termes de pourcentage de l'eau pompée des nappes phréatiques. La base de données fournit une demande en eau totale estimée à 71,412 m^3/jour.

1 INTRODUCTION

The Annapolis Valley is located in western Nova Scotia, bordered to the north by the Bay of Fundy (Figure 1). The Valley setting results in an extended growing season with respect to other parts of Nova Scotia, and combined with fertile well drained soils, is among Canada's most productive and intensively farmed regions. Agricultural activity in the Valley has benefited by a relative abundance of freshwater available in Valley rivers and aquifers. Annual precipitation consistently exceeds 1000 mm/year (Environment Canada, 2008) providing reliable recharge to Valley aquifers and associated base flow to rivers. Yet increasing demands by farms, municipal utilities, and industry places increasing pressure on surface and groundwater sources. Past surface water shortages have made groundwater increasingly appealing, highlighting the need for a complete understanding of groundwater inputs and demands in the Valley.

The Valley study area is defined as the Gaspereau and Annapolis primary watersheds, divided into the subwatersheds shown in Figure 1. The study area approximately corresponds to the Annapolis and Kings County political boundaries. The Valley geology and hydrogeology were described by Rivard *et al.* (2007, 2006) and Trescott (1968). Groundwater flow in the valley is characterized by flow down the valley slopes and into the valley plain where groundwater discharges to the Annapolis and Cornwallis Rivers or flows along the long axis of the Valley as regional groundwater flow. Surface soil thicknesses tend to be lesser on the valley sides, providing varying degrees of confinement according to the proportion of fine material present.

The valley floor typically exhibits thicknesses of over 15 metres of Quaternary materials, often comprising sand mixed with silt and clay or sandy till. Outwash, kame and esker gravel features comprise unconfined to semi-confined aquifers in parts of the Valley, providing water of good quantity and quality. In many parts of the Annapolis Valley, Quaternary deposits have proven to be very good aquifers supplying groundwater of excellent quality to municipal water systems, industry, domestic and agricultural users. The mean hydraulic conductivity (k) of wells in unconsolidated deposits is 3 x 10^{-4} m/s (Rivard *et al.*, 2006).

Wolfville Formation sandstone and conglomerate comprise the most widely exploited aquifer in the Valley, supplying water of generally good quality in large quantities to domestic, municipal, industrial and agricultural users along the Valley floor (k = 10^{-9} to 10^{-3} m/s). Other formations in the Valley provide water of varying quantity and quality and include the South Mountain (granite), the Blomidon Formation (sedimentary sandstone and shale), and the North Mountain Formation (basalt).

The potential for Valley aquifers to meet demand has been the subject of past studies by AGRA (2000), AMEC (2002), Dillon (2003), and CBCL Limited (2003). The scope and focus of investigations has varied from estimates of supply and demand for the entire Valley area, to farms within Kings County situated specifically in the fast draining sandy Cornwallis type soils. Methods of data collection included mail-out surveys, census data, GIS mapping, NSE databases, standard rates of consumption, known industrial rates of use, and crop and livestock consumption patterns.

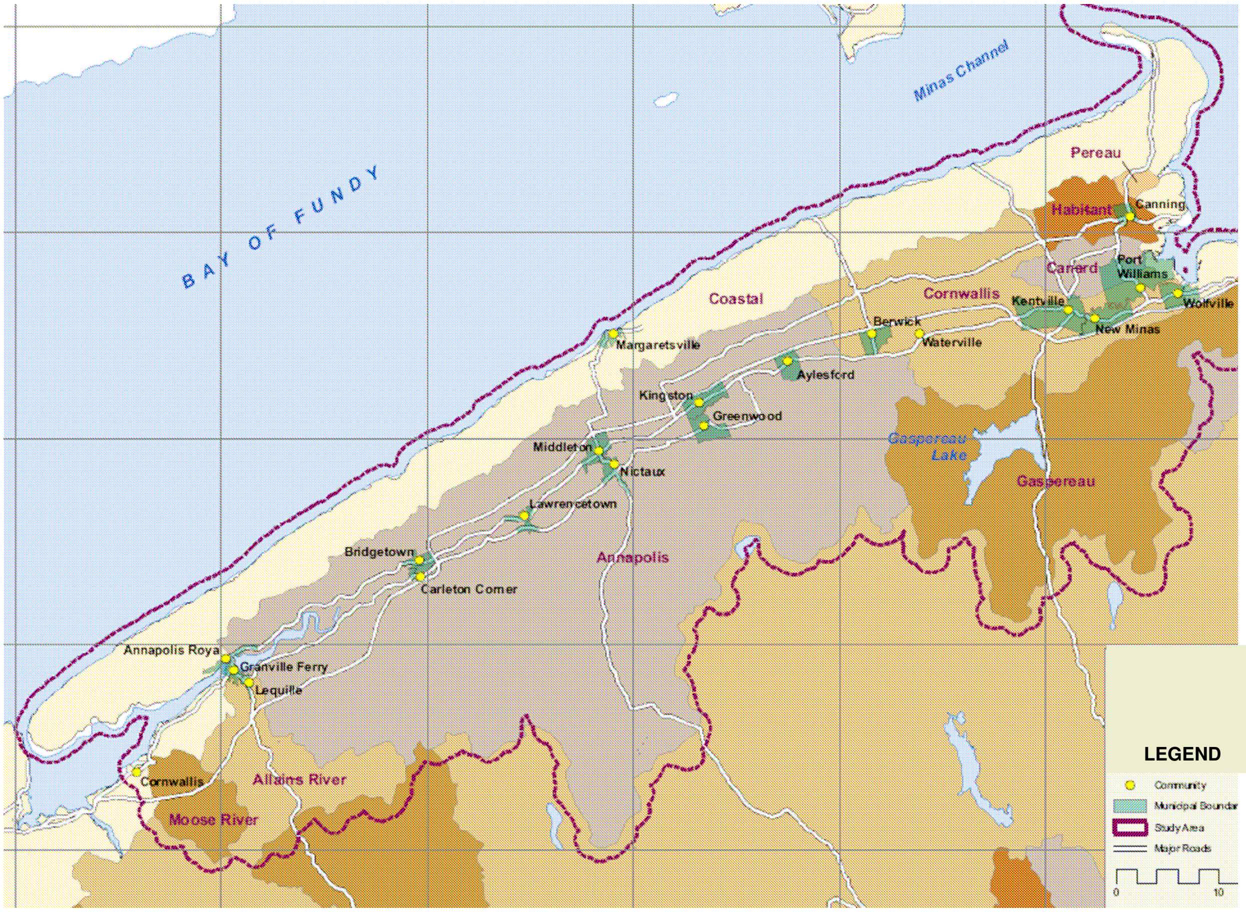

Figure 1. Annapolis Valley region of Nova Scotia showing sub-watershed divisions and municipal boundaries.

A consistent limitation of each study was the need for estimation and extrapolation of water use.

MacPherson (2004) provided a more complete summary of these studies, and performed a comparative analysis of supply and demand estimates. Demand estimates varied by as much as 100 000 m^3/day for a given sub-watershed. Most studies noted uncertainties in the method of irrigation demand in particular; estimates varied by as much as ten times between studies. Previous studies have consistently stressed the need for a more comprehensive inventory of major groundwater users in the Valley.

The purpose of this study was to prepare a database of groundwater use in the Annapolis Valley. The database was intended to include the location and a daily estimate of average groundwater use for each major groundwater user in the Valley, including municipal utilities, farms, industries, public buildings, communal supplies, and businesses. The database also included estimates of non-serviced domestic use grouped by sub-watershed.

Particular attention was directed toward obtaining accurate coordinate data and accurate groundwater demand data. Coordinates were recorded at GPS or property mapping level accuracy wherever possible. Groundwater demand data were based on records of actual use if possible. The completed database was intended to show the distribution of actual groundwater use in the Valley, and to provide a basis for on-going updates and refinement.

2 CONSTRUCTION OF DATABASE

The Groundwater Use Database was developed in successive stages, beginning with the synthesis of existing information into a preliminary database. Key elements of each record in the database included the user or facility name, UTM NAD83 coordinates, and average daily demand. Other groundwater use, well information, and user information were included for additional reference.

Existing water use studies and methods were reviewed to determine the most efficient and effective ways to collect information and improve the dataset. Interviews with municipal utilities and selected major water users were conducted to improve the level of accuracy and/or the amount of information available for each record. Mail-out and internet-based questionnaires were developed to collect additional information for smaller users, and to allow for addition of records not already captured in the database. After processing interview and questionnaire data, remaining data gaps were filled using calculations based on available information, or where necessary by applying a generic use figure. Watershed and aquifer information were added to each record using coordinate data and GIS mapping. Literature values for Consumptive Use Coefficients were applied to each record based on the water use sector and type.

2.1 Preliminary Database

The preliminary Groundwater Use Database for the Annapolis Valley was compiled from existing groundwater data found in government databases such as the Nova Scotia Well Logs database, the Nova Scotia Pumping Test database, the Nova Scotia Water Licenses database, and the Nova Scotia Registered Public Water Supply database (for additional details refer to Kennedy, 2008). Subsequent investigations were based on this initial group of approximately 400 water users, including a record to represent domestic uses in each sub-watershed.

2.2 Interviews

Municipal utilities were identified as the most intensive point-source water users in the Valley. The supervising engineer and/or operator for each public utility was interviewed on-site whenever possible, and by phone when a site visit could not be arranged. There were eleven communities in the study area that depended in part or in whole on groundwater for municipal water supply including Annapolis Royal/Granville Ferry, Canning, Greenwood, Kentville, Lawrencetown, Margaretsville, Middleton, New Minas, Port Williams, Sandy Court/Aylesford, and Wolfville. Particular emphasis was placed on obtaining and confirming actual water use data for the utilities. Average and maximum withdrawal rates were obtained.

2.3 Questionnaires

A total of 861 survey questionnaires were mailed out to agricultural and non-agricultural water users and a total of 162 questionnaires were returned (19%), including those that were completed via a web-based interface. Each questionnaire included a section on contact information, water use, and well construction. As water use is rarely metered by non-municipal groundwater users, questions were structured to collect information that was immediately available or easily obtained by the well owner/operator. Information on water use patterns was collected to allow for a calculation or estimate of water use, when records and user estimates were unavailable. Two separate questionnaires were developed to allow for collection of specific information on (1) The Agricultural Sector, and (2) Commercial, Industrial, and Institutional Users. Interviews were conducted with two agricultural users and one industrial user to test and modify the questionnaires according to effectiveness and ease of use.

The agricultural questionnaire was designed to collect information on farm type, acreage, and livestock to allow for calculation of water use. Information on irrigation methods and intensity of use was also collected if available. The questionnaire was sent to all farms registered with the Nova Scotia Federation of Agriculture. Local representatives for farm organizations were contacted and notified of the survey to help promote the survey at the local level.

A separate questionnaire was prepared for non-agricultural users. This questionnaire was mailed to 280 industrial, commercial, public, and institutional supply operators listed in the preliminary database. Questions focused on readily available usage patterns, fixture types and quantities, daily number of users (e.g. employees, patrons) and production rates for industry.

2.4 Groundwater Use Estimates

The average daily water use for each record in the database was based on actual water use records wherever possible. All water use records for municipal utilities were based on usage data. Water use estimates were also provided by some users. Provided that a user estimate was within tolerable limits for a given user type, this estimate was recorded in the Groundwater Use Database.

In many cases it was necessary to calculate the water use for a given record. The water use was calculated for each individual record where sufficient survey data was available (crop type and acreage, livestock count, customers per day, unit production per day, etc.). If survey data was unavailable, the daily water use for a given record was based on a standardized rate, calculated using relevant census data and established water usage rates.

In selected cases where existing data and/or methods of estimation were unavailable, the maximum permitted pumping rate, or the well yield as determined by a pumping test was used as the average daily water use.

Survey data for each farm was subdivided between livestock and crop production (including field crops, berries, tree fruits, and greenhouses). Calculations for livestock were based on a per-animal consumption rate, together with appropriate rates for leakage/loss, animal washing, and equipment washing. As domestic consumption by farms accounts for a nominal part of a farm's water use, it was omitted from calculations. Domestic use by all non-serviced users was furthermore grouped under separate calculations of non-serviced domestic demand.

Methods of calculation and animal consumption rates followed de Loë (2005). Water use coefficients were developed by Myslik (1991), and updated by Ecologistics (1993) and Ivey (2003). Methods of calculation and tables of standard animal consumption, animal washing, equipment washing, irrigation, losses, and spraying were provided by Dr. Rob de Loë. The basic calculation was as follows:

[1] Number of Animals x Consumption Rate per Animal + Losses + Animal Washing + Equipment Washing
= Average Daily Use for Animal Type (m^3/day)

Where multiple animal types were listed, water use was calculated for each animal type, and then summed to provide the average daily use for the farm. Calculations for crop production were in some cases based entirely on user data. The standard calculation was as follows:

[2] Crop Area (m^2) x Irrigation amount per event (m) x Number of events per season / Length of Operating Season (days) + Washing + Processing + Spraying
= Average Daily Use of Farm (m^3/day)

For farms where only the acreage of a given crop was available, a standard annual irrigation rate was applied. Rates of spraying, washing and processing followed de Loë (2005). Water use coefficients were developed by Myslik (1991), and updated by Ecologistics (1993) and Ivey (2003). For multiple crop types and/or mixed livestock-crop operations, the water use was calculated for each animal and crop type, and then summed to provide the average daily water use for the farm.

Data from the Statistics Canada Census of Agriculture was compiled for Kings and Annapolis Counties. Rates of consumption were calculated for each individual crop type, and aggregated into the following categories: Livestock, Field Crops, Fruit Orchards and Berries, Vegetables, and Greenhouses. The average produced for each category was used as a standard rate of consumption where the farm type was known but no data were available. For records in the Agricultural Sector lacking a discernible farm type, an average water use rate calculated based on all farm census data was used. Rates of consumption for fish farms were assigned solely on permitted pumping rates and/or pumping test data.

The water use coefficients used by de Loë (2005) were developed in Ontario based on conditions relating to Ontario farms. Factors such as climate, soil conditions, technologies, local growing practices and farm size were built into the coefficients. Water use coefficients have not been developed for conditions specific to the Annapolis Valley.

Calculations for non-Agricultural users were based on the Nova Scotia Design Flows for On-Site Sewage Systems (2007; “Table F3”). Standard flow rates were applied according to the number of persons, beds, bathrooms, kitchens, units etc. for a given facility type. Wastewater flows were assumed to be approximately equal to water withdrawal rates. The number of users or other relevant units was drawn from survey data where available. If the number of users / units was unknown, a standard quantity was applied for each facility type and sub-type in order to complete the calculation.

Wastewater design flows were not used to calculate water use rates for the Industrial sector or for Water Co-ops. Consumption by these users was assumed to be dependent on rates of product production, washing, and other sources of demand. If survey data on the nature of the operation were unavailable, the permitted withdrawal rate or test pumping rate was assigned as the average daily water use. In practice actual water use rates tend to be lower than the permitted withdrawal rate or test pumping rate.

Bulk rates of consumption were calculated for non-serviced domestic users. The calculation was based on a standard rate of consumption of 320 L/person/day, the rate estimated for the Annapolis Valley region of Nova Scotia by Natural Resources Canada (1999). The number of domestic users was determined for each secondary watershed using a combination of GIS mapping and census data. Serviced boundaries were obtained from Kings and Annapolis Counties and applied to the study area (Figure 1). Civic unit data were overlain and subtracted from the areas within the serviced boundaries. The number of remaining residential civic units was assumed to represent the number of non-serviced domestic users in each secondary watershed. The number of persons per residential civic unit (2.1) was calculated as the total population in Kings and Annapolis counties divided by the total number of residential units in Kings and Annapolis Counties

2.5 Watershed and Aquifer Data

The primary, secondary, and tertiary watershed for each record was determined by overlaying the groundwater use location coordinates with provincial mapping using GIS software. The coordinates for each record were similarly overlain with bedrock geology mapping to determine the most likely contributing geologic formation for drilled wells. Records indicating dug wells or wells drawing water from a sand and gravel formation were listed as “Quaternary” wells. All other drilled wells were assumed to draw water from bedrock formations.

2.6 Consumptive Use Coefficients

Consumptive Use Coefficients were assigned to each groundwater user in the database to allow for an assessment of Consumptive Use of pumped groundwater. Consumptive Use in this context distinguishes the amount of pumped water that is permanently removed from a given watershed from pumped water that is recycled within the Valley hydrologic system. Consumptive Use Coefficients were assumed to apply at the primary watershed scale for the Valley system (i.e. groundwater may be transferred between sub-waterhseds but is still conserved within the primary watershed area). Coefficients were drawn from an Ontario Ministry of the Environment Study (2006), and a review of data for the Great Lakes Climatic Region by the USGS (Shaffer and Runkle, 2007). The latter study compared Consumptive Use Coefficients within several districts of the Great Lakes region with other areas worldwide. Because these Consumptive Use Coefficients were developed for both surface and ground water uses, and tended to apply to non-coastal areas, sewage discharges were considered to be relatively conservative. By contrast, sewage discharges in the Valley setting are largely lost as outflow to the Bay of Fundy and are not conservative. Future work on the Valley system will require that Consumptive Use Coefficients for uses such as municipal groundwater supplies be adjusted to reflect this loss.

3 WATER USE ESTIMATES

After new information was compiled, the database contained 562 records, including a record representing domestic groundwater use for each of nine sub-watersheds. A total of 162 survey responses were processed, composed of 97 surveys from agricultural users and 65 surveys from non-agricultural users. Web-based surveys accounted for 15 agricultural users and 35 non-agricultural users. Municipal wells accounted for 34 records (grouped within 11 municipal groundwater systems), agricultural users for 215 records, commercial users for 124 records, industrial users for 35 records, and non-municipal, non-domestic water supplies for 139 records. Six records represented recreational water uses or earth exchange systems.

Although most groundwater users in the valley are represented in the database, it is assumed that some users could not be identified. Agricultural users in particular may represent a significant component of additional groundwater use in the valley, not tabulated in the Groundwater Use Database. It is anticipated that additional records will be added as they are identified over time.

Groundwater use estimates and pumping records were available for 46 records, and water use was calculated for an additional 121 records based on survey data. Facility-type calculations accounted for 358 groundwater use records. Eleven records were assigned based on the permitted water withdrawal rate, and 26 records were assigned based on the pumping test rate. Survey data was not available for many industrial users in the database.

Figure 2 shows daily groundwater withdrawal rates for each sector within the Annapolis Valley. Potable water supplies accounted for the most intensive withdrawal rates (43%), followed by industrial users (28%). Industrial uses were estimated based on permitted withdrawal rates and pumping test rates, which may in some cases have resulted in overestimation of the actual withdrawal rates.
Agricultural uses accounted for just 12% of the total. This may in part reflect the fact that many farms did not respond to the questionnaire and are not accounted for in the database.

Table 1 provides a summary of water use data from the Groundwater Use Database. Use of groundwater for potable water supplies predominates in all sub-watersheds, particularly in the Allains River, Moose River, Pereau, Gaspereau, and Coastal watersheds where industrial activity is limited. Industrial groundwater use, accounting for 28% of all water withdrawals in the Valley, is concentrated in the Annapolis, Cornwallis, Canard, and Habitant sub-watersheds.

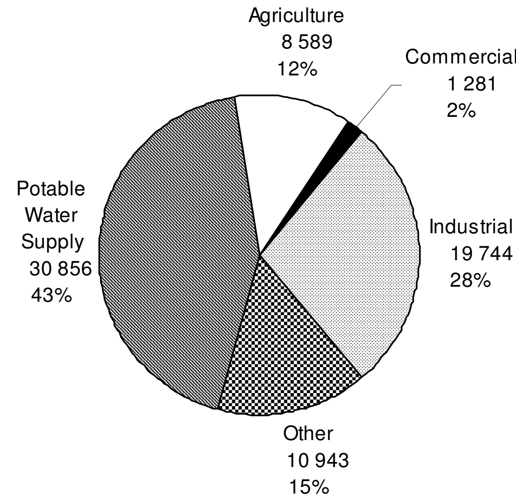

Figure 2. Daily groundwater demand (m^3/day) in the Annapolis Valley, NS, grouped by water use sector.

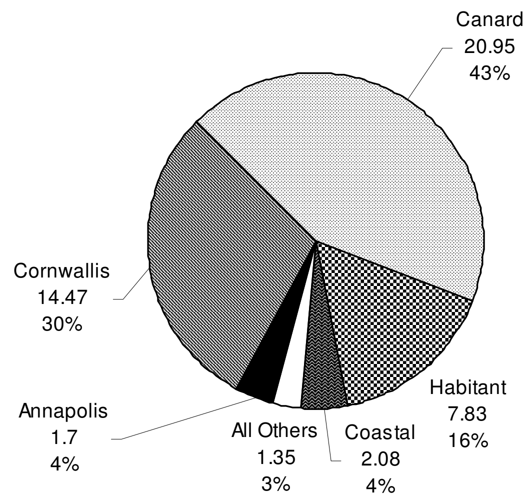

Figure 3. Normalized yearly consumptive use (mm/year) of groundwater in the Annapolis Valley, NS, grouped by sub-watershed.

Figure 3 shows normalized groundwater consumptive use rates for each sub-watershed. By normalizing groundwater withdrawal rates according to sub-watershed areas, the intensity of use is demonstrated. This figure can be further modified by applying the consumptive use coefficient to each record. The Canard watershed shows the most intensive use (43%), followed by the Cornwallis (30%) and Habitant (16%) watersheds.

Table 1. Summary of Groundwater Use Data for each Secondary Watershed and Groundwater Use Sector

Primary Watershed	Sub-Watershed	Daily Groundwater Use by Sector (m^3/day)					Sub-Total
		Water Supply[1]	Agriculture	Commercial	Industrial	Other	
Annapolis	Annapolis	6 677	1 869	568	5 585	1 538	16 237
	Allains River	181	8	14	0	2	205
	Moose River	231	15	1	0	66	313
	Coastal	3 958	1 541	97	65	193	5 855
	Sub-Total =	11 047	3 433	681	5 651	1 798	22 610
Gaspereau	Cornwallis	16 941	2 479	424	9 697	8 191	37 733
	Canard	1 098	280	13	2 680	71	4 142
	Habitant	567	647	101	901	53	2 268
	Pereau	70	3	0	0	0	72
	Gaspereau	1 134	648	19	0	216	2 017
	Coastal	0	1 098	43	815	613	2 569
	Sub-Total =	19 809	5 155	600	14 093	9 145	48 802
	Grand Totals =	30 856	8 589	1 281	19 744	10 943	71 412

[1]Potable Water supply for municipal utilities and private domestic users

These areas are concentrated in the eastern part of the Valley, which serves as a hub for collection and processing of Valley products and transport to receiving areas. Census data show that the population of Kings County increased between 2001 and 2006, whereas the population of Annapolis County decreased. A further breakdown of normalized groundwater consumptive use is shown in Table 2.

Table 2. Yearly Groundwater Consumptive Use Normalized to Watershed Area

Primary Watershed	Sub-Watershed	Yearly Groundwater Consumption (m^3)	Watershed Area (ha)	Normalized Groundwater Consumption (mm/year)
Annapolis	Annapolis	2 720 195	160 186	1.70
	Allains River	15 998	14 476	0.11
	Moose River	22 696	6 570	0.35
	Coastal	203 830	46 364	0.44
	Sub-Total =	2 962 719	227 597	1.30
Gaspereau	Cornwallis	5 215 398	36 045	14.47
	Canard	1 115 497	5 323	20.95
	Habitant	431 981	5 517	7.83
	Pereau	5 548	851	0.65
	Gaspereau	124 460	52 011	0.24
	Coastal	551 096	33 637	1.64
	Sub-Total =	7 443 981	133 385	5.58
	Grand Totals =	10 406 700	360 982	2.88

Geographic and economic features have concentrated packaging and food processing industries in the mouth of the valley at its eastern most extent. Consumptive use coefficients for bottled water and food processing tend to be relatively high, representing water that is packaged and sold in areas outside of the Annapolis Valley. These factors combine to place intensive pressure on the groundwater resources of the Canard, Cornwallis, and Habitant watersheds.

Whereas the Annapolis Valley as a whole may receive and store groundwater adequate to meet the needs of the Valley as a whole, location and intensity of use will present the greatest challenge for water management in coming decades. Not only is groundwater use concentrated within a relatively small region, but demands are highest in the late summer and early fall when dry periods overlap with the growth season followed by intensive periods of food processing.

A preliminary water budget for the Annapolis Valley was developed by the Geological Survey of Canada (GSC) in association with several other agencies (Rivard *et al*., 2006). The water budget incorporated climate data, soil and geological data, hydrological data, and groundwater data gathered from existing sources and as part of an extensive field program. The data were used to develop a groundwater flow model of Valley aquifers, and allowed for calibration of a water budget for the Valley, but groundwater withdrawals were not included in model calibrations. The georeferenced data in the Groundwater Use Database provides an opportunity to integrate groundwater use patterns into the Valley water budget. These combined tools will allow for the best possible analysis of the pressures placed on sub-watersheds, such as the Canard, Cornwallis, and Habitant.

The total daily groundwater use reported in the present study is 71 411 m^3/day. The GSC study (Rivard *et al*., 2006) estimated total groundwater demand to be between 31 000 and 404 000 m^3/day, placing the current estimate toward the lower end of this range. As additional agricultural users are added to the Groundwater Use Database the current estimate will increase, but it is likely to remain closer to the lower bounds of the estimate provided by the GSC.

Preliminary calculations based on work by the GSC indicate an average infiltration rate of 0.172 mm/year. When applied over the area of the Annapolis Valley, the aquifer yield could be as high as 361.2 million m^3/year. Assuming 50% of this infiltration is retained for base flow, 180.6 million m^3/year could theoretically be available for use, suggesting that just 9% of available water is currently used. Similar calculations applied over each of the sub-watersheds suggest higher proportions of use for the Canard (44%), Cornwallis (33%) and Habitant (17%) sub-watersheds. These figures are expected to increase when the water available is recalculated to account for the production capabilities of Quaternary and Wolfville Formation aquifers only.

The Groundwater Use Database provides a framework for the collection of additional and better quality groundwater use data, and provides a management tool that is increasingly recognized as necessary for the assessment of groundwater use patterns and sustainable allocation of groundwater resources.

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