ESTIMATION OF REGIONAL GROUNDWATER BUDGETS IN NOVA SCOTIA

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NOVA SCOTIA
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1. INTRODUCTION

In April 2007, the Province of Nova Scotia passed the *Environmental Goals and Sustainable Prosperity Act*. One of the targets set out in the act is the development of a comprehensive water resource management strategy by late 2010. This strategy will help the government make decisions about Nova Scotia's water resources, including groundwater, the source of drinking water for approximately 55% of Nova Scotians. Planning for the strategy highlighted the need to develop preliminary regional groundwater budgets to answer fundamental questions about groundwater use and availability, and to prioritize groundwater assessment activities.

The use of groundwater budgets as an indicator of groundwater sustainability has been applied at various scales. The regional scale is generally considered to be greater than 1000 km^2, the local scale is considered to be hundreds of square kilometres, and the site scale is considered to be less than 100 km^2 (Rivera, 2004). In Canada, regional groundwater systems are generally observed to be in steady-state conditions, whereas local groundwater systems may be both in steady-state and transient conditions. Groundwater flow at the site scale is typically in transient conditions due to pumping.

The objective of this work was to develop preliminary groundwater budgets at the regional scale, highlight potential sustainability issues at the local and site scale, and to make recommendations for an appropriate scientific framework to identify groundwater sustainability concerns.

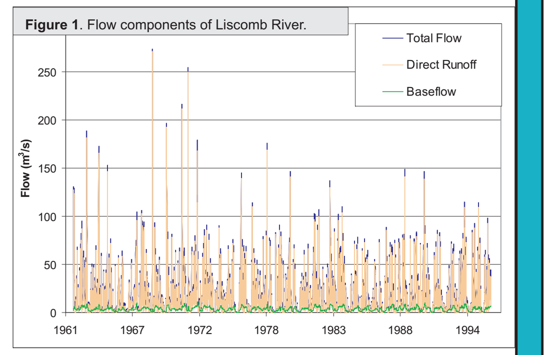
2. APPROACH

Regional groundwater budgets were estimated for 44 groundwatersheds across Nova Scotia. Groundwatershed boundaries were assumed to correspond to primary surface watershed boundaries. In Nova Scotia groundwater flow systems are relatively shallow (i.e. most groundwater flow occurs in the upper 150 m) and, therefore, are likely to be controlled by the hydraulic boundaries associated with primary watersheds. The province's geology does not lend itself to simple determination of large regional aquifer flow systems, and large scale groundwater flows between primary watersheds have not been observed. The budgets were developed for Nova Scotia's bedrock aquifers, and it was assumed that all groundwater use was from these aquifers (>90% of wells installed in Nova Scotia target bedrock aquifers).

Two major components are needed to derive groundwater budgets:

1. Estimated recharge to bedrock aquifers from precipitation
An integrated, indirect estimate of recharge is often derived using baseflow estimates from gauged watercourses. A literature survey was conducted and all available baseflow estimates in Nova Scotia were compiled. Additional flow data from Water Survey of Canada (WSC, 2009) gauging stations (>20 year continuous record, non-regulated) were compiled and baseflow estimates were generated using a digital recursive filter (Lim et al., 2005). Baseflow estimates were converted to recharge ratios, which could be used to estimate the distribution of groundwater recharge across the province.

Figure 1. Flow components of Liscomb River.

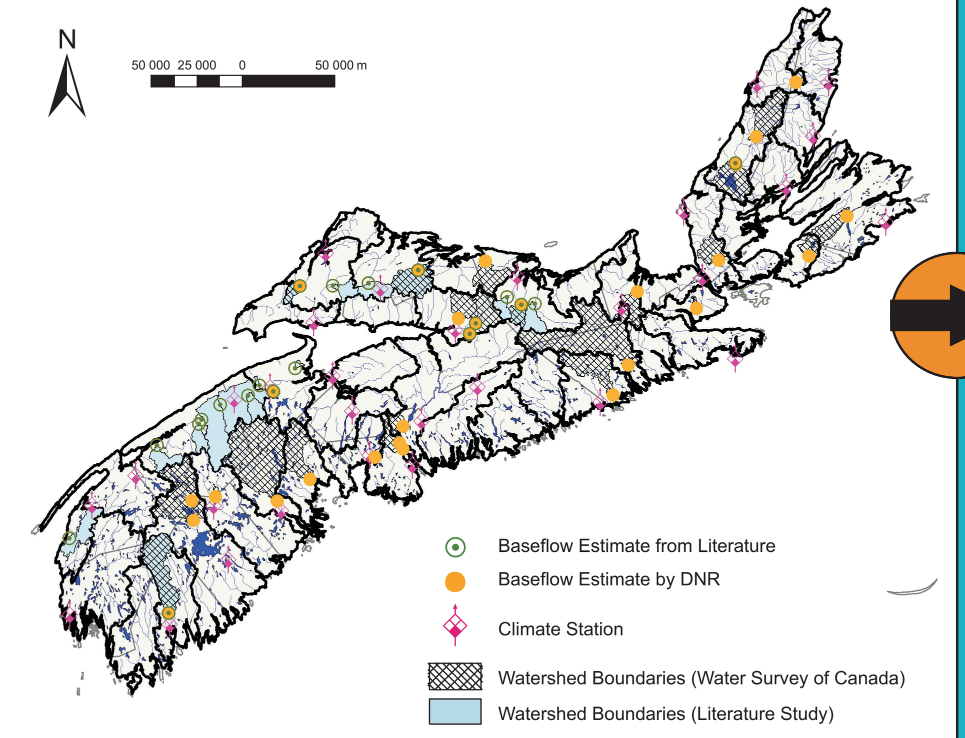


2. Estimated groundwater use (abstraction and consumption)
Groundwater users were plotted across the province, and for each user an estimate of groundwater use and consumption was assigned. Three major types of groundwater users were identified:

- municipal groundwater users,
- non-residential/unserviced groundwater users, and
- residential/unserviced groundwater users.

3. GROUNDWATER RECHARGE

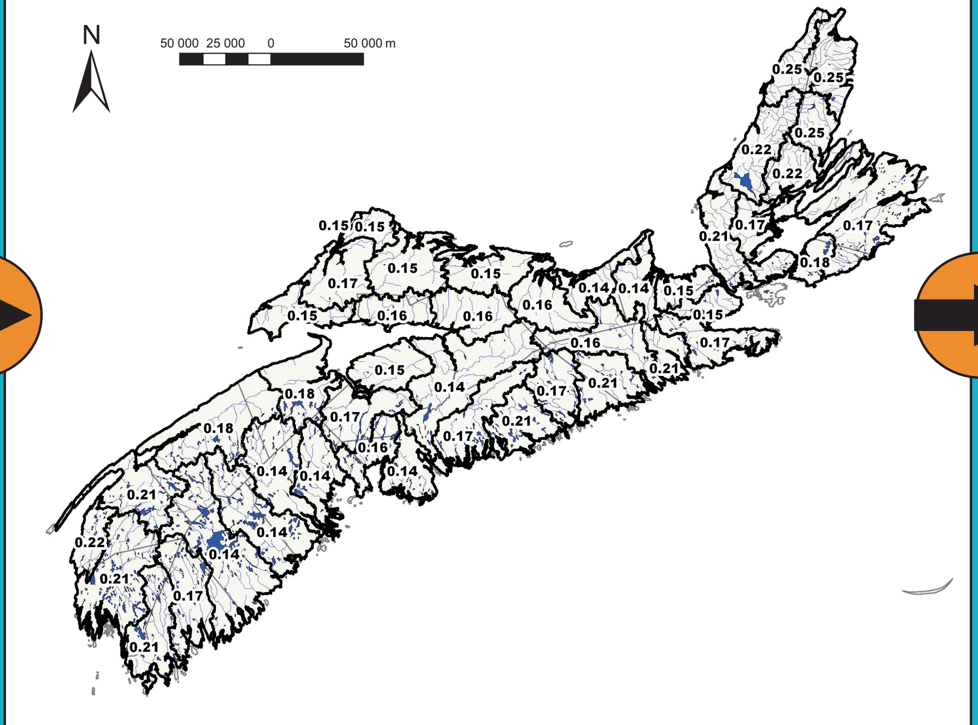
Figure 2. Recharge ratios, watershed area and precipitation stations.



A. Precipitation normals and estimates of baseflow were plotted across the province. Recharge ratios (r) were calculated as mean annual baseflow (q) divided by mean precipitation (P)(Environment Canada, 2009)

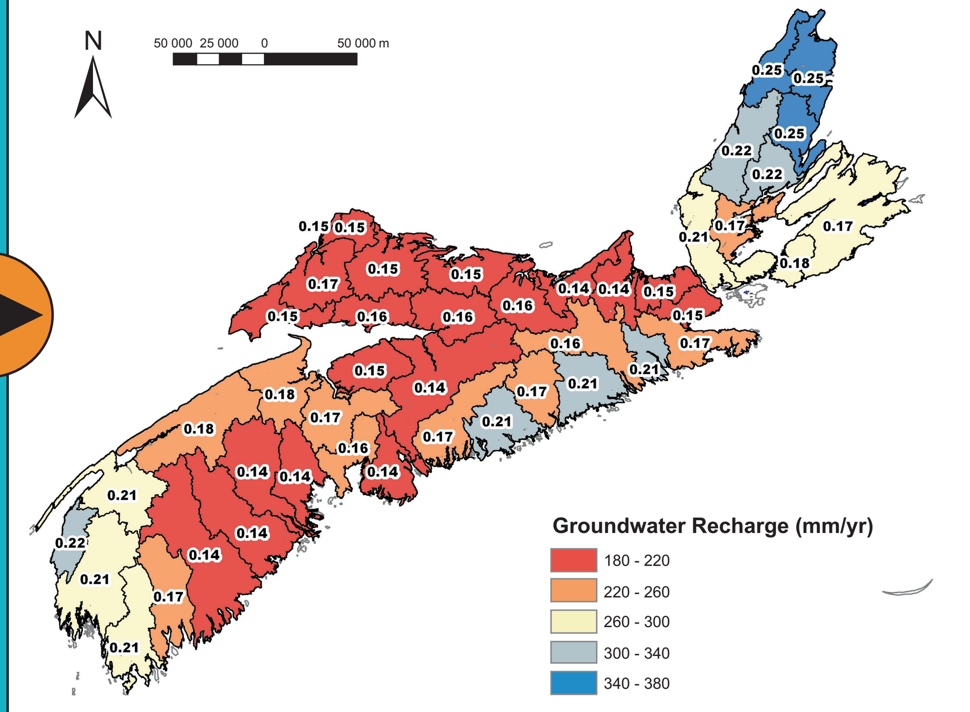
$r = q / P$

Figure 3. Estimated recharge ratios across Nova Scotia.



B. Primary watersheds were assigned a recharge ratio based on available baseflow estimates generated within the watershed area. Primary watersheds lacking available baseflow data were assigned the recharge ratio from a watershed with similar characteristics of slope, drainage density and geology.

Figure 4. Estimated groundwater recharge across Nova Scotia.



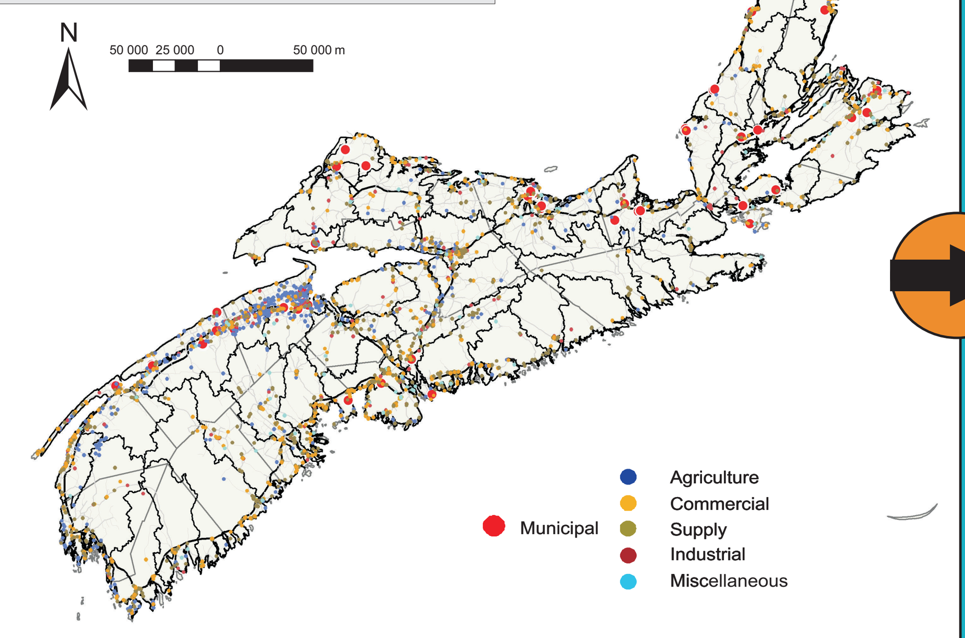
C. An ArcGIS® geoprocessing model was developed to calculate recharge to bedrock aquifers within each primary watershed area. The model considers precipitation patterns by way of euclidean allocation of precipitation normals within ecoregion boundaries. Recharge was calculated as:

Recharge (bedrock) = P x r x Watershed Area

Recharge was found to be highest in southwest Nova Scotia, along the eastern shore, and in Cape Breton, which is due to the greater observed mean precipitation and recharge ratios in these areas.

4. GROUNDWATER USE

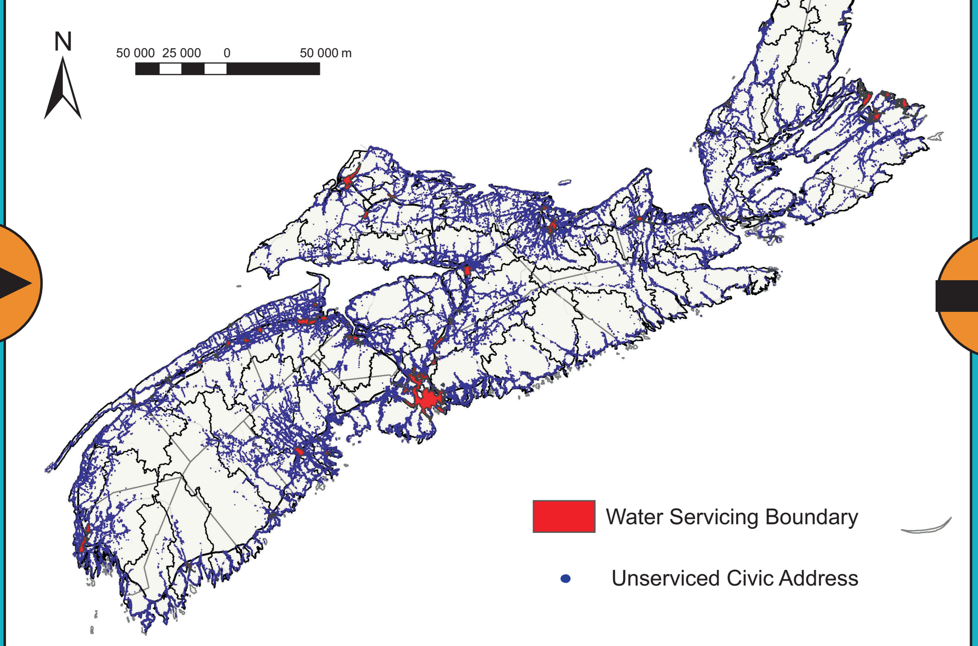
Figure 5. Municipal and non-residential unserviced groundwater users.



D. All municipal and non-residential/unserviced groundwater users were compiled into a spatial database (recorded from various existing government databases). Approximately 3000 non-residential users were identified, and divided into five major categories of use (Agricultural, Commercial, Supply, Industrial, Miscellaneous). These users were further subdivided into 76 subcategories. Categories of groundwater use were developed during a pilot groundwater use study in the Annapolis Valley (CBCL Ltd., 2009).

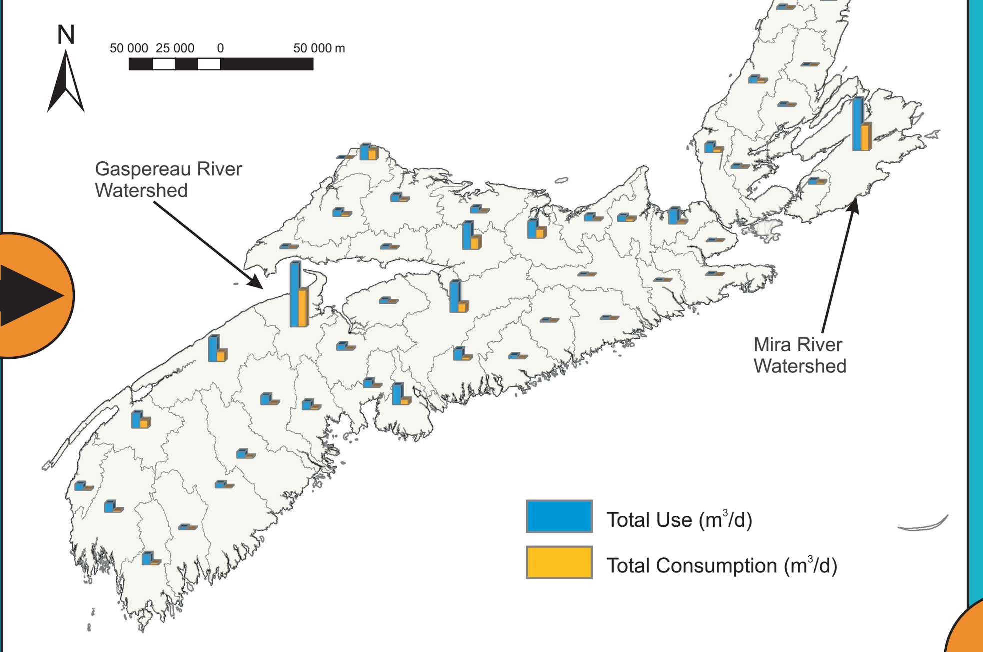
For each of the identified users, groundwater use was estimated by methods ranging from flow records (1% of users) to typical use figures for a given type of facility (55% of users).

Figure 6. Residential unserviced groundwater users.



E. Residential/unserviced groundwater users were estimated using the following approach:
i. municipal servicing areas were mapped;
ii. all civic address points outside of the municipal servicing area were counted by primary watershed (these civic addresses were all assumed to be groundwater supplied);
iii. the count of non-residential users (**D**) was subtracted from the count of civic address points;
iv. the remaining number of civic address points were multiplied by regional estimates of household density (Statistics Canada, 2006) and per capita water use (NRCAN, 1999), and total water use was calculated for each primary watershed.

Figure 7. Total and consumptive groundwater use.



F. Groundwater usage calculated in (**D**) and (**E**) was then totalled for each primary watershed. An estimate of consumptive use for each primary watershed was also calculated by multiplying total use by a consumption coefficient for each type of groundwater user. Consumption coefficients were compiled from literature sources during the pilot groundwater use study in the Annapolis Valley (CBCL Ltd., 2009).

The highest total groundwater use estimates were associated with the Gaspereau watershed in the Annapolis Valley area and the Mira watershed in Cape Breton, primarily due to the influence of large municipal groundwater withdrawals.

5. DISCUSSION

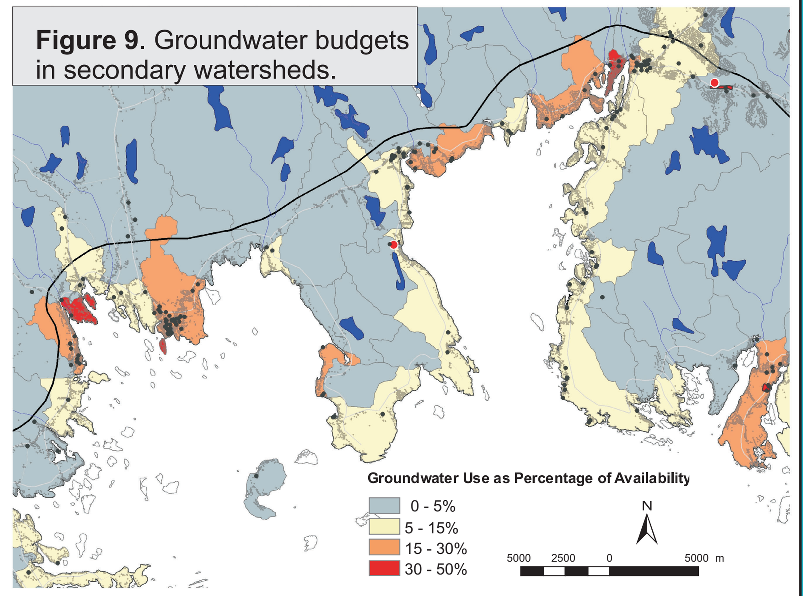
Various indicators have been used to characterize the sustainability of groundwater use (Rivera, 2007). A frequently used indicator is the annual renewable groundwater that can be exploited to avoid water depletion. The amount of available groundwater for abstraction in Nova Scotia is assumed to be no greater than 50% of the annual recharge (unless a water withdrawal applicant can demonstrate that additional withdrawals will not cause unacceptable effects). The 50% unallocated portion is retained to maintain baseflow for surface water bodies. Groundwater budgets can therefore be expressed as the total groundwater use (U_{out}) divided by ½ of the groundwater recharge due to precipitation (R_p): $U_{out} / 0.5 \times R_p$.
Due to high uncertainty with respect to groundwater usage (number of users, location and flow rates), a conservative approach of using total groundwater use rather than consumptive use is applied in the calculation.

Groundwater budgets for Nova Scotia's 44 major primary watersheds are shown in Figure 8, with groundwater use as a percentage of availability ranging from 0.1% to almost 13%. A greater percentage of available groundwater is used in watersheds with significant population centres, especially those watersheds that host municipal groundwater systems (e.g. Gaspereau watershed, Fig. 8). Although on a regional scale groundwater use is significantly less than groundwater recharge, groundwater quantity issues are demonstrated by the increasing number of water servicing requests (e.g. ~15 in Halifax suburbs) and well modifications to improve yield (e.g. well deepening, well stimulation). Locally, problems may occur where groundwater is used at a faster rate than the capacity of regional bedrock aquifers to transmit groundwater to areas of extraction. These concerns are exacerbated in coastal areas due to the potential for seawater intrusion, which has been reported by well drillers in various areas of the province. By applying the same methodology outlined in **A** through **G** to estimate groundwater budgets in secondary coastal watersheds, groundwater use as a percentage of availability is as high as 40% (Fig. 9).

Most of the province is underlain by bedrock aquifers where groundwater movement is controlled by fracture flow. These aquifers are sensitive to small changes in water level because they can result in the dewatering of critical groundwater-producing fractures. Local scale sustainability issues appear to be emerging in areas of medium to high density suburban unserviced growth that rely on these types of aquifers for water supply (e.g. Halifax suburbs).

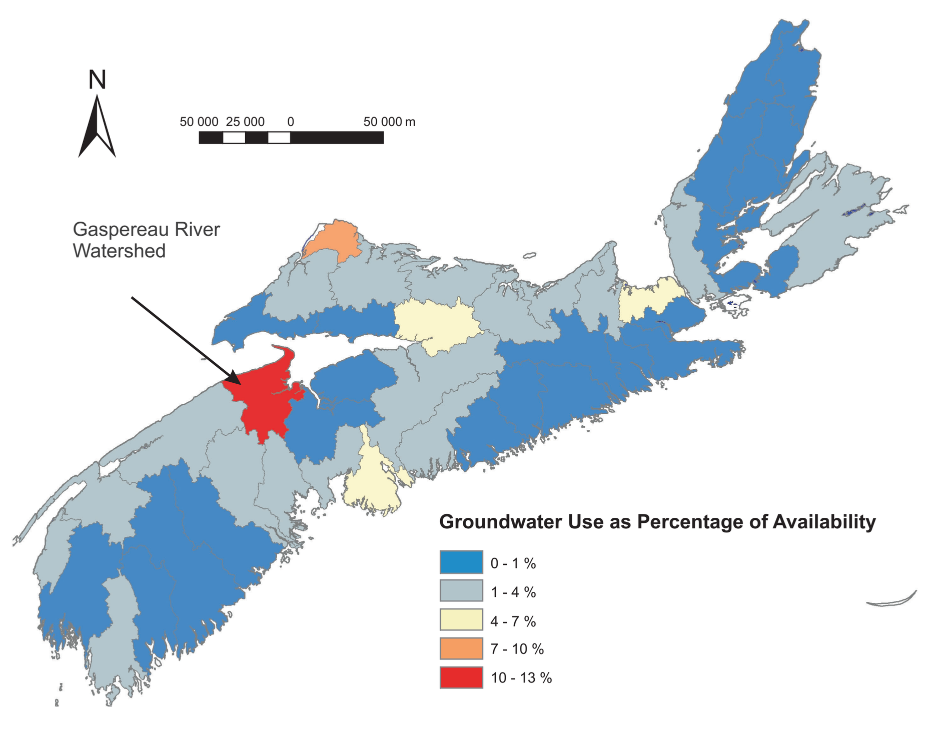
In addition to the uncertainty associated with groundwater use estimates, limitations of the study include poorly defined baseflow requirements, the assumption of steady state use and recharge, and the exclusion of surficial aquifer systems.

Figure 9. Groundwater budgets in secondary watersheds.



6. GROUNDWATER BUDGETS

Figure 8. Regional groundwater budgets.



G. Total groundwater use for each watershed expressed as a percentage of groundwater availability.

7. SUMMARY

1. The approach and spatial database developed during this study will permit the integration of additional and/or more refined datasets for the continuing evaluation of groundwater budgets.
2. On a primary watershed (regional) scale Nova Scotia is using groundwater sustainably.
3. Sustainable groundwater management requires water managers to recognize the importance of both regional and local scale assessment and management.
4.The following scientific framework is recommended to support sustainable management of Nova Scotia's groundwater resources (after Rivera, 2004):
   i. Sustainability Indicators: Develop and apply valid sustainability indicators that will identify existing and potential problem areas at a scale appropriate to planning decisions.
   ii. Monitoring: Expand the observation well network and target problem areas for new observation wells, track withdrawals of high capacity groundwater users and monitor changes in recharge.
   iii. Quantitative Assessment: Build knowledge of aquifers through systematic regional groundwater assessment studies with an initial focus on priority areas in terms of stress and state of existing knowledge base.
   iv. Groundwater Modelling: Build and calibrate numerical models to predict aquifer responses.

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