Science, policy and management of groundwater in Canada

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Canada is a very large confederation composed of 13 different jurisdictions; each jurisdiction manages water resources separately. There is no Canadian water policy; rather, there are water laws and water regulations for each jurisdiction and, until very recently not every jurisdiction had groundwater regulations. A common vision for groundwater resources assessment and management is slowly emerging.

Introduction

Canadians are blessed with a plenitude of freshwater resources, with the generous presence of lakes, rivers and aquifers. Yet the abundance mentality that used to prevail in the past decades has changed to a mentality of protection, preservation and sustainability. A recent national survey indicated that water is the number one issue for Canadians (Ipsos Reid, 2009). Water is widely recognised as a resource not only in the service of Canadians but also in support of a very vast number of ecosystems (such as wetlands). In addition to domestic use and nature's use, Canadians use water for economic development in a large number of industries and for agriculture. In fact, the use of water resources in Canada is much larger in the economic sector than in the domestic sector. Mining, energy and agriculture are the three main sectors using both surface and groundwater.

Canada's total freshwater withdrawals (surface water and groundwater) by all sectors is roughly 45 km3 per year, which is small compared to the total yearly "renewable" freshwater in Canada (3,281 km3) (Rivera, 2014). Nevertheless, we should be careful when considering these numbers because of geography, population distribution, and other factors. Most of the runoff from Canadian rivers (60%) drains north and is "lost" into oceans, while most of our population (85%) lives along the southern border with the United States. Furthermore, Canada does not have the installed dam's capacity, with its present infrastructure, to capture runoff. That is one of the reasons why the use of groundwater for domestic purposes has increased so much over the past three decades—from 10% in the late 1960s to 30% in the 2000s (Fig. 1).

Most water withdrawals come from surface water with ca 44 km3 per year, while total groundwater use in Canada is ca 1 km3 per year (Rivera, 2014), mostly withdrawn for domestic and agricultural purposes. Nearly 30% of the Canadian population uses groundwater for domestic drinking water, and trends indicate that future groundwater use will continue to increase at a rate faster than that of surface water use (Fig. 1). Possible explanations for such an increase are (a) abundant freshwater at shallow depths, (b) generally good water quality in aquifers, and (c) the fact that acquisition facilities for groundwater are faster and cheaper to build and maintain.

The single largest disadvantage about groundwater, as compared to surface water, is that there is not enough information at regional scale. The knowledge gaps at regional and national scales are groundwater recharge and discharge, its interactions with surface water and ecosystems, its volume in storage, vulnerability, and sustainable yields. However, at the local level (well scale), where groundwater is critical for economic development, the resource is studied in more detail and is better understood.

The yearly use of 45 km^3 of water by Canadians does not come without issues. Water quality, climate variability, climate change, point source and distributed contamination, water-use conflicts, and transboundary issues are amongst the problems Canadians need to take into consideration, on a yearly basis. Thus, it seems that the main concern of Canadians is not water quantity but water quality, sustainability and vulnerability. A trend is slowly emerging whereby alliances involving scientists, civil society and policy makers are considering a common vision for groundwater resources assessment and management and protection against pollution. This article describes science, policy and management aspects and issues of groundwater in Canada. We discuss how we are enhancing sustainable groundwater resources management in Canada in an integrated manner (all jurisdictions) with cooperation, knowledge generation, shared management and governance.

Application of Water Sciences in Canada

Groundwater is defined as water below the water table, which moves in response to gravity and hydrostatic pressure. It results from precipitation and surface water that seep into the ground, filling voids and fractures in rocks

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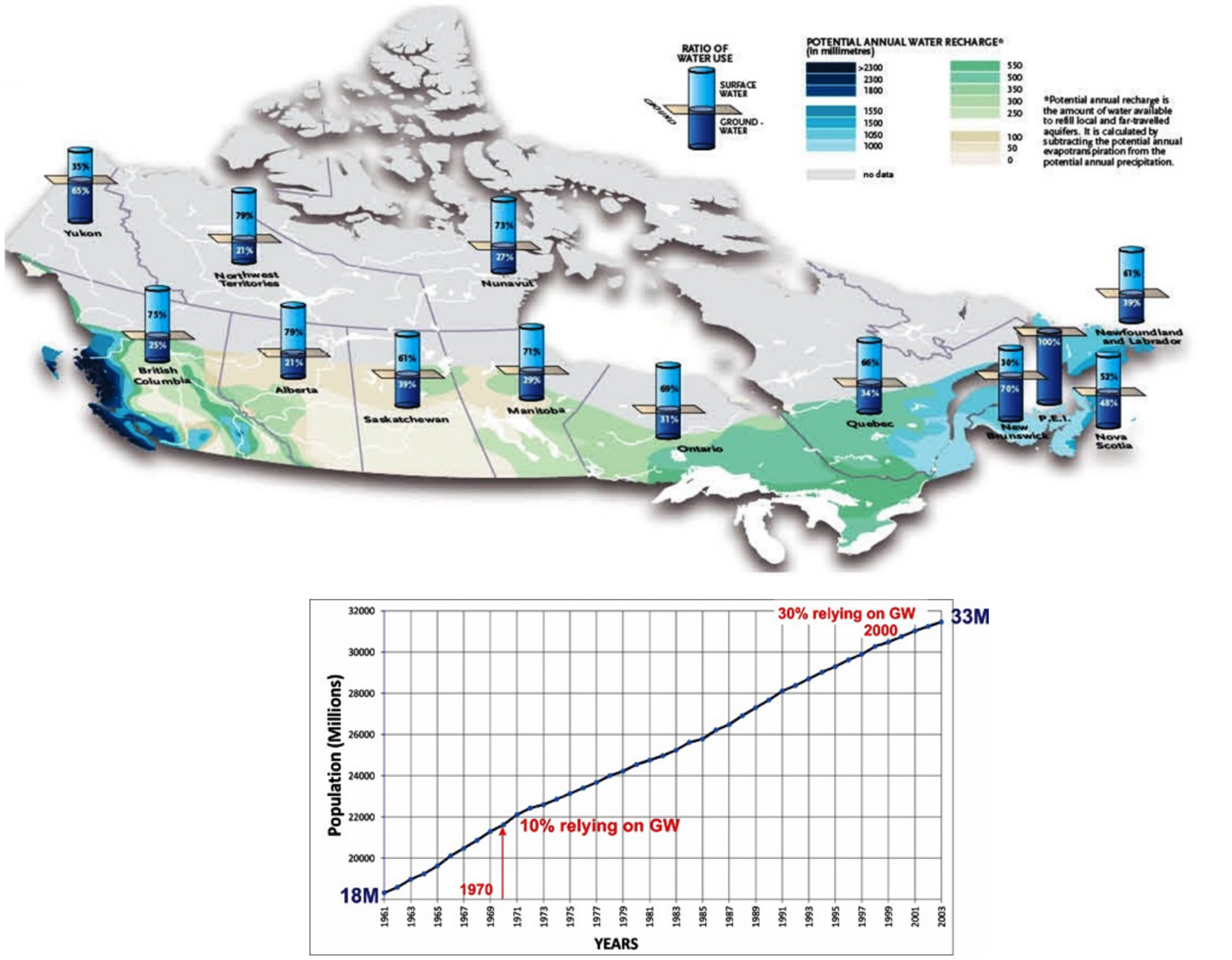

Figure 1. Canada's groundwater resources (A); and groundwater use (B).

Source: Canadian Geographic, adapted from Rivera (2014)

to form aquifers. Ground and surface water are inextricably interconnected since the amount and availability of groundwater influence surface water availability via groundwater discharge into rivers, lakes, wetlands, and reservoirs. For many Canadian rivers, groundwater plays an important role in sustaining base flow in rivers. Groundwater is generally measured at local (individual wells) or aquifer scales (hundreds of km^2). In Canada, the principal source of data originates from most provincial government agencies consisting of water well records, hydrogeological maps, groundwater levels, information on groundwater extraction, and geophysical logs (CCME, 2010). Although provincial wells represent direct data for the estimation of aquifer recharge, they are localized and typically short (around 30 years with none longer than 50 years) (Rivard et al., 2009). They are not always located near climate and/or streamflow stations, making comparisons with surface conditions difficult; they can also be affected by groundwater pumping (Rivera et al., 2004). Recently, however, aquifer-mapping remote sensing - based has become significant and shows great potential (Rivera et al., 2015).

In Canada, groundwater recharge rates typically are not more than 7% of annual precipitation, but are difficult to quantify. Normally, the measuring of precipitation is required followed by the performance of a water balance through the estimation of all the other surface water fluxes (runoff, evaporation, transpiration). There are regional differences clearly marked in groundwater recharge across the Canadian landmass. Groundwater recharge in eastern Canada varies between 1000 and 1500 mm/yr.; the Prairies region between 50 and 400 mm/yr; western Canada averages 500 to 2000 mm/yr.; and there is not enough information for northern Canada (Allen et al., 2014). Groundwater discharge occurs through direct discharge to surface water bodies, flow through formations, or pumping from a well. In semi-arid regions such as the Canadian Prairies, direct evaporation and/or evapotranspiration from the shallow water table is the primary discharge mechanism. Discharge is also difficult to quantify, especially in areas dominated by well pumping or evaporation.

Resource assessment, modeling, monitoring and mapping

Federal government and most of the provincial governments use a wide set of tools to assess groundwater resources: hydrogeology, geomatics, geology, geophysics, geochemistry, groundwater modeling, isotope fingerprinting, aquifer mapping, and groundwater data management and dissemination. Currently the department of Natural Resources Canada is the lead for aquifer mapping and groundwater quantity and assessment strongly relaying in geology, geophysics and geomatics as its main tools.

Modeling of the Canadian water cycle, water resources and disasters (drought and flood) are among the most advanced studies at regional to national scales using remote sensing (Wang et al., 2013; Huang et al. 2012). Multi-satellite, interdisciplinary approaches to assessing water balance closures, groundwater storage changes and environmental change impacts (including climate change) are part of the current scientific endeavors of federal government, together with the strong cooperation of universities and provinces.

Furthermore, great efforts are being developed to generate national and international hydrographic networks and standardized data on aquifer and groundwater, which are easily accessible through the Internet using a Groundwater Information System (GIN, 2017). New activities are underway to include groundwater data on transboundary aquifers located along the Canada-US international border.

Policy and Management Water Issues in Canada

Being such a large Federation represents a challenge for Canada: close to 10 million km2 of landmass, 10 Provinces, 3 Territories, 3 Oceans, and ashared water management mandate. Water resources management is shared by 13 jurisdictions, divided in four levels of government. At the Federal level, there are at least 20 federal departments involved in water management. The top five departments leading some aspects of water resources are: Environment and Climate Change Canada (surface and groundwater quantity and groundwater quality), Natural Resources Canada (groundwater quantity), Agriculture and Agrifood Canada (surface and groundwater quantity and quality), Health Canada (surface and groundwater quality), and Fisheries and Oceans (Water regulations for federal lands).

Provinces have the principal lead on water management and protection within their boundaries, though they have delegated certain water activities to municipalities or local agencies. As a result of multiple players and responsibilities, data and knowledge are dispersed across jurisdictions and entities. This makes management and access to data for decision-making one of the most important challenges.

The importance of water -environmentally and strategically- justifies a federal presence. The Government of Canada has broad powers over environmental issues. It also has authority when it comes to "peace, order and good government", when there is an issue of "national concern" (Côté, 2006). Shared federal-provincial responsibilities include water issues relating to agriculture, health, and the environment. Various regional and national workshops, as well as reports from expert panels, have recognized that gaps in groundwater knowledge might hinder good groundwater management and governance (CCA, 2009).

Social participation

Participation of society on government-related decisions has always been a Canadian trait. It has been recognized that the best management practices on groundwater governance require the review of socioeconomic and cultural issues. For instance, current activities led by CCME (2010) incorporate shared rights and obligations with a common vision for sustainable use of groundwater, in promoting science in the decision-making process. Frameworks of public governance supported by regulations are slowly emerging to build trust and increase cooperation. For example, the Quebec PACES program (Programme d'Acquisition de Connaissances sur les Eaux Souterraines (MDDELCC, 2009) addresses groundwater sustainability and provides useful context for the implementation of the CCME's Groundwater Sustainability Assessment Approach (GSAA). The Quebec PACES program is creating local groups with specific mandates and technical and administrative support.

Conclusions

The aim of this article was to describe science, policy and management issues of groundwater in Canada. There was also the intention to show how the country is enhancing sustainable groundwater resources management in an integrated manner. Canada is a very large confederation composed of thirteen different jurisdictions where each jurisdiction manages water resources separately. Gaps in groundwater knowledge are recognized by all governments. There is no single institution in Canada dedicated to all aspects of groundwater; nonetheless, the last decade has seen an emerging trend where institutions and organizations have been including groundwater in their plans more explicitly (research, management and governance). Strong science-based regulations are the preferred choice of most provinces for water management and governance. Public consultation, collaboration, shared management and governance are Canadian traits of applying a code of values and ethics in all aspects related with governance. Despite the scale and diversity of the country, and its highly decentralized government, Canada seems to be coming together as a country with the same (almost) water resources vision, management and governance. The future for acquiring data and knowledge on the aquifers and groundwater resources of Canada looks promising.

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