PREFACE TO THE SPECIAL ISSUE

Groundwater – Surface Water Interactions in Canada

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Canada is a water-rich country. Its rivers and lakes comprise 7% of the global annually renewable surface freshwater supply (Rivera 2014). Although it is very difficult to quantify available groundwater resources, it is estimated that there is more groundwater in Canadian aquifers than surface water in rivers and lakes, similar to what is observed elsewhere (Rivera 2014). In the generally humid and cold Canadian climate, groundwater-surface water interactions are omnipresent (Devito et al. 1996; Langston et al. 2013; Brannen et al. 2015; Foster and Allen 2015), but remain relatively seldomly studied. The Canadian Council of Academies (CCA) (2009, p.185) expert panel on groundwater concluded that a sustainable use of groundwater resources requires that "groundwater and surface water be characterised and managed as an integrated system within the context of the hydrological cycle in a watershed or groundwatershed". It is only reasonable to expand this recommendation to surface water resources.

This has been a growing concern in the last two decades as groundwater and surface water are increasingly considered as a single resource (Winter et al. 1998). Using integrated approaches to understanding and manageing water resources is increasingly important given the growing demand for water related to development, industry and agriculture (United Nations Educational, Scientific and Cultural Organization [UNESCO] 2015), and the superimposed stress of a changing climate (Intergovernmental Panel on Climate Change [IPCC] 2014). These issues are relevant in a variety of geological and climate conditions around the world, especially in densely developed areas and in dry climates (IPCC 2014). However, the stresses on groundwater–surface water connections should not be overlooked in water-rich countries such as Canada, despite water scarcity not imposing a significant hindrance to development in most regions. It has been reported that some Canadian regions have only limited groundwater and surface water reservoirs (Cook and Bakker 2012). Moreover, water quality is a growing concern that will be exacerbated in a changing climate (e.g. Crossman et al. 2013), and groundwater-dependent ecosystems are increasingly threatened by human development (e.g. Smerdon et al. 2012).

Groundwater-surface water interactions are most often thought of as the connection between aquifers and rivers. In temperate and humid climates, such as those found in Canada, groundwater most often flows into rivers, where it contributes to maintaining river low flows during dry periods, whereas the opposite is more common in dry climates. This groundwater influx provides thermal refugia and supplies nutrients for a variety of plant and animal species (e.g. Kurylyk et al. 2014). Groundwater-wetland and groundwater-lake connections are expressions of similar processes where an aquifer provides water to a shallow surface water reservoir or vice-versa (e.g. Winter 1999). When water flows from an aquifer to a wetland or a lake, it regulates humidity and temperature conditions which sustain rich ecosystems (e.g. Hoffmann et al. 2009). When water flows from a wetland or lake to an aquifer (typically in drier climates), it contributes to the recharge of underground reservoirs. Submarine groundwater discharge (SGD) is yet another flowpath through which aquifers provide water to marine environments (e.g. Burnett et al. 2003). Salt water intrusion is the corresponding opposite pathway of this connection (e.g. Ferguson and Gleeson, 2012). SGD is extremely important in coastal areas around the world, where a large proportion of the world's population lives.

Considering the importance of groundwater-surface water interactions, relatively little is known about the geological and climate conditions under which these exchanges prevail, how and where they occur, and what affects their stability. More knowledge on this topic is necessary to provide essential information on Canadian water resources, and crucial new data for integrated water resources management. The purpose of this Special Issue was to highlight the variety of issues related to groundwater-surface water interactions, and recent developments in the methods used to study these interactions under a range of conditions across Canada. The inspiration for publishing this Special Issue in the Canadian Water Resources Journal was the large number of high-level contributions to the Groundwater-Surface Water Interactions session of the GeoMontreal2013 conference, which was also the 11th joint Canadian Geotechnical Society - International Association of Hydrogeologists Canadian National Chapter (CGS-IAH-CNC) conference, held in Montreal in October 2013. Many of the authors who contributed to this session responded positively to the invitation, and were joined by other Canadian experts on groundwater-surface water interactions. This Special Issue contains eight contributions from university researchers and private consultants on topics that are relevant to regions across Canada.

The highly diversified geology and climate of Canada provide a large variety of aquifer types, and recharge and groundwater flow conditions (Rivera 2014). A large array of river flow conditions are also observed throughout the country. As a result, groundwater-surface water interactions are expected to vary significantly from one region to the next, as well as over time. In eastern Canada, Chaillou et al. (2016) studied SGD in the Magdeleine Islands archipelago of Quebec (Maritimes Permo-Carboniferous Basin of the Northeastern Appalachian Geological Province), where groundwater resources are strictly dependent on precipitation and flow in the Atlantic Ocean. Chaillou et al. (2016)

provide a first estimate of volumetric and chemical groundwater fluxes to a coastal Canadian ocean.

Similar to other regions of the world, many Canadian rivers have undergone significant changes over the last several decades as a result of regulation, drainage systems, dyking and removal of flood retention areas (World Wildlife Fund [WWF] 2009). When still present, natural riparian conditions can be the focal point of a variety of aquifer-river connections, providing water storage during floods, and rich ecosystems in an otherwise homogeneous agricultural landscape (e.g., Bullock and Acreman, 2003). Buffin-Bélanger et al. (2016) highlight the complex relationship between flood event discharge and groundwater flooding in the gravelly floodplain of the Matane River (Gaspésie region). Their work provides important new data on how groundwater floodwaves could be included in flood mapping. Larocque et al. (2016) illustrate how geomorphic setting can control groundwater-surface water exchanges in riverine wetlands located in the Matane River floodplain, and at the limit of the St. Lawrence Lowlands/Appalachian Foothills of the Montérégie region (Champlain Sea silt and clay deposits).

A better understanding of aquifer recharge is necessary to predict groundwater discharge to surface reservoirs. Because of the ever increasing pressure from urban sprawl, various industries, and industrial agriculture, river low flows, wetlands, and springs can be threatened by drainage and by contracting recharge areas. Understanding the connections between recharge and discharge is crucial to implementing better management and conservation methods. Levison et al. (2016) investigated groundwater recharge and discharge through rivers and springs in the Covey Hill area of southern Quebec, at the northernmost extension of the Adirondack Mountains (Potsdam Group of the Covey Hill Formation). The improved understanding of how the natural system responded to a wide range of climatic conditions over the last century provides insight into its resilience to future climate change. Marchildon et al. (2016) studied Ecologically Significant Groundwater Recharge areas (ESGRA) of the Oro Moraine in the glaciated landscape of southern Ontario. ESGRAs are areas of land supporting hydraulic pathways that sustain sensitive groundwater-dependent ecosystems, such as coldwater streams and wetlands. Identifying ESGRAs provides a means to protecting them from development and ensuring the maintenance of the groundwater-fed ecosystems they support. Through a synthesis of existing science, tools and experience, Bradford (2016) provides an important overview of how to avert the degradation of southern Ontario's wetlands.

Alpine watersheds represent an important source of water in many areas of the world, where they contribute to the sustainance of downstream water sources. The contribution of groundwater to the total flow of alpine rivers is still poorly understood. Paznekas and Hayashi (2016) provide new insight into this question through their investigation of the physiographical factors that control the hydrogeological behavior of mountain river basins in the Rocky and Columbia Mountain Ranges. Their study shows that geological and hydraulic properties are the dominating factors influencing winter flows in the studied alpine rivers.

Temperate climate valleys are regions of intensive agricultural production worldwide. These often develop in Quaternary deposits, which host extensive and productive aquifers to which river systems are dynamically connected. By maintaining low flows, groundwater contributions to these rivers contribute to maintaining healthy ecosystems. Middleton et al. (2016) compared two watersheds which drain the Abbotsford–Sumas sand and gravel aquifer in the Lower Fraser Valley of southwest British Columbia, and show that local conditions can influence aquifer-river connections.

State-of-the-art methods to study groundwater-surface water interactions are numerous and diverse (see Kalbus et al. (2006) for a summary). The papers in this Special Issue highlight an array of available methods, and examples of how and under what conditions they can be used. Among the field methods typically used to identify and quantify the interactions, contributions included here use flow rate and water level monitoring (Larocque et al. 2016; Middleton et al. 2016; Paznekas and Hayashi 2016), water temperature as an indicator of groundwater inflow to a river (Larocque et al. 2016; Middleton et al. 2016), and dissolved organic and inorganic carbon (Chaillou et al. 2016). Time series analyses of water levels and water temperature rivers and aquifers are used to identify connections between underground and surface reservoirs (Buffin-Bélanger et al. 2016; Larocque et al. 2016). Groundwater flow modeling and particle tracking are integrative approaches which require abundant data to describe the studied conditions; data are usually acquired through aquifer characterization. Models can be used to understand flow directions to surface features (Marchildon et al. 2016) and to quantify groundwater discharge to rivers and springs (Levison et al. 2016). They are particularly relevant to understanding past and future conditions, which can be linked to climate change scenarios, as illustrated by Levison et al. (2016). Distinct insight into current conditions and a clearer understanding of changing conditions in groundwater-surface water interactions can also be gained through the interpretation of policy statements (Bradford 2016). This approach is particularly interesting as a means of providing science-based understanding to management approaches.

The topics covered by the articles in this Special Issue are necessarily incomplete in that they do not address all possible conditions that can be encountered in Canada, nor all of the methods that could be applied. Other reviews have reported wider geological and climatic conditions, flow connections between different reservoirs and at different scales, and a more exhaustive array of methods (e.g. Brunke and Gonser 1997; Sear et al. 1999; Amoros and Bornette 2002; Krause et al. 2011; Krause et al. 2014). Nevertheless, we believe that this Special Issue provides a valuable snapshot of the current, state-of-the-art knowledge on groundwater-surface water interactions across the country. It also provides new knowledge on the conditions under which these interactions occur, as well as the methods that can be used in given situations. It is our hope that it will generate interest in the initiation of new projects on this matter of critical importance for integrated water resources management.

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