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Review

Synthesis review on groundwater discharge to surface water in the Great Lakes Basin

Kurt C. Kornelsen [a,*], Paulin Coulibaly [a,b,1]

[a] School of Geography and Earth Science, McMaster University, Hamilton, Ontario L2S 4L8, Canada
[b] Department of Civil Engineering, McMaster University, Hamilton, Ontario L2S 4L8, Canada

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ABSTRACT

Groundwater in the Great Lakes Basin (GLB) serves as a reservoir of approximately 4000 to 5500 km^3 of water and is a significant source of water to the Great Lakes. Indirect groundwater inflow from tributaries of the Great Lakes may account for 5–25% of the total water inflow to the Great Lakes and in Lake Michigan it is estimated that groundwater directly contributes 2–2.5% of the total water inflow. Despite these estimates, there is great uncertainty with respect to the impact of groundwater on surface water in the GLB. In terms of water quantity, groundwater discharge is spatially and temporally variable from the reach to the basin scale. Reach scale preferential flow pathways in the sub-surface play an important role in delivering groundwater to surface water bodies, however their identification is difficult a priori with existing data and their impact at watershed to basin scale is unknown. This variability also results in difficulty determining the location and contribution of groundwater to both point and non-point source surface water contamination. With increasing human population in the GLB and the hydrological changes brought on by continued human development and climate change, sound management of water resources will require a better understanding of groundwater surface–water interactions as heterogeneous phenomena both spatially and temporally. This review provides a summary of the scientific knowledge and gaps on groundwater–surface water interactions in the GLB, along with a discussion on future research directions.

Contents

* Corresponding author. Tel.: +1 905 525 9140x27875.
E-mail addresses: kornelkc@mcmaster.ca (K.C. Kornelsen), couliba@mcmaster.ca (P. Coulibaly).
[1] Tel.: +1 905 525 9140x23354.

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Introduction

The Great Lakes Basin contains approximately 20% of the world's supply of fresh surface water and serves as a groundwater reservoir which Granneman et al. (2000) estimated to be 4000 km^3 of groundwater for the entire GLB and Coon and Sheets (2006) estimated to be 5500 km^3 of groundwater for the U.S. portion of the GLB only. Traditionally, groundwater and surface water stores have been considered as independent resources from the perspective of both water quality and quantity. However, the inter-connections between groundwater and surface water create a requirement to consider both as a single water resource (Winter et al., 1998) and there is a need to develop an integrated understanding of groundwater–surface water interactions (GWSWI), including riparian, hyporheic and biogeochemical processes that impact groundwater. Groundwater discharge is estimated to directly contribute to approximately 2–2.5% of the annual water budget for Lake Michigan (Feinstein et al., 2010; Granneman et al., 2000) while discharge from groundwater to tributaries is responsible for an estimated 40–75% of the tributary inflow to the Great Lakes and is therefore important for the overall health of the Great Lakes ecosystem (Neff et al., 2005). However, determining the correct impact of the role of groundwater in the Great Lakes Basin (GLB) is difficult as direct groundwater contribution is highly uncertain and poorly estimated (Neff and Nicholas, 2004) and baseflow separation estimates also vary widely as seen in Fig. 2 (Neff et al., 2005).

In light of the significant role of groundwater as a source to surface waters in the Great Lakes, there is a need for a thorough understanding of GWSWI in terms of water quantity as well as an understanding of the role played by GWSWI in the management of surface water quality in the GLB. Despite early recommendations for such an integrated understanding of GWSWI (IJC, 2010) the heterogeneity throughout the basin, lack of available data and limitations of research methods have hampered efforts to consider groundwater and surface water as a single resource. With increased pressures on water resources as a result of continued human development and the potential impacts of climate variability, a comprehensive baseline understanding of the role of GWSWI is critical for the forecasting, management and preservation of this important resource.

To promote a comprehensive understanding of the impact of groundwater on surface water in the GLB a review has been conducted which encompasses peer-reviewed scientific literature, reports and other studies specific to the Great Lakes or which are considered relevant for extension to the Great Lakes. The approach selected for the literature review was to search based on combinations of keywords 'groundwater', 'surface water' or 'groundwater surface water interactions' in combination with 'Great Lakes' and each of the Great Lake names individually. The material presented herein is derived from an unpublished report produced for Environment Canada (Coulibaly and Kornelsen, 2013) where specific emphasis was placed on the role of scale and spatial–temporal heterogeneity of groundwater discharge to surface waters in the Ontario portion of the GLB. Herein, the review covers the entire GLB.

Overview of groundwater–surface water interactions

The discharge of groundwater to surface water bodies occurs through a variety of flow pathways, the interaction of which is governed by relative potential of the groundwater table, the surface water level and the potential rate of flow (hydraulic conductivity) of the system. While there are many definitions of an aquifer, it is considered here in a loose sense to refer to subsurface areas (or geologic units) that can store and transmit water. It is also noteworthy that not all groundwater is stored in 'aquifers' as saturated zones occasionally form above what would traditionally be considered an aquifer. Generally, groundwater can provide a range of ecosystem goods and services such as water purification, maintaining ecosystem health and mitigation of erosion and floods (Herman et al., 2001). A brief overview of select groundwater–surface water interactions (GWSWI) is provided, however the reader is referred to Winter et al. (1998), Granneman et al. (2000) and Sophocleous (2002) for a more comprehensive description of the processes.

Groundwater, as a mobile part of the hydrosphere, can be loosely grouped into two categories, deep or regional aquifers, which underlay relatively large geographic areas and shallow aquifers which are local in scope. While both are sources of groundwater discharge, shallow aquifers represent shorter flow pathways, are more susceptible to contamination and provide a significantly larger contribution to surface waters (Granneman et al., 2000; Sophocleous, 2002; Winter et al., 1998). Infiltration of precipitation and surface water causes a rise in the water table, resulting in increased flow toward surface water bodies and producing baseflow in many streams. This process is reversed during dry periods when the water table lowers, decreasing or reversing groundwater flow. Lateral groundwater flow also occurs in the unsaturated zone, particularly following precipitation, where a rapid increase in the soil water content results in interflow (shallow subsurface flow) (Sophocleous, 2002). The build-up of pressure displaces 'old water', stored in the soil, into surface water bodies, producing a considerable

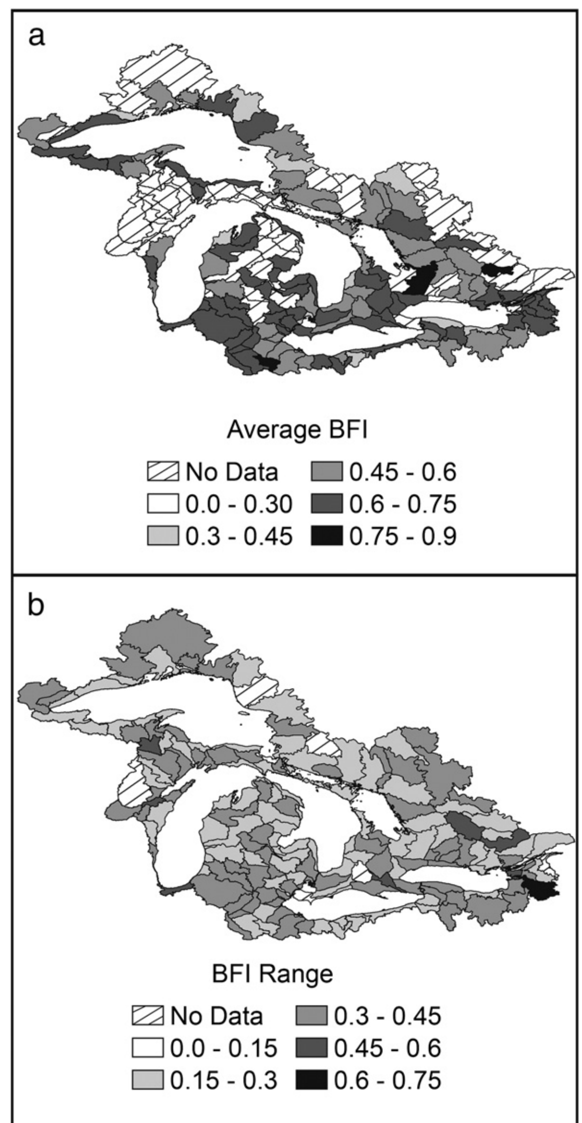

Fig. 1. Mean BFI (a) and the range of BFI values (b) produced by different hydrograph separation methods for each watershed using data from Neff et al. (2005).