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PII: S0075-9511(17)30118-4
DOI: http://dx.doi.org/doi:10.1016/j.limno.2017.04.006
Reference: LIMNO 25582

To appear in:

Received date: 1-6-2016
Revised date: 12-4-2017
Accepted date: 18-4-2017

Please cite this article as: Mithra-Christin Hajati, Mette Frandsen, Ole Pedersen, Bertel Nilsson, Carlos Duque, Peter Engesgaard, Flow Reversals in Groundwater-Lake Interactions: A Natural Tracer Study Using *rmdelta*^{18}O, *<![CDATA[Limnologica]]>* (2017), http://dx.doi.org/10.1016/j.limno.2017.04.006

Flow Reversals in Groundwater-Lake Interactions: A Natural Tracer Study Using δ^{18}O

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Abstract

Lake Hampen, (Central Jutland, Denmark) is located high in the landscape near a seasonal moving groundwater divide. The lake is regarded as a flow-through lake during average to wet weather conditions with a large catchment making the lake groundwater-dominated. Monitoring of δ^{18}O in mini-piezometers in the lake bed and wells at the lake shore and in the catchment was used to investigate changes in groundwater-lake interaction as a result of three years with below-average precipitation (2009-2011). It is demonstrated that the lake experienced a flow reversal, where the lake switched to being mainly a recharge lake during this period, before returning to a flow-through lake in early 2012. The observations correlate well with observed changes in hydraulic gradients. A 2D groundwater flow and transport model was used to simulate this natural tracer experiment in order to evaluate the extent and timing of the flow reversal as well as supply information during periods, where there were no δ^{18}O and hydraulic head data. The results show that δ^{18}O is a robust tracer for tracking the extent of flow reversals. Furthermore, time series of hydraulic heads (2007-2013) demonstrate that the lake experienced short-lived annual flow reversals typically during late summer.

Keywords: Groundwater - lake water interaction, flow reversal, recharge-discharge lake, groundwater divide, δ^{18}O, tracer, FEFLOW

1. Introduction

It is well known that the position of a lake in the landscape (high or low) may determine the relative importance of precipitation and groundwater inputs on the lake water budget and quality (Kratz et al., 1997). Lakes located high in the landscape and near recharge zones are more susceptible to seasonal changes in exchange fluxes with groundwater than lakes located lower in the landscape and in discharge zones. This is similar to concepts for rivers and how they are hydrologically connected to the upland regions (Hill, 1996). Within-season and year-to-year changes in weather and water withdrawal may cause boundaries of the hydrologic catchment of a lake located high in the landscape to change and move (Holzbecher, 2001), in which case the lake and topographic catchments will not necessarily coincide (Winter et al., 2003). As a result, the magnitude of the various exchange fluxes (precipitation, groundwater, streams) will be different and change relative to each other, the lake may switch between being a groundwater-dominated and a precipitation-dominated lake, and the water residence time in the lake will be affected. This may impact lake water quality as the main source of water may come from different land uses during different times (Kratz et al.,

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