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Hydrological functions of a mine-impacted and natural peatland-dominated watershed, James Bay Lowland

Melissa Leclair, Pete Whittington*, Jonathan Price

Wetlands Hydrology Lab, Dept. of Geography and Environmental Management, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada

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ABSTRACT

Study region: This study was conducted in Northern Ontario, Canada, in the middle of the Hudson-James Bay. Lowland: one of the world's largest wetland complexes.
Study focus: Northern latitudes are expected to be the most impacted by climate change in the next century and adding to this stressor are increased mineral exploration activities, such as the De Beers Victor Mine, a large open-pit diamond mine. Because of the extremely low relief and presence of marine sediments, horizontal runoff and vertical seepages losses are minimal. As a consequence of this aquifer dewatering must occur to keep the open-pit mine dry. What is unknown is how the aquifer dewatering would impact the water balance of a peatland-dominated watershed. This study examines 3 years of aquifer dewatering from 2009 to 2011.
New hydrological insights: Deep seepage (groundwater recharge) varied with marine sediment thickness and represented a significant loss to the local system. Large downward fluxes were also measured in fen systems that are typically local discharge zones. Evaporation rates were also found to be lower in the bogs and fens and where impacted by lower water tables. When evaluating the water balance, with only 14.5% of the watershed impacted by the mine, the hydrological function of the entire watershed is more driven by seasonal climate variations than mine dewatering.

1. Introduction

The Hudson and James Bay Lowlands comprise the second largest peatland complex in the world and represent a significant contribution of the fresh water to the brackish James Bay (Rouse et al., 1992). These peatlands develop as a result of low topographic relief and a cool, moist subarctic climate. In the James Bay Lowland, ~85% of the area is covered by peatlands, with the remaining area consisting of mineral soil or fluvial systems (Glaser et al., 2004a). This area is underlain by a deposit of fine-grained marine sediments with low hydraulic conductivity (Glaser et al., 2004a), which along with the very low relief restricts drainage, thus contributing to high water tables and peat development. The peatlands of the James Bay Lowland sequester more than 12 million tons of carbon dioxide each year (MNR, 2012), making this landscape very important to the global carbon balance. Consequently, ongoing changes in global and regional processes (e.g., climate change) and local development (e.g., mining, transportation and infrastructure) and how they will affect the hydrology of this region is important to understand to create sound management and regulatory frameworks.

* Corresponding author. Present address: Dept. of Geography, Brandon University, 270 18th Street, Brandon, Manitoba, Canada R7A 6A9.
E-mail addresses: melisleclair@gmail.com (M. Leclair), whittingtonp@brandonu.ca (P. Whittington), jsprice@uwaterloo.ca (J. Price).

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Recent discovery of diamondiferous kimberlite deposits in the James Bay Lowland has prompted the development of the De Beers Canada Victor Diamond Mine. Pumping of dewatering wells surrounding the mine pit is required to maintain the dry conditions within the open pit for safe and efficient mining operations, which began in early 2007. This pumping is depressurizing the permeable Silurian aquifer that underlies the surrounding peatlands, increasing the percolation rate and causing their partial and spatially variable desiccation (Whittington and Price, 2013). What is currently unknown is how the depressurization of this system affects the hydrology and water balance of the peatlands, which overlie the bedrock and glacio-marine deposits, particularly the differential sensitivity of bogs and fens (the two dominant peatland types).

Mine pumping has resulted in a cone of depression in the limestone bedrock underlying the marine surficial deposits and peatlands. As of August 2011 the cone of depression, defined here as the 0.5 m head drawdown in the upper Attawapiskat bedrock formation, extends ~6 km (see Section 2) from the mine pit (AMEC, 2012), and encroaches on a series of small watersheds that may be impacted by increased seepage losses caused by the changing hydraulic gradients. While pre-mining percolation losses were estimated at 2.6–26 mm year^{-1} (HCI, 2004b), the increase in head gradient caused by deep aquifer depressurization has resulted in vertical losses of 1–4 mm day^{-1} in the regions that have smaller vertical depth to bedrock (Whittington and Price, 2013). The spatial pattern of enhanced recharge is not uniform; the thickness and hydraulic conductivity of the overlying marine sediments (Whittington and Price, 2013), as well as the presence of interbedded sand layers (Ali, 2013) have a significant impact on the peatlands' ability to retain water. Therefore, enhanced recharge occurs where the relatively low permeability marine sediments are thin or non-existent, such as where bedrock subcrops or is fully exposed (Whittington and Price, 2012). These bedrock exposures are "bioherms", which are relict coral reef structures extending upwards from the Silurian bedrock (Cowell, 1983). Examination of the patterns of recharge around bioherms illustrates that their effectiveness as local drainage nodes is limited (to about 25 m from the bioherm edge) by the poor lateral transmissivity of peatlands surrounding them (Whittington and Price, 2012). Nevertheless, increased vertical gradients have resulted in declining water tables in some areas (Whittington and Price, 2013), which can affect peatland hydrological, biogeochemical and ecological function.

As previously noted, this area is covered by ~85% peatlands, mostly bogs and fens (Glaser et al.,2004a). The peatlands have developed over low-gradient low permeability marine sediments that have been lifted by isostatic rebound from beneath the waters of James and Hudson Bay (Glaser et al., 2004b; Price and Woo, 1988). Peat thickness averages 2.5 m, somewhat thicker in bogs, which have become raised above the base level to a greater extent than fens (Glaser et al., 2004b). Since bogs are raised above the surrounding environments in such a low gradient region they are oligotrophic, and only receive inputs from precipitation (Sjors, 1963). Bogs tend to act as storage units but discharge to fens when there is excess water (Quinton, 2003). Fens, in contrast, have developed as water conveyance systems that link directly to the stream network, providing drainage networks for bogs that occupy more interfluvial locations (Sjors, 1963). Fens are able to maintain high water tables as a result of surface and groundwater inflows, allowing them to support more constant runoff throughout the year (Verry and Boelter, 1975). The higher water table in fens also results in them losing larger amounts of water to evapotranspiration than bogs (Lafleur and Roulet, 1992). The nature and magnitude of hydrological processes operating in bogs and fens such as water storage changes, evapotranspiration and runoff are distinctly different. Consequently, the impact of seepage losses that affect water table position, for example, will affect bogs and fens differently. Moreover, the nature and extent of these impacts will alter the water budget of small peatland-dominated sub-watersheds located within or across the cone of depressurization caused by mine dewatering.

These peatlands are the zero- first-order sources/streams delivering fresh water to rivers draining into James Bay. Understanding how they are hydrologically connected will help determine the potential impacts development might have on the larger scale hydrology of the region. Decreasing water tables as a result of development could affect both the horizontal and vertical connectivity of these peatland systems. The potential for reduction in surface runoff will affect the peatlands ability to maintain baseflows for aquatic biological communities (although streams near the mine most likely affected have supplemental water lines in anticipation of this (HCI, 2003)). Increased flowpath length may occur as the system becomes more strongly connected to the deep groundwater system through enhanced vertical seepage losses. Increased flowpath lengths will impact the chemical balance within peatlands and suspended and dissolved sediment loads of streams, including the ability to regulate production and transport of methyl mercury from peatlands to major rivers (Siegel et al., 1995). However, the degree of this impact to the different hydrological components on the local bogs and fens is unknown. Therefore, the objectives of this study are to evaluate components of the hydrological cycle to (1) gain insight on the impact of mine dewatering on peatland hydrological functions and water balance (2) extrapolate the potential impact to the hydrology of the peatland systems at peak depressurization.

2. Study site

The study site is located ~500 km north of Timmins, Ontario, Canada, and 90 km West of Attawapiskat, in the James Bay Lowland (52°49′15″N and 83°53′00″W) near the De Beers Canada Victor Diamond Mine in Ontario, Canada (Fig. 1). The landscape is dominated by peatlands (bogs and fens) with a peat thickness generally between 1 and 3 m. The bogs in this area typically consist of a hummocky terrain dominated by *Sphagnum* spp., particularly *Sphagnum rubellum*, *Sphagnum magellanicum* and *Sphagnum fuscum*. The vegetation cover of the fens is mainly sedges (*Carex* spp.), but also has a significant amount of *Sphagnum* spp. and cotton grass (*Eriophorum spissum*) (Riley, 2011). Underlying the peat layer is Tyrell Sea marine sediments and glacial till deposits ranging from 0 to 200 m thick, with no marine sediments present where bedrock outcrops