

Assessing the impacts of mine dewatering on the hydrogeochemistry of peatlands and surficial aquifers

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Summary

This study focuses on the simulation of groundwater flow and mass transport in peatlands under natural conditions and under the influence of mine dewatering. Six piezometer nests, each composed of three piezometers opened at different depths, were installed within a peatland located in the immediate vicinity of a future open pit mining site in Val d'Or, Quebec, Canada. Hydraulic heads were measured on an hourly basis in each piezometer. Chemical analyses (*in situ* physico-chemical parameters, major elements, trace elements, ultra-trace elements, dissolved organic carbon, dissolved inorganic carbon, dissolved nutrients) were conducted on 47 water samples collected from the piezometers throughout the summer and fall of 2019. Coupled groundwater flow and transport simulations are performed using SEEP/W and CTRAN/W for modeling present day conditions. The models will subsequently be used for predicting the impacts of mine dewatering on the peatland hydrology and hydrochemistry.

Background and objectives

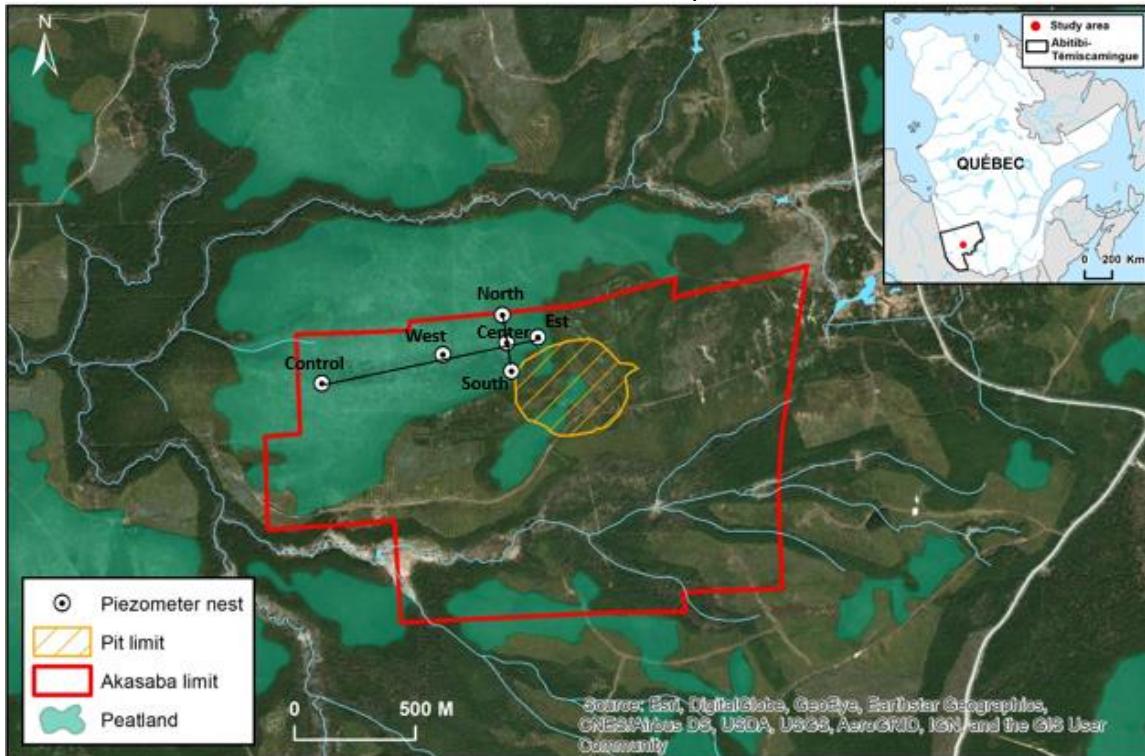
Peatlands host highly valuable ecosystems that can play significant roles in surface and groundwater flow systems. Such ecosystems are widespread in the Canadian Shield and their protection is critical. Nevertheless, the impacts of mining activities on peatlands are still poorly understood. While studies have assessed the impacts of underground mine dewatering on peatlands of the Hudson Bay Lowlands (Whittington and Price 2012; 2013; Leclair et al., 2015), research focussing on the impacts of open pit mine dewatering are still critically lacking. Fitting in this context, the general objective of this study is to simulate the variations in groundwater heads and groundwater quality in a peatland under natural conditions and under the influence of mine dewatering. The target site is the Akasaba West Mining Project, property of Agnico Eagle Mines, located in the Bourlamaque River watershed, approximately fifteen kilometers southeast of Val-d'Or (Quebec, Canada). Mining at this site is expected to begin in the near future.

Methods

Six piezometer nests (each consisting of three piezometers) were installed within the peatland along two perpendicular transects (Figure 1). The piezometers consist in 2.54 cm inside diameter PVC pipes equipped with 30 cm long intakes (model 601 from Solinst). All piezometers (n=18) were instrumented with *Solinst 3001 LT Levelogger Edge M5* data loggers for measuring hydraulic heads and temperatures within the peat. The monitoring network is configured to allow data collection near the margin of the peatland as well as in its center. A barometric probe (3001 LT Barologger Edge, M1.5) is used for atmospheric compensation. The monitoring initiated in this project will be maintained over a period of 10 years, thus allowing an assessment of hydraulic heads and water temperatures before, during and after the exploitation of the open pit. The elevations of piezometers were measured using a differential GPS (Trimble GNSS R8) with a vertical error ≤ 0.008 m. Hydraulic heads are reported as elevation values, in meters above the average sea level. The piezometers installed in the peatland were used for collecting water samples in June, August and October 2019. Piezometers were purged of at least one time their volume

before sampling. A total of 47 samples were collected. These water samples were analyzed for major ions (Ca, Mg, Na, K, Fe, Cl, SO₄, NO₃), trace and ultra-trace elements (Al, Sb, Ag, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Sn, Fe, Hg, Li, Mg, Mn, Mo, Ni, Pb, K, Rb, Se, Si, Na, Sr, Ti, U, V, Zn), dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) concentrations. Stable isotopes of the water molecule ($\delta^2\text{H}$ - $\delta^{18}\text{O}$) will also be analyzed. The *in situ* parameters (pH, temperature, dissolved oxygen, electrical conductivity and oxidation-reduction potential) were measured in the field using a YSI professional plus multi-parameter probe. Samples for trace and ultra-trace elements analyses were filtered in the field using 0.45 µm hydrophilic PES (polyethersulfone) membranes attached to disposable syringes. Samples for major ions and DOC were filtered at 0.45 µm using Waterra-FHT cartridges. All samples were stored at 4°C until analysis. All chemical analyses were performed at a laboratory that is accredited by the Quebec Ministry of the Environment.

Figure 1 Location of the study area. The satellite image presents the location of the projected pit for the Akasaba West project and the location plan of the piezometer nests installed to instrument the peatland.

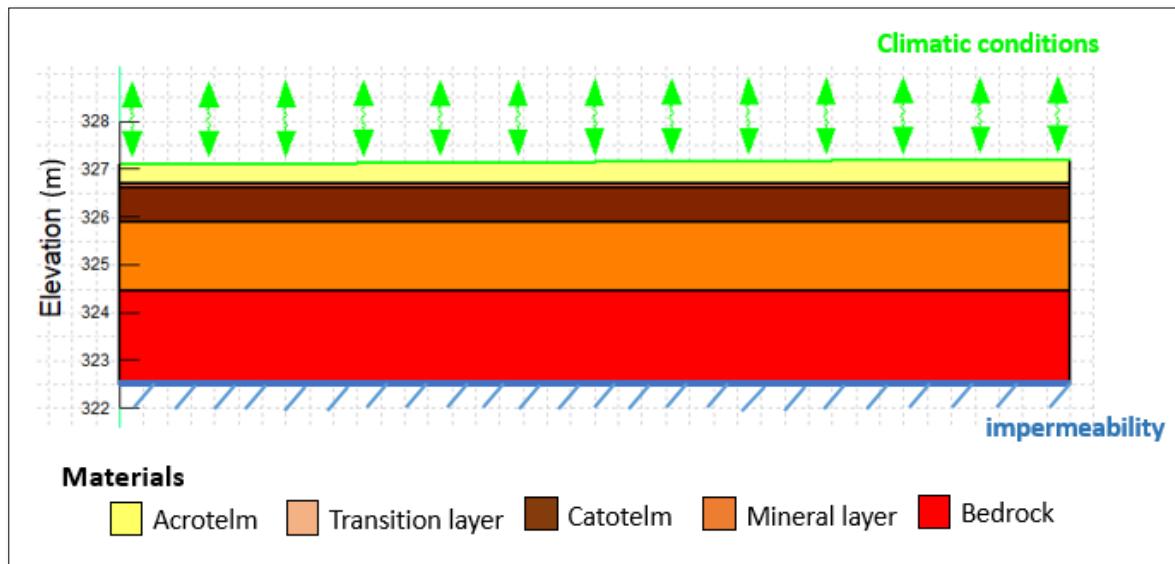


The available field data is used to calibrate 2D groundwater flow and mass transport models corresponding to the two transects identified in Figure 1. The simulations are performed using SEEP/W and CTRAN/W under steady state and transient state conditions. The 2D models are composed of five layers including, from top to bottom: (1) the acrotelm (30 cm), (2) a transition zone (10 cm), (3) the catotelm (variable thickness, based on field measurements), (4) unconsolidated deposits (variable thicknesses, based on previously available data) and (5) the bedrock (down to a depth of 2 meters in order to

limit the time of convergence of the model). Figure 2 shows an example of the model structure.

The hydraulic properties of these layers are determined using local field data or estimated based on scientific literature. Air temperature, precipitation, relative humidity and wind speed were used to define surface boundary conditions in SEEP/W. Evapotranspiration was estimated using the Penman-Wilson equation (Wilson, 1990; Wilson et al., 1994) implemented in SEEP/W. An impermeable boundary condition is applied at the base of the numerical model while different boundary conditions are tested at the horizontal limits of the model in order to simulate current conditions and future mine dewatering. The mass transport simulations conducted using CTRAN/W account for diffusion, advection and dispersion processes, and SEEP/W model results are used as a parent analysis. Simplified 2D sections are currently being developed for modeling the transport of conservative ions (such as chlorine) and non-conservative trace elements such as iron and manganese. The effects of sorption can be simulated for non-conservative trace elements, while the potential impacts of precipitation-dissolution reactions are evaluated separately using PHREEQC. The models are systematically calibrated using the available field data (hydraulic heads and geochemical monitoring).

Figure 2 Numerical model geometry and boundary conditions.

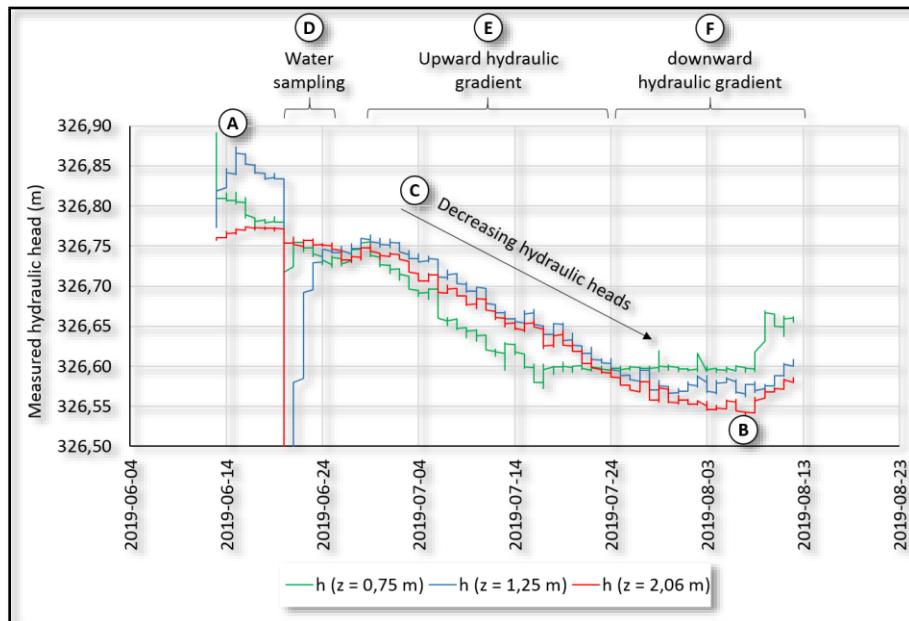


Preliminary results and discussion

The measured hydraulic heads range from ~326,9 m in the eastern part of the peatland to ~324,6 m in the western part of the peatland. Used as an example, Figure 3 shows the monitored hydraulic heads at three different depths within the central piezometer nest. The data reveals hydraulic heads ranging between ~326,9 m in mid-June (Figure 3A) and ~326,5 m in early August (Figure 3B), with generally decreasing values throughout the summer (Figure 3C). This suggests a negative change in storage within the peatland throughout the summer due to the combined effect of water flow (out of the peatland) and evapotranspiration. The vertical component of the hydraulic gradient is oriented upwards throughout most of July (Figure 3D), and subsequently shifts downwards in August (Figure 3E). This suggests that a reversal occurs in the hydraulic exchanges between the

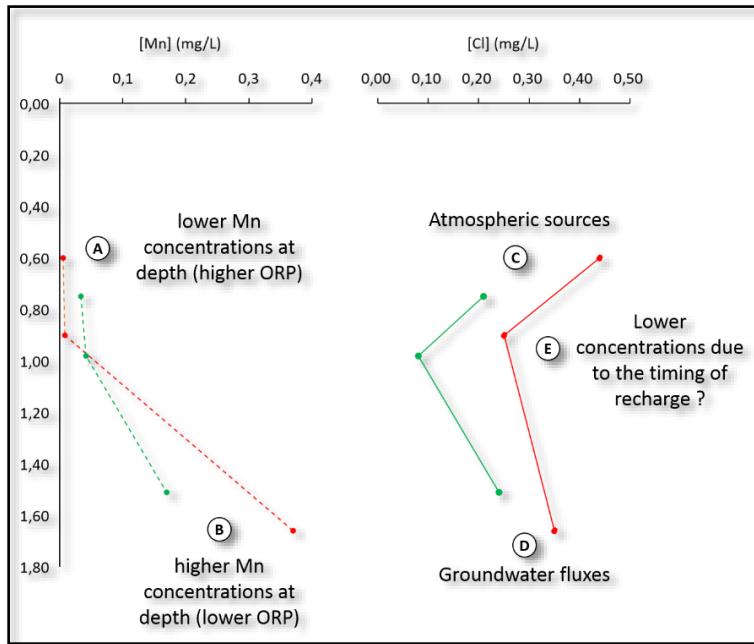
peat and underlying inorganic unit. Understanding these hydrological connexions between the peatland and underlying units is critical in order to predict the impacts of mine dewatering on the peatland. The SEEP/W models are currently being developed for simulating these mechanisms and providing a quantitative analysis of peatland-aquifer hydrological exchanges.

Figure 3 Variation of the hydraulic head in time and space for the central piezometer nest.



Chemical analyses of water reveal a marked spatiotemporal variability in peat pore water composition. Used by mean of example, Figure 4 shows the dissolved manganese (Mn) and chlorine (Cl) concentrations measured in samples collected from the reference, western and southern piezometer nests in October 2019. The data reveals overall lower Mn concentrations near surface (Figure 4A) and higher Mn concentrations at greater depth (Figure 4B). This most likely reflects the combined influence of a Mn source from the underlying inorganic substrate and of the greater propensity of Mn to remain in solution under the more reducing conditions prevailing at greater depth. Dissolved Cl concentrations show a different pattern according to depth. Overall, for the two illustrated piezometer nests, Cl concentrations are around 20-40 mg/L near surface (Figure 4C), lower values at intermediate depth (Figure 4E) and a subsequent increase at greater depth (Figure 4D). This suggests that the atmosphere and groundwater both constitute sources of Cl to the peatland. The lower concentrations measured at mid-depth could reflect water recharged at a different time, although this hypothesis has not been tested yet. The coupled SEEP/W-CTTRAN/W models are currently being developed for simulating the mechanisms responsible for the variability in the concentrations of conservative (e.g.: Cl) and non-conservative (e.g.: Mn) elements in the peatland. Ultimately, these simulations will provide insights for better understanding the influence of advection, dispersion, diffusion and sorption on the chemical composition of peat pore waters and the potential impacts of mine dewatering on water quality.

Figure 4 Variation of the Mn and Cl concentrations in depth for western (in red) and southern (in green) piezometer nests (October 2019).



Scientific outcomes

The results from this study will provide tools for better understanding groundwater flow and transport processes in peat under natural conditions and under the influence of mine dewatering. Such tools are critically needed in order to better evaluate and mitigate the impacts of mining on peatlands and associated ecosystems.

Acknowledgements

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