Hydrogeological Data Collection at Canadian Arctic Mines in Permafrost

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Abstract
Groundwater quantity and quality data collection issues at existing and proposed mines in the Precambrian Shield rocks of the Canadian Arctic (Nunavut and Northwest Territories) are discussed based on literature review and recent hydrogeological testing at proposed mine sites. The Canadian Environmental Assessment process requires the collection of data on baseline groundwater conditions and predictions of mine inflow quantities and any potential impacts on groundwater quality and quantity during the construction, operations and closure phases of the mine. This portion of the Precambrian Shield is a continuous permafrost zone. The presence of permafrost tends to reduce the potential for groundwater inflows into mines but presents a number of technical issues for: a) collection of hydrogeological data, b) interpretation of ground water flow systems, c) prediction of mine inflow volumes, and d) assessment of potential groundwater quantity/quality impacts on local water resources.

Introduction
A number of new mines are in the Environmental Impact Assessment (EIA) permitting stage due to the recent global demand for commodities. This paper is based on hydrogeological testing conducted for environmental impact assessment and mine permitting at the Zinifex High Lake and Izok proposed poly-metallic mines in Nunavut and considers other published hydrogeological information for the Snap Lake, Ekati, Diavik diamond mines and research conducted at the closed Lupin gold mine, as well as other pertinent literature. All of these existing and proposed mines are in the Canadian Shield Precambrian metamorphic rocks, although the local rock types vary widely between mines. Overburden deposits are generally very thin on the arctic portions of the Canadian Shield.
All of these mines are within western Nunavut or just to the south in the Northwest West Territories. Mean annual air temperatures in this area are approximately –10 to –15 degrees centigrade. The ground is frozen to depths of 200 to 500m depending on location. Only the upper 1 to 7m melts during the brief summers. This shallow zone is known as the “active layer”
The presence of permafrost significantly affects how hydrogeological data is collected and interpreted. Permafrost lowers the hydraulic conductivity of the rock and soil by several orders of magnitude and frozen zones are often interpreted to be impermeable for the purposes of mine inflow and contaminant transport calculations. The shallow “active layer” melts during the summer period (June to September) and shallow groundwater flow occurs during this time period. There are melt zones known as “taliks” below surface water bodies that are more than 2m deep that do not freeze to the bottom over the winter. If lakes are sufficiently wide (0.2 to 0.5 km) then they may have “through taliks” that extend through the full depth of the continuous permafrost to the deep groundwater flow system below the permafrost. The paper discusses the technical issues and methods for hydrogeological data collection in: a) shallow “active layer”; b) “taliks” below lakes; and c) deep groundwater flow system below continuous permafrost.

Shallow “Active Layer” Data Collection and Significance
The ground is generally frozen from late September to late June. Shallow groundwater flow within the “active layer” only occurs during July, August and early September. EIA baseline data collection requires assessment of the shallow, seasonal “active layer” groundwater flow system as well as the deeper regional groundwater flow system below the bottom of the permafrost.
Due to the thin seasonal nature of the active layer, shallow groundwater flows into mines are generally small and are managed as part of seasonal surface runoff. However, the active layer can provide a seasonal pathway for contaminant movement away from tailings management system, which are often constructed in small lakes to permit a water cover system to prevent ARD issues. If the lakes are dammed to allow water levels to rise high then the active zone will become thicker at least for several years until the permafrost surface aggrades. Global warming scenarios, which could cause the active zone to be thicker or unfrozen for a longer period each year must be considered in environmental

impact assessments. Global warming could make contaminant transport through the active layer more significant.

The thickness of the active layer ranges from 0 to 7 m depending on the latitude, season, recent weather, the presence type and thickness of vegetative cover, peat and organic soils insulation, slope aspect and orientation and human disturbance. The installation of thermistor strings in boreholes with data loggers is required to identify the seasonal depth and location of permafrost for the EIA process and for mine/facility design. Permafrost information can be as important as rock type and geological structure for determining groundwater mine inflow quantities and contaminant pathways/transport times from potential contaminant sources such as tailings management facilities.

The active layer thickness increases gradually over the summer months. The water table elevation often declines along with the declining permafrost depth and is often less than 0.5m from the depth of the permafrost. Thus both the groundwater level and thickness of the saturated active zone varies over time and accurate interpretation of the shallow groundwater flow directions and velocities is difficult. Typically shallow groundwater monitors are installed in the upper 3 to 7 m with screens that extend to near surface. During the summer melt period, water levels and depth to permafrost are measured and water samples are taken when possible. There is a limited amount of water in these shallow wells for well purging and sampling for water quality. During the rest of the year the active layer is frozen and it is not possible to obtain meaningful data on flow or quality.

Lake “Talik” Hydrogeological Data Collection and Significance

In the area of these mine sites, the continuous permafrost is generally 200 to 500m thick except below water bodies that are more than 2m deep. The Canadian Shield in this area has numerous lakes; many that have melt zones below them known as “taliks”. If these taliks are not hydraulically connected they are called “closed taliks”. It they are connected to other melt zone features that allows continuity of groundwater flow they are known as “open taliks”. If they penetrate through to the deep groundwater flow system below the permanent permafrost (200 to 500m thick) they are known as “through taliks” and are significant for interpreting regional groundwater flow systems. Knowledge and understanding of talik groundwater flows system is very important for assessing groundwater mine inflows and for assessing potential for contaminant transport in the deep regional flow system. The potential for “through taliks” below lakes can be theoretically calculated with geothermal models that consider the mean annual temperature over the quaternary time scale, the size and depth of the lake and adjacent water bodies and the geothermal gradient at depth and the quaternary history of the location and the type and density of snow cover.

Due to the numerous lakes in the Precambrian Shield it is very common for mine workings to be below a lake basin. Mines that are near or below larger lakes can have significant groundwater inflows if the unfrozen rock in the talik has permeable fracture zones (Bieber *et al.*, 2006). The hydraulic conductivity, of rock formations within lake taliks is of critical importance for predicting groundwater mine inflow quantities for underground mines below lakes or open pit mines that intersect lakes. The hydraulic conductivity of the rock mass is generally determined by drilling boreholes from the lake ice during the March to May period when the ice is thick enough to support the drill rig and there is sufficient daylight. Typically constant head permeability tests are conducted in specific depth intervals isolated by inflatable packers (Johnson and Mills, 2006). Tests can be conducted with a single packer system used at the bottom of the borehole as drilling proceeds or with a double packer system after the borehole has been completed to its’ complete depth. Water quality samples can also be collected from different depth intervals using the inflatable packer system but if the hydraulic conductivities are low it can be expensive to pay the diamond drill hourly rate while the boreholes are being purged and sampled. Hydraulic heads at different depths can also be measured from packed off intervals. Permanent groundwater monitoring installations are generally not installed into taliks from lake ice due to difficult boat access when the ice has melted and the potentially damaging t effects of shifting lake ice. If there has been underground test mining below the lake then there is an opportunity to collect better groundwater flow and quality data from permanent borehole installations.

Deep Groundwater Flow Data Collection and Significance

A deep regional groundwater flow system exists below the 200- 500m of permanent permafrost. This flow system is only hydraulically connected to surface via "through taliks" below larger lakes. The occurrence of very old, brine water quality in a number of places on the Canadian Precambrian Shield suggests that these deep flow systems are very sluggish and slow moving under natural conditions (i.e. pre-mining) (Frape and Fritz, 1987). Research projects for assessing permafrost impacts on nuclear waste disposal (Ruskeeniemi *et al.* 2002), (Ruskeeniemi *et al.* 2004) and for assessing biological conditions below permafrost are also being conducted at existing and proposed arctic mine sites in Nunavut.

On a few EIA projects hydraulic conductivity data has been collected using inflatable packer systems in boreholes drilled below the base of the permafrost (300 to 500m deep) (Johnson and Mills, 2006). These are usually mining exploration diamond drill boreholes. The boreholes are typically drilled with a heated brine solution to avoid having the drill rods freeze in the borehole. Hydraulic conductivity values at depths below 300m tend to be relatively low and it is expensive a difficult to obtain valid hydraulic conductivity values. Hydraulic head information over time can be obtained by installing vibrating wire peizometers below the bottom of the permafrost. If they are installed above they will freeze and will not work. Due to the great depth and cost of installing and testing deep boreholes in permanent permafrost it is unusual to have sufficient data to construct a regional groundwater flow map. Often the water levels in larger lakes (with "through taliks") are considered to be representative of water levels in the deep groundwater flow system and are used to interpret the regional direction of deep groundwater flow.

Borehole and mines that penetrate below the base of the continuous permafrost may have inflows of deep groundwater that may be saline and very old. Sampling of deep saline groundwater from boreholes installed through 200 to 500m of permafrost is very difficult because the drill rods can freeze in the hole within the time it takes to flush the drilling brines from the borehole interval to permit collection of a representative groundwater sample. In addition, the hydraulic conductivity of crystalline bedrock at these depths is typically very low so groundwater inflows into the borehole are very slow. The most representative deep groundwater quality samples have been collected from underground mine workings that extend below the permafrost (Ruskeeniemi et al., 2004). Emerson *et al.* (2006) reported some success in sampling deep groundwater below permanent permafrost from surface using a multi-level sampling device.

Groundwater Flow Assessment Issues

Digital 3D groundwater flow modelling is used to assess a) mine inflow volumes (which may require treatment prior to discharge) b) potential mine drawdown impacts on nearby lake levels c) potential contaminant migration from tailings facilities or from mines after closure. For mines below lake taliks these models can be constructed in a similar manner to non-permafrost areas, by just assuming that the adjacent permafrost areas have a very low hydraulic conductivity. However, seasonal effects of permafrost need to be considered. The ground surface, smaller streams and many rivers are frozen solid to the bottom for nearly nine months of the year. Many lakes that are fed by these smaller streams and rivers have no inflows or outflows during winter. Groundwater flow models in continuous permafrost cannot be calibrated by using typical methods such as fitting to the existing water table contours.

The elevations of larger lakes with "through-taliks" (that provide hydraulic connection to the deep groundwater flow system below the permafrost) are often used to estimate regional groundwater flow directions because of the difficulty in obtaining adequate hydraulic head measurements for the deep flow system. Recharge to the groundwater flow system is restricted by the presence of permafrost and is not defined by a clear relationship to precipitation or catchment area. Recharge to the deep flow groundwater system is via downward flow below lakes with "through taliks". The winter (when there are no surface inflows or outflows into many lakes) is the most sensitive time (low flow period) for assessing mine dewatering drawdown impacts on nearby lake or river levels.

Conclusion

Despite significant data collection challenges, hydrogeological investigations for environmental impact assessments of proposed new mines and scientific investigations at existing mine sites are yielding information on the deep and shallow groundwater flow systems in the remote, continuous permafrost region of western Nunavut and adjacent areas of the Northwest Territories, Canada.

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