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Groundwater Resources Evolution in Degrading Permafrost Environments: A Small Catchment-Scale Study in Northern Quebec, Canada

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A two square kilometre catchment in a discontinuous permafrost zone near the Inuit community of Umiujaq on the eastern shore of Hudson Bay in Northern Quebec, Canada, is being investigated to determine the impact of permafrost degradation on groundwater resources. The catchment, which became deglaciated about 7500 years ago, lies in a valley which includes about 30-40 m of glacial-fluvial and marine Quaternary sediments. Permafrost mounds at the site extend from a few meters below ground surface to depths of about 10-30 m. Instrumentation has been installed to measure groundwater levels and temperature, as well as groundwater and surface water geochemistry, isotope signatures (including δ18O and 3H) and stream flow. Preliminary groundwater isotope data reflect depleted δ18O signals that differ from expected values for local groundwater, possibly representing permafrost thaw. In addition, stable water isotopes indicate evaporation from shallow thermokarst lakes. Meteorological conditions including air temperatures, precipitation and snowpack are also being monitored. Near-surface geophysical surveys using electrical resistivity tomography (ERT), induced polarization tomography (IPT), georadar and seismic refraction tomography have been carried out to characterize the catchment and to build a 3D geological site model.

A numerical model of coupled groundwater flow and heat transport, including thermal advection, conduction, freeze-thaw and latent heat, is being developed for the site to help develop the conceptual model and to assess future impacts of permafrost degradation due to climate warming. The model (Heatflow/3D) includes nonlinear functions for the temperature-dependent unfrozen moisture content and relative permeability, and has been tested against analytical solutions and using benchmarks developed by the INTERFROST modelling consortium. A conceptual 2D vertical-plane model including several permafrost mounds along a 1 km section shows dynamic seasonal behavior with preferential melting from below due to sub-permafrost horizontal groundwater flow and upward flow to surface water through taliks. Under current environmental conditions, the simulations suggest the remaining permafrost in the basin could completely thaw within 50 years.

The long-term monitoring program in the catchment will help develop optimal investigative methods for monitoring hydrogeological systems and groundwater resources under permafrost-degrading conditions, and will help determine how new groundwater resources may become available for northern communities as permafrost thaws and recharge to aquifers increases.