Assessment of groundwater contribution to surface water quantity, quality and temperature in rivers of northern Quebec

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Introduction

Northern Quebec is covered by permafrost with different classes (continuous, discontinuous, sporadic). Furthermore, allover Quebec because of cold climate, the freeze-thaw cycle of the active layer is present. Due to climate change, the variations in freeze-thaw cycles of the active layer and alterations in the thickness of permafrost are likely to happen. This impacts the groundwater flow system, thus the quantity of surface water-groundwater interaction can be changed. The alteration in the quantity of surface water-groundwater interaction affects the quality of surface water bodies and the health of aquatic systems. For instance, Rivers in northern Quebec are known for their abundance of salmonids. The optimal temperature range for salmonids' growth varies between 7 °C and 17 °C depending on the species. During summer, salmonids can experience thermal stress in rivers, which affects their growth and even threaten their survival.

Some zones with groundwater discharge in the rivers constitute thermal refuges, allowing fish to be more comfortable, to grow and to survive in extreme temperature conditions. As a result of predicted climate change, extreme conditions are more likely to occur. Therefore, the effect of groundwater refuges in the rivers thermal budget is important to predict the health of the aquatic system.

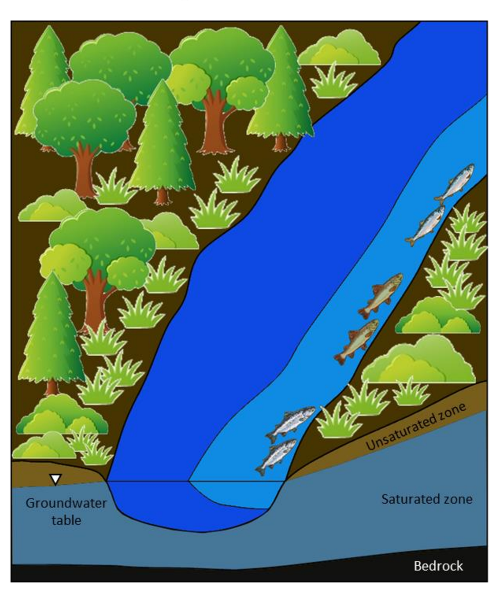

Figure 1- zones with cold groundwater seepage (light blue), suitable for fish in extreme temperature conditions.

Study Sites

Two sites have been selected for detailed studies: one on Berard River and one on Saint-Marguerite River. These two rivers are located in different climates and permafrost conditions. Saint-Marguerite River is in a zone without permafrost and continental cold climate, and Berard River in a zone with discontinuous permafrost and subarctic climate. This way the effect of permafrost and climate on groundwater-surface water interaction will be analyzed.

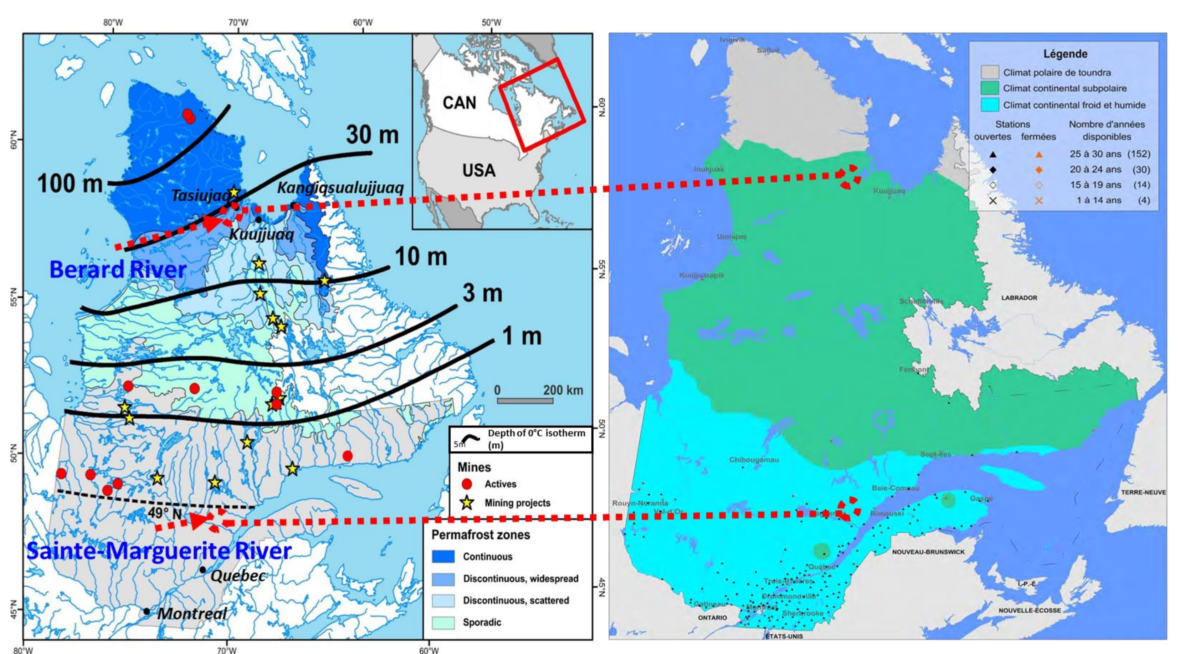

Figure 2- location of study sites on permafrost map (left) and Koppen climate classification map (right) of Quebec.

Methodology

The methodology can be summarized into two main parts: field measurements and modelling.

Field measurements are required since there are no hydrological data available for the selected sites. Moreover, the detailed continuous data will be used for model calibration and history matching in order to have a more reliable prediction from the models.

Field measurements

1) Taking thermal aerial imagery of rivers:

By flying over the selected rivers, thermal and optical images are taken. This way the location of cold refuges in the rivers will be detected, which helps to select a suitable location for further detailed measurements.

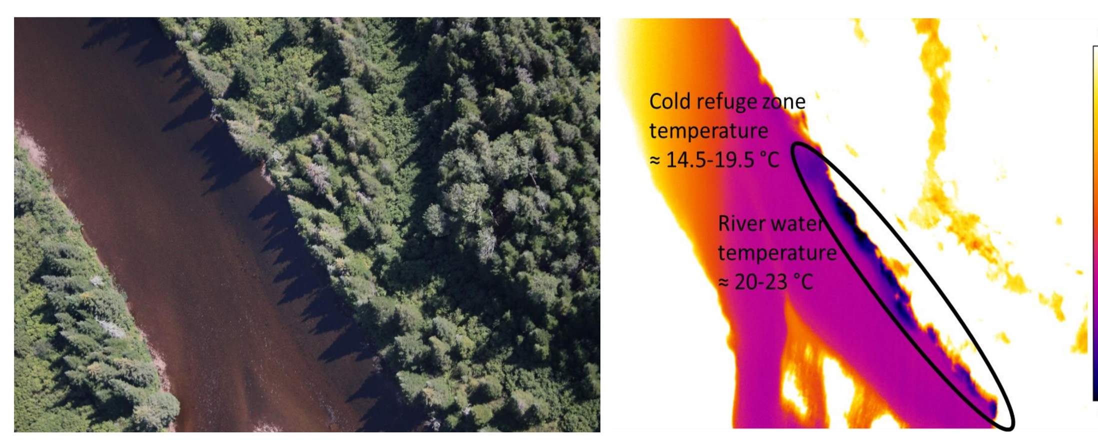

Figure 3- optical image (left) and thermal infrared image (right) showing a cold water refuge.

2) Seepage measurements

By installing the seepage meters in different locations at the bottom of the river, the amount of water the river gains or loses is measured. This is important for quantifying and analyzing surface water and groundwater interaction.

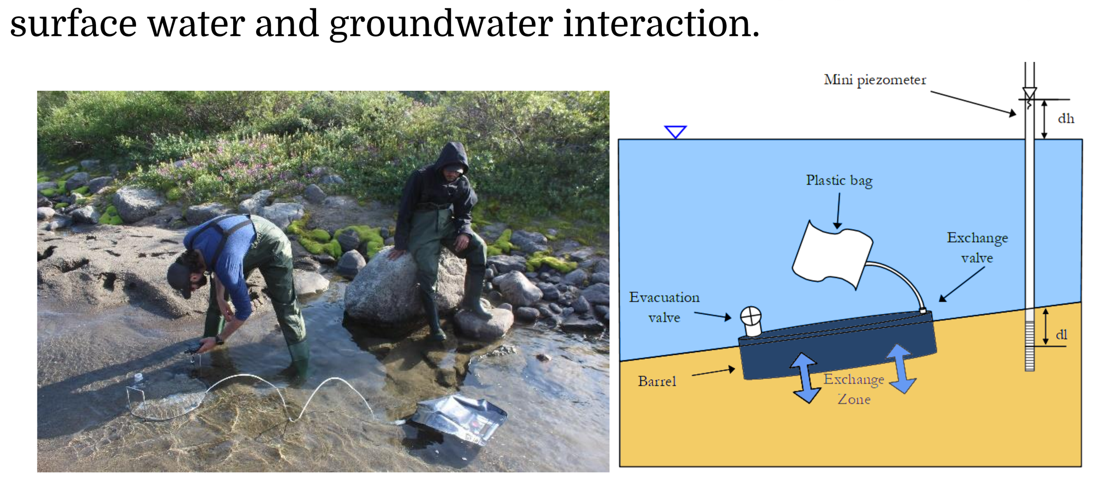

Figure 4- installed seepage meter (left) and schematization of the seepage meter device (right).

3) Observation wells and data logger installation

Shallow observation wells (depth of 0.5-3 metres below ground) have been installed in different locations and depths to measure the water level and temperature continuously. This way, seasonal variation of the hydraulic gradient of flow from the groundwater to the river as well as the groundwater temperature profile will be measured.

Figure 5- slotted stainless steel pipes as observation wells, temperature sensors, and water-level loggers and their installation from left to right respectively.

4) Geophysical measurements

Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) enable the detection of different geological formations, depth of bedrock, and presence of permafrost, at the site.

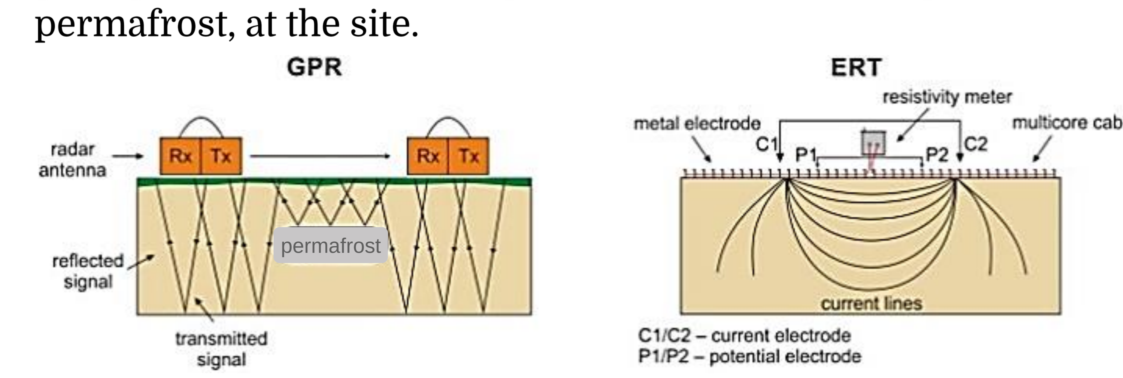

Figure 6- diagram of GPR (left) and ERT (right) measurements.

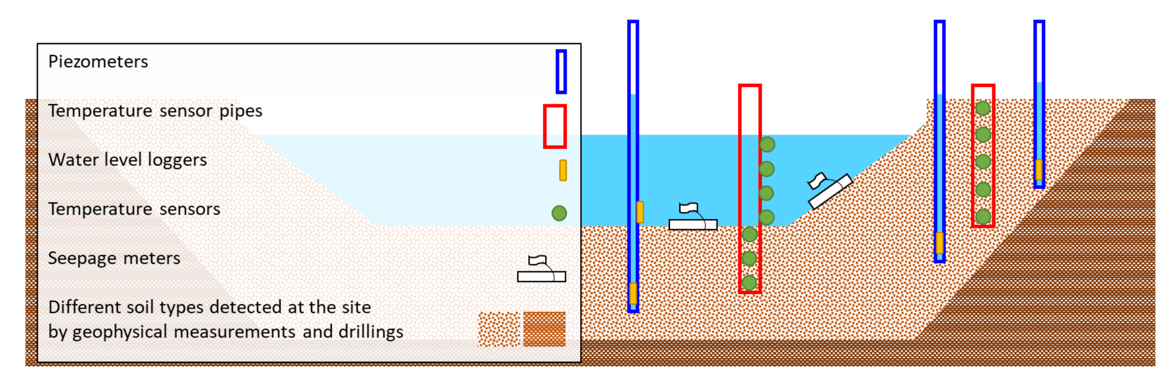

Figure 7- summary of all field measurements on the study site in cross-section view.

Modelling

Modelling is done using COMSOL software. The models combine free flow (flow in the river), groundwater flow (saturated and unsaturated flow) and heat transport to simulate water and heat circulation in the system.

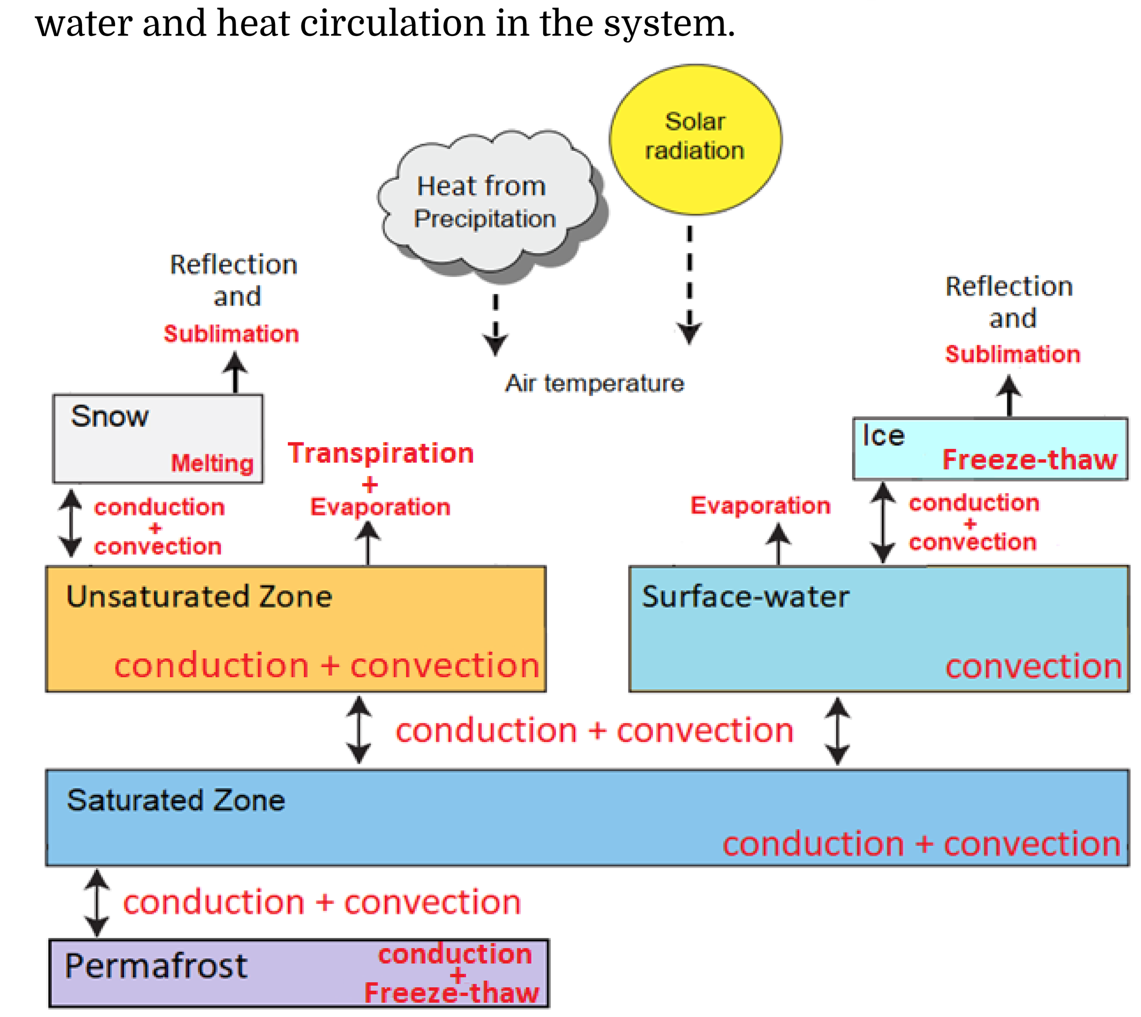

Figure 8- schematization of water circulation (black arrows) and methods of heat transport (in red) in the system.

A 3D model of the system is built by setting the representative equations at each section and a good coupling boundary condition between them.

Primary Results

Since this is an ongoing project and not all the measurements have been completed on the selected study sites, the models are currently based on simplified geometry. Models simulate groundwater flow and heat transport at different conditions based on designed scenarios. Two cases, without permafrost and with sporadic permafrost are presented.

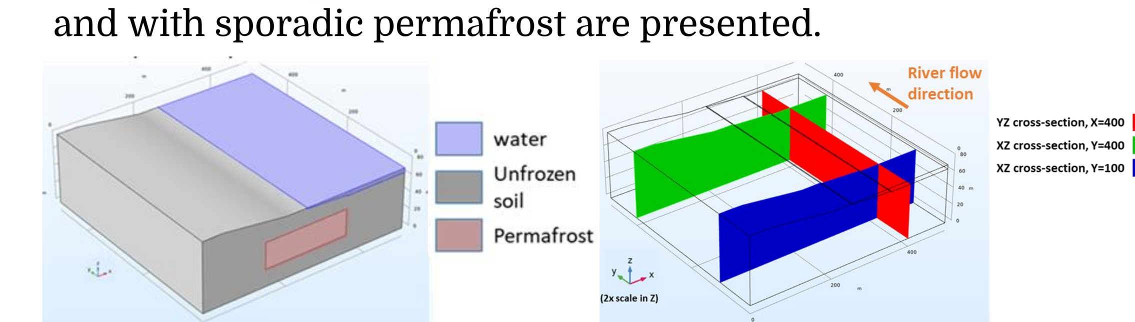

Figure 9- different zones and materials in the model (left) and cross-sections selected for better visualizing the model results (right).

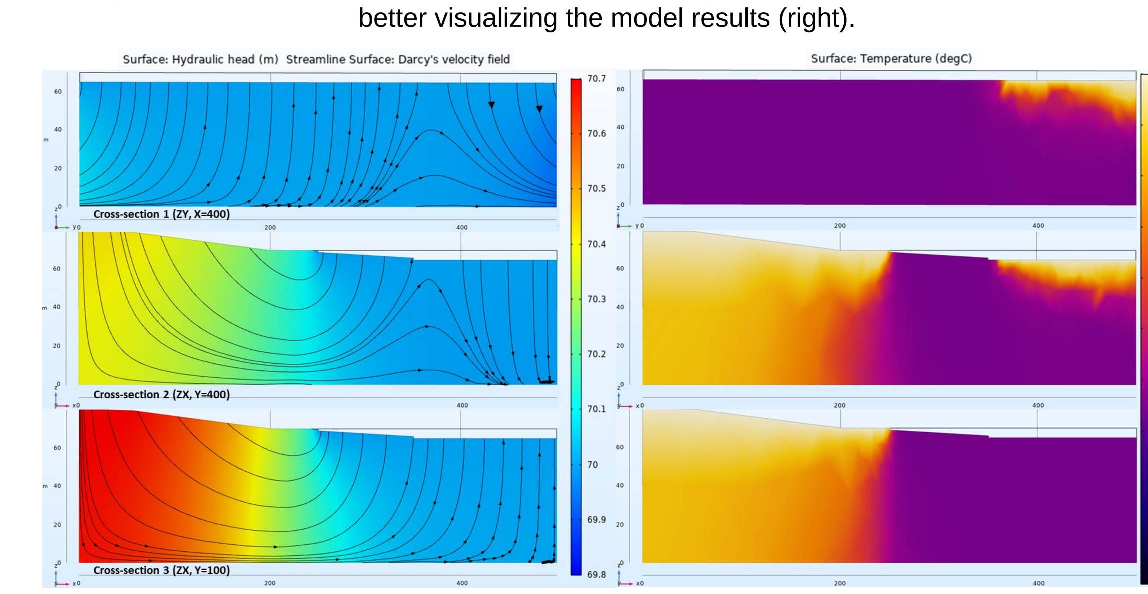

Figure 10- simulated hydraulic head in metres of water (left, colour bands), streamlines (left, line and arrows) and temperature in degree Celsius (right) in the case without permafrost.

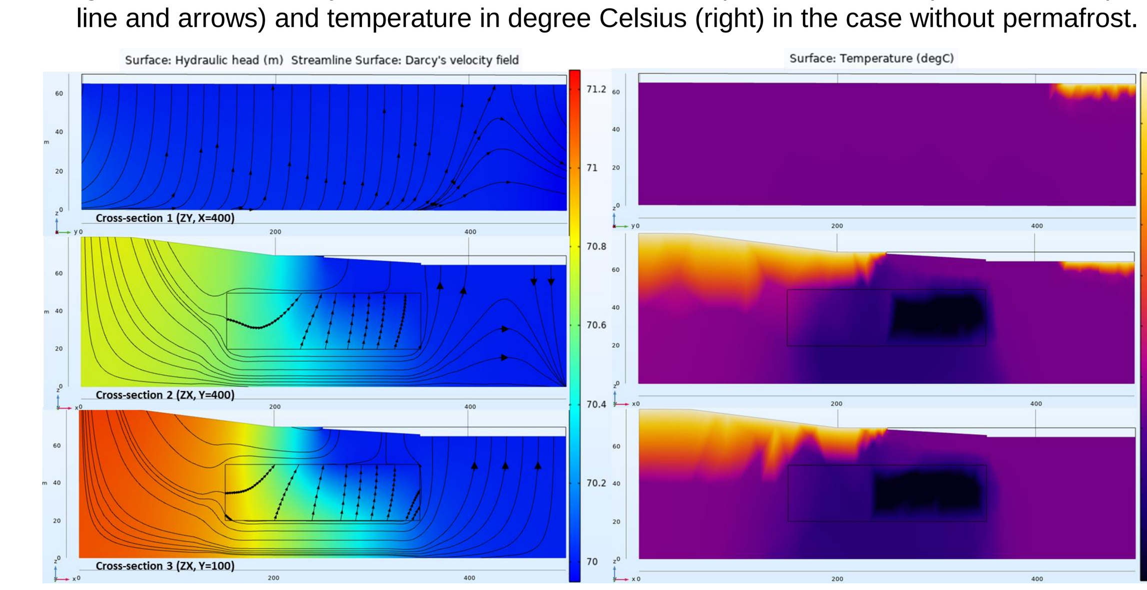

Figure 11- simulated hydraulic head in metres of water (left, colour bands), streamlines (left, line and arrows) and temperature in degree Celsius (right) in the case with sporadic permafrost.

Discussion

Change in the flow pattern modulates the temperature distribution in the system; since heat transport due to convection is significant in surface water-groundwater interaction modelling.

Even a small section of permafrost (sporadic) can significantly change the groundwater flow system. The freeze-thaw cycle of permafrost and active layer (layer on top of permafrost) causes the quantity of surface water-groundwater interaction to vary in summer and winter. Therefore, considering all terms of conduction, convection and phase change as methods of energy transport is important.

Simulating free flow in a river is also important in order to see how fast the cold groundwater can be mixed to river water and the extent of its effect.

More about MiraNor project

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