# ASSESSMENT OF GROUNDWATER CONTRIBUTION TO RIVER WATER TEMPERATURE

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## INTRODUCTION

Groundwater (GW) and surface water (SW) are connected and the extent of the interconnection between GW and SW bodies depends on the climate and the geological setting . 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 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.

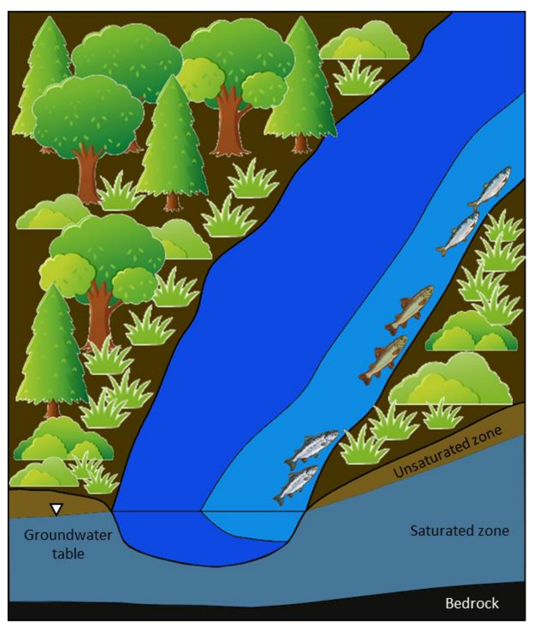


Figure 1- zones with cold groundwater seepage (light blue), suitable for fish in extreme temperature conditions.

## STUDY SITES

The study site is located on the Sainte-Marguerite River main branch 36 km upstream from the river mouth in the Saguenay region of Quebec, Canada.

Geology near the study site consists of bedrock outcropping on both sides of the valley that is partly filled with quaternary deposits filling the central depression. The bedrock is made of Proterozoic intrusive igneous rocks, which is overlaid by quaternary sediments consisting of glacial till with a maximum thickness of 30 m and alluvial sand, sandy silt and gravel with 1-30 m thickness.

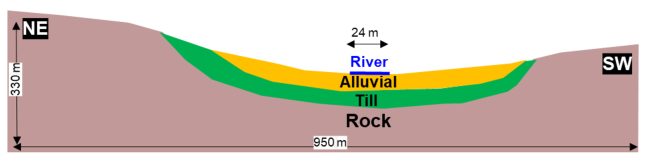


Figure 2- Simplified cross-section of study site showing geological units

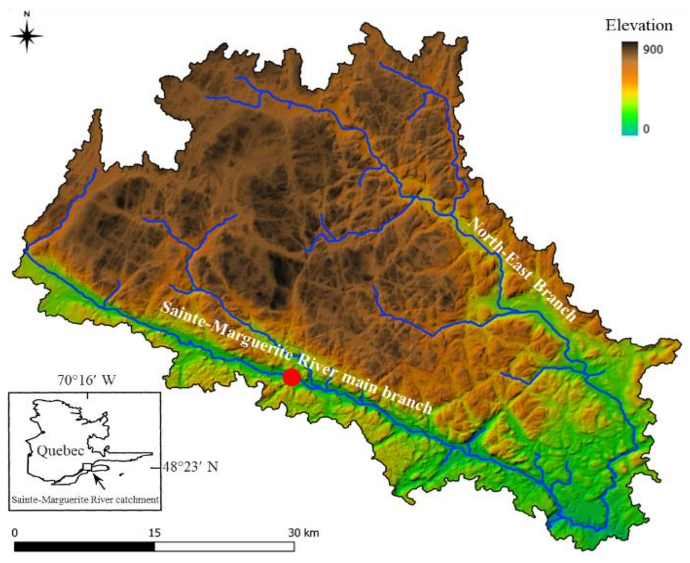


Figure 3- Location of study site (red dot) on Sainte-Marguerite River catchment

## METHODOLOGY

GW and SW levels and temperature were collected at a field site. The collected data were used to identify extreme atmospheric events and possible suboptimal or critical river water temperature for fish. Then, the time-series data have been used for construction and calibration of the numerical models of GW and SW flow coupled with heat transfer.

### 1) Data collection

Water level and temperature of the river and groundwater has been collected for a period of one year with 15-minute intervals. The sensors have been installed in shallow piezometers installed in the ground at a depth of up to 3 metres below ground surface.

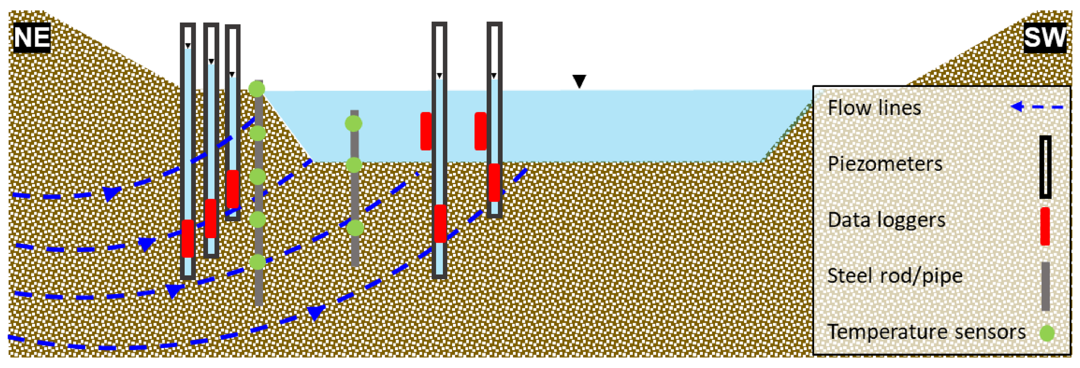


Figure 4- Location of installed instruments in simplified cross-section of the river.

### 2) Numerical modelling

Simulating short-term changes like daily and seasonally variation of water temperature in rivers affected by the GW seepage requires a combined GW-SW simulation of flow and heat transfer.

Two models have been developed to evaluate the effect of GW inflow to the river. The first model (M:R) is a free flow model only, simulating the river flow and water temperature changes caused by air temperature. The second model (M:R+GW) is a combination of both free flow in the river and GW flow in porous media.

A D3 with model has been made based on simplified topography of the study and 3 present geological units. The three present units are: Alluvial, Till and Rock. The hydraulic and thermal properties of these layers have been shown in the tables below.

The boundary condition for flow and heat transfer model play an important role since the dimensions of the model is relatively small. The considered boundaries have been presented in Figure 7.

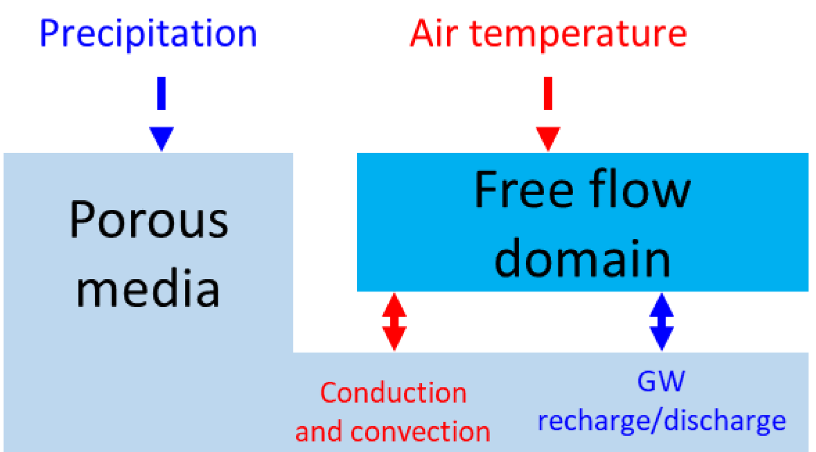


Figure 5- Schematization of a simplified GW-SW flow and heat exchange.

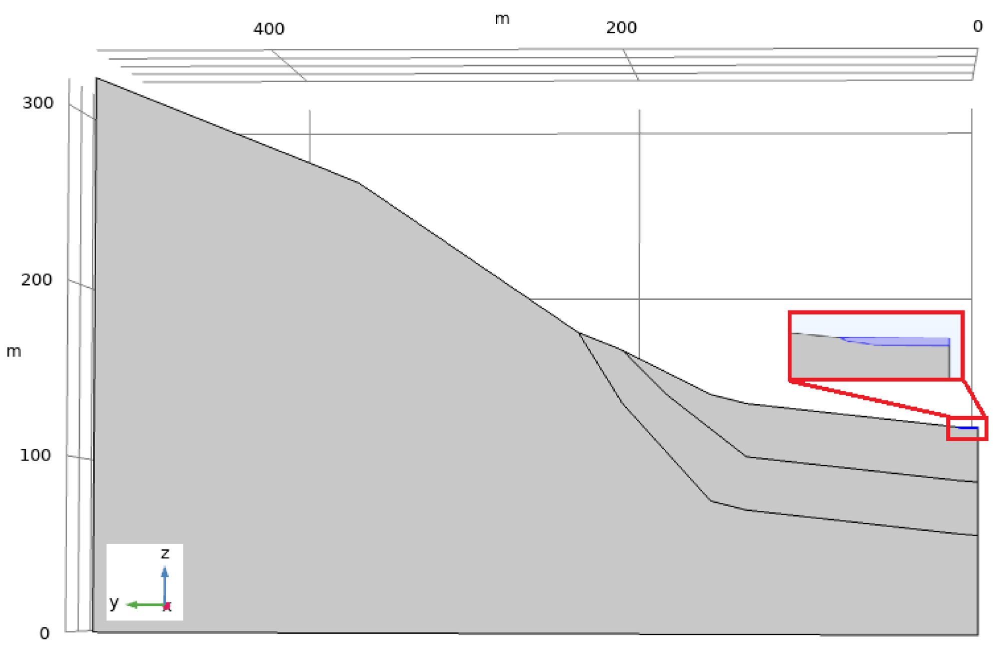

Figure 6- Model geometry showing river and porous media with three different units.

Table 1. Hydraulic properties of geological units.

| Geological unit | Permeability ($m^2$) | Porosity (-) |
|---|---|---|
| Alluvial | 1e-11 | 0.4 |
| Till | 1e-14 | 0.2 |
| Rock | 1e-17 | 0.05 |

Table 2. Thermal properties of geological units.

| Geological unit | Thermal conductivity W $m^{-1}K^{-1}$ | Heat capacity $J.kg^{-1}.K^{-1}$ |
|---|---|---|
| Alluvial | 0.5 | 300 |
| Till | 1 | 500 |
| Rock | 2 | 1000 |

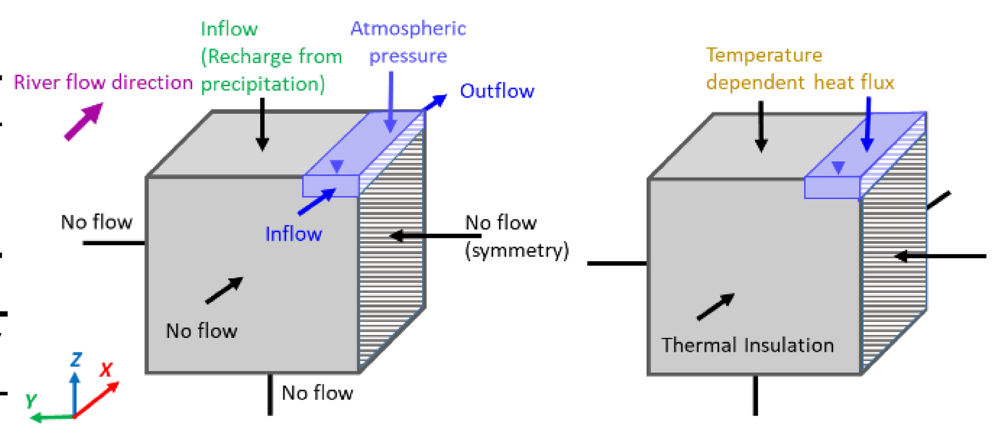


Figure 7- Boundary conditions of the flow (left) and heat transfer (right) models.

## Results

### 1) Time series of recorded temperatures

The average daily air temperature increase at the study site is 11.7°C while the average daily river water temperature increase is 1.5°C.

Standard deviation of river water temperature data is 60% of air temperature data (Table 3). This can be explained by GW inflow to the river.

Table 3. Maximum (MAX), minimum (MIN) and standard deviation (SD) of recorded hourly temperature during July 2019 to July 2020 (°C).

| | Groundwater | River | Air |
|---|---|---|---|
| MAX | 9.6 | 24.6 | 36.8 |
| MIN | 0.2 | -0.1 | -33.0 |
| SD | 2.5 | 7.3 | 12.1 |

During the monitored period at the study site, 13 days with air temperature exceeding 30°C were recorded (Table 4). During these 13 days, both the daily air and river water temperature increases are higher than calculated average. Thus, these days can be considered as extreme atmospheric events.

Table 4. Summary of recorded extreme atmospheric events (air temperature above 30°C).

| Date | Number of continuous days | Number of hours with temperature above 30°C | Maximum hourly air temperature (°C) | Air temperature increase (°C) | Maximum river water temperature (°C) | River water temperature increase (°C) | Average groundwater temperature (°C) |
|---|---|---|---|---|---|---|---|
| 2019-07-26 | 2 | 2 | 30.1 | 21.6 | 20.2 | 4.5 | 7.6 |
| 2019-07-27 | | 5 | 33.0 | 19.6 | 22.4 | 4.0 | 7.6 |
| 2019-07-29 | 1 | 4 | 31.2 | 16.4 | 22.8 | 4.0 | 7.7 |
| 2020-05-28 | 2 | 3 | 32.7 | 23.7 | 9.0 | 3.9 | 1.8 |
| 2020-05-29 | | 4 | 31.1 | 15.9 | 8.4 | 2.3 | 1.9 |
| 2020-06-17 | 4 | 1 | 30.0 | 24.6 | 17.8 | 5.8 | 3.7 |
| 2020-06-18 | | 5 | 31.4 | 23.5 | 19.2 | 5.2 | 3.8 |
| 2020-06-19 | | 8 | 36.8 | 23.6 | 21.9 | 6.2 | 3.9 |
| 2020-06-20 | | 9 | 35.4 | 21.6 | 23.2 | 5.3 | 4.1 |
| 2020-06-23 | 1 | 1 | 31.9 | 16.5 | 23.5 | 3.8 | 4.7 |
| 2020-07-01 | 1 | 2 | 31.5 | 19.9 | 23.4 | 4.9 | 5.7 |
| 2020-07-09 | 2 | 5 | 32.2 | 18.2 | 23.5 | 3.7 | 6.3 |
| 2020-07-10 | | 1 | 30.5 | 14.8 | 24.6 | 3.6 | 6.4 |
| Average | 1.9 | 3.8 | 32.2 | 20.0 | 20.0 | 4.4 | 5.0 |

The extreme atmospheric event with the longest duration and the highest magnitude was recorded between 17th and 20th of June 2020 (Figure 8). Average daily air temperature increase is 23.3°C and river water temperature increase is 5.6°C during this event.

This event has been selected for simulation with the numerical models.

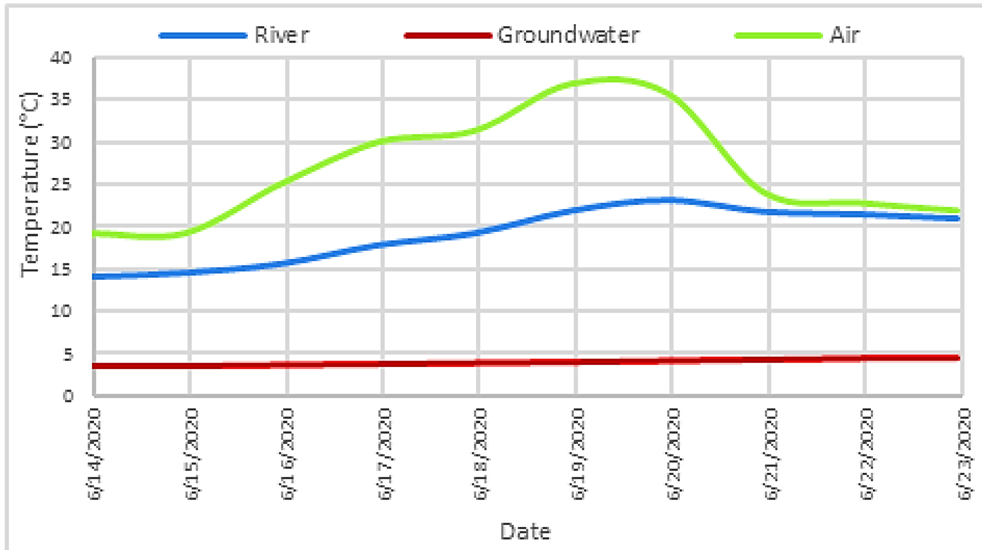


Figure 8. Daily maximum temperature data during the selected extreme atmospheric event.

### 2) Modelling results

The simulated groundwater flow has a greater travel time in the till and rock and velocity is about 10 times slower than in the alluvial unit (Figure 9). This shows the important impact of the unconfined aquifer made of unconsolidated alluvial deposits on the river thermal and water budget.

The maximum simulated river water temperature with the model considering the GW inflow to the river (M: R+GW) is 12°C less than the model considering only river flow (M:R) (Figure 10).

Simulated river water temperature with M:R model is on average 43% higher than with the M:R+GW model. This can be translated to an influence of 43% on river thermal budget by GW inflow during the simulation period. Considering difference of simulated river water temperature by the two modelling approaches when the maximum air temperature occurred (2020-06-18, 17:00:00), the GW reduced the maximum river water temperature by 52%.

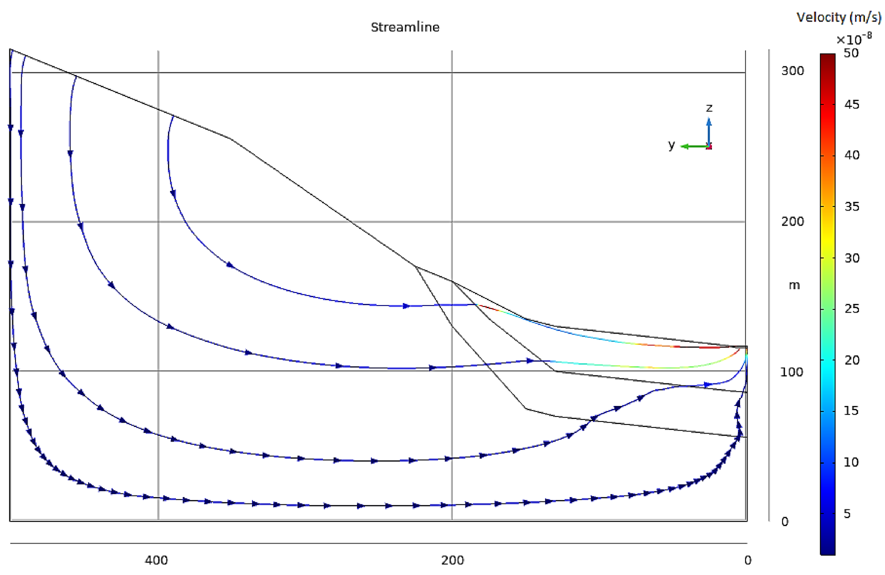


Figure 9. Simulated groundwater flow streamlines and velocity.

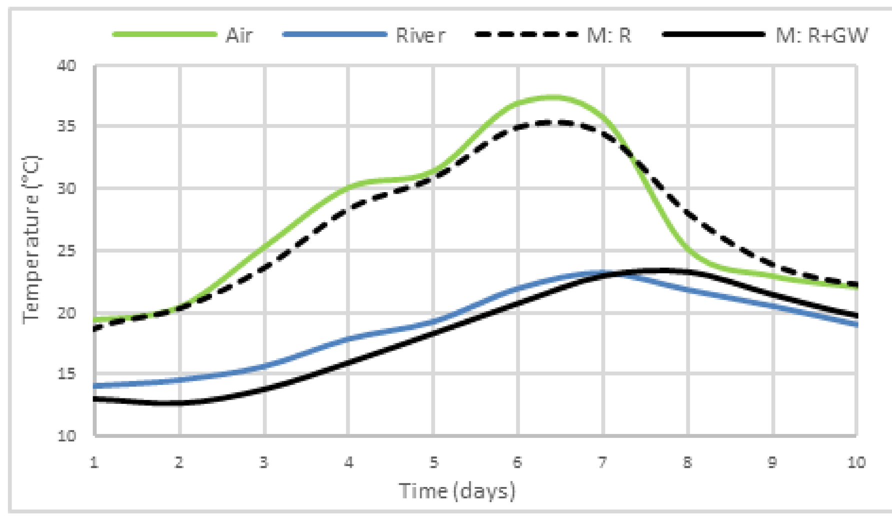


Figure 10. Observed air (green) and river water (blue) temperature comparison with simulated river water temperature with the M:R (black dashed line) and M:R+GW (solid black line) modelling approaches.

## CONCLUSIONS AND FUTURE WORK

The time of occurrence of high air temperatures is mainly in low river flow season of June and July except one being in the month of May. This is in accordance with previous studied of heat waves in the region (Khaliq et al., 2005).

Temperature time series showed the clear dependency of river water temperature to air temperature. During days with high air temperature or heat waves, the river water temperature can have higher increases. High air temperature does not mean a high river temperature. Therefore, while the increase in air and river temperature can be correlated directly during a heat wave, the river water temperature cannot be calculated by a direct correlation to air temperature.

Numerical modelling showed that river water temperature is not only related to atmospheric conditions like air temperature but GW temperature and inflow can have significant effect on river thermal budget (over 40%).

As of future works, the completed models can be implemented in different conditions other than the study sites of this research as part of scenario analysis. The combination of numerical modelling and climate change scenarios can show if the river temperature budget in the future will be suitable for certain fish species like Atlantic salmon that are more vulnerable to high temperature. For instance, different heat waves with different duration and magnitude can be simulated in the model to evaluate what type of heat waves can cause river water temperature to exceed the optimal or critical temperatures for fish.

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