Regional hydrogeological mapping in Abitibi-Temiscamingue, Quebec, Canada: from groundwater knowledge to land management

Vincent Cloutier*, Eric Rosa, Simon Nadeau, Pierre-Luc Dallaire, Daniel Blanchette, Magalie Roy, Nathalie Rey, and Raphaël Bondu

Groundwater Research Group, Research Institute on Mines and the Environment, Université du Québec en Abitibi-Témiscamingue, Campus d'Amos, Amos, Québec, Canada, e-mail address: gres@uqat.ca

ABSTRACT

The regional hydrogeological mapping in Abitibi-Temiscamingue was completed as part of the Groundwater Knowledge Acquisition Program, an initiative of the Quebec Ministry of the Environment aiming at the regional characterization of aquifers. The study area covers 20,000 km^2 and encompasses the Barlow-Ojibway Clay Belt within the Abitibi-Temiscamingue region. The regional conceptual hydrogeological model developed recognizes four main types of aquifers within the study area: unconfined granular aquifers, unconfined fractured rock aquifers, confined granular aquifers and confined fractured rock aquifers. The project involved the creation of an exhaustive inventory of preexisting data and the acquisition of complementary field and laboratory data. A comprehensive geodatabase was constructed and used to create more than 20 regional hydrogeological maps (1: 100 000) allowing an unprecedented characterization of the territory. However, despite these advances, the adequate integration and use of the hydrogeological information in land management remains a challenge, notably due to the complexity related to an adequate interpretation of the data and to the lack of dedicated knowledge transfer endeavors. Transfer strategies are therefore being developed in order to create user-friendly tools and regional maps providing basic hydrogeological information. This basic information is intended to be shared with municipal, regional and provincial governments in an effort to integrate hydrogeological data into prevention rather than remediation measures. This hydrogeological information also seems much needed for allowing the evaluation of the long-term effects of climate change and human pressure on groundwater resources and groundwater dependent ecosystems.

Keywords: Hydrogeological mapping, Aquifers, Groundwater protection, Land management, Canada

1. INTRODUCTION

Groundwater is a very important supply of freshwater for Canada. About 30% of its population (nearly 10 million inhabitants) depends on groundwater for their water supply (CCA, 2009). In the province of Quebec, 20% of the population relies on groundwater for its drinking water (MDDELCC, 2015). On the other hand, pressure on Canada's groundwater resource is increasing due to contamination, overexploitation and land-use conflicts (CCA, 2009). The intensification of industrial and agricultural activities, as well as natural climate variability and climate change, are threats to Canada's groundwater (CCA, 2009; Rivera et al., 2004).

To face this challenge, a unique and systematic program of regional hydrogeological mapping, the Groundwater Knowledge Acquisition Program, was implemented in 2008 by the Quebec Ministry of the Environment to ensure the protection and long-term sustainability of groundwater resources. Owing to the implementation of this Program, the Groundwater Research Group of the University of Quebec in Abitibi-Temiscamingue received funding to characterize comprehensively the hydrogeology of western Quebec, Canada (Figure 1), to better protect and sustainably manage groundwater resources (Cloutier et al., 2013; 2015).

Figure 1. Location of the study area in western Quebec, Canada.

*Corresponding author: vincent.cloutier@uqat.ca

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2. STUDY AREA

The study area covers approximately 20,000 km^2 in the administrative region of Abitibi-Temiscamingue, in western Quebec. Precambrian rocks of Archean age from the Superior geological Province of the Canadian Shield underlie the study area. Bedrock units essentially consist of north-west – south-east elongated belts of metamorphosed volcanic and sedimentary rocks, intruded by granitic rocks (MERQ-OGS, 1983).

The last glaciation and ice retreat left a strong imprint on the landscape of the region, including 1) fluvioglacial sand and gravel of eskers and moraines and 2) glaciolacustrine fine-grained deep-water deposits of the Barlow-Ojibway Clay Belt that act as a regional aquitard (Figure 2). Considering the similarities between the eskers and moraines within the region, both terms are jointly called "eskers" on Figure 2. Figure 3 illustrates an esker segment, bordered on its sides by finer sediments of the Clay Belt (clay plain) and overlying older sediments (till and subaqueous deposits) or sitting directly on the bedrock. Nadeau et al. (2015) provide a detailed description of the development of eskers within the Barlow-Ojibway proglacial lake.

About 73% of the population of Abitibi-Temiscamingue depends on groundwater for their water supply. Consistent with the regional hydrogeological framework of Figure 3, there are two main sources of groundwater in the region:

(1) the granular aquifers found in eskers;

(2) the fractured rock aquifers of the Canadian Shield.

The hydrogeology of the study area was comprehensively characterized through the Groundwater Knowledge Acquisition Program (Cloutier et al., 2013; 2015). The eskers contain aquifers supplying groundwater of excellent quality to several municipalities, and to a water bottling company. Inhabitants of the region that settled in the clay plain have their wells generally installed in the fractured Canadian Shield rocks below the clays, under confined conditions.

The regional conceptual hydrogeological model developed thus recognizes four main types of aquifers within the study area:

(1) unconfined granular aquifers;

(2) unconfined fractured rock aquifers;

(3) confined granular aquifers;

(4) confined fractured rock aquifers.

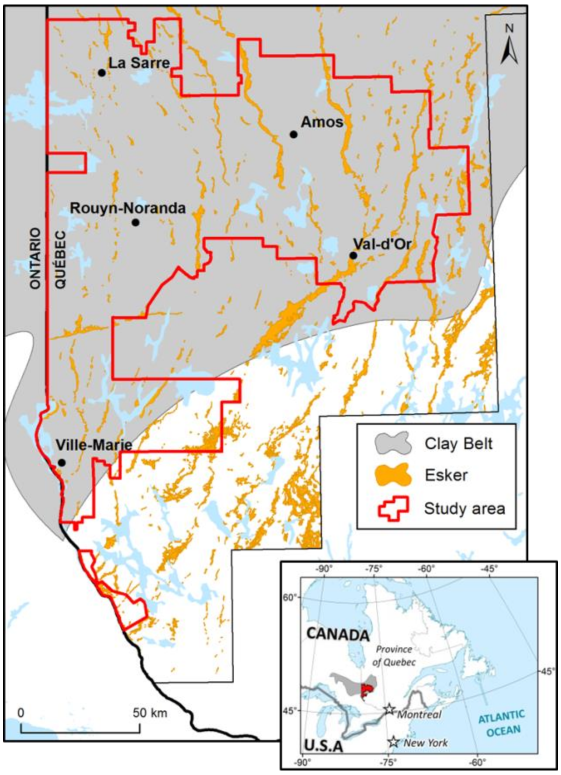

Figure 2. Context of the study area showing the imprint of the last glaciation, including the eskers that can host significant aquifers and the Clay Belt that acts as a regional aquitard.

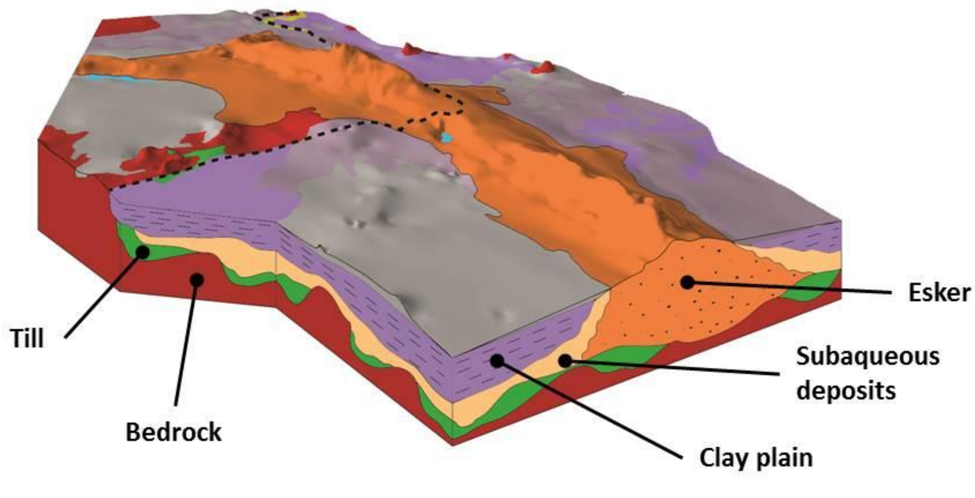

Figure 3. Conceptual diagram illustrating an esker segment and its relation with the fine-grained deposits of the clay plain (regional aquitard) within the hydrogeological framework of the study area (adapted from Cloutier et al., 2015).

3. METHODOLOGY

The projects of the Groundwater Knowledge Acquisition Program are carried out in partnership with regional stakeholders in water issues and land managers. The projects are to be completed in three phases:

(1) Exhaustive inventory and compilation of existing data;

(2) Complementary field work and laboratory analyses;

(3) Data analysis, interpretation, production of thematic maps and research reports, and transfer to regional stakeholders.

During the first phase, geological and hydrogeological data were collected from different sources, including government database, consulting firm reports, industries, etc. Following the compilation and integration of the data in a database, data were validated and used to produce preliminary thematic maps and to identify missing data.

The second phase was dedicated to the acquisition of complementary data necessary to establish the complete portrait of the groundwater resource. These include topography surveys, water sampling and analysis (precipitation, surface water, and groundwater), characterization of bedrock and surface deposits using drilling and geophysics, land use characterization, survey of groundwater levels, *in situ* hydraulic testing, etc. These new data were integrated into the project's database.

Finally, the third phase of the project included data analysis and interpretation to produce the final version of the thematic maps and the scientific report. This report presents the physical and human portrait of the region, the methodological approach for field and laboratory characterization, the regional geological context, the hydrogeological conditions (hydraulic properties, potentiometric surface, water budget, recharge, vulnerability, and aquifers delimitation), the hydrogeochemistry, the anthropogenic activities, the groundwater uses, as well as recommendation for sound groundwater management and monitoring of the resource.

One noticeable fact is that a total of thirteen regional hydrogeological mapping projects of the Groundwater Knowledge Acquisition Program were completed during the 2009-2015 period. These projects were led by research teams from seven Quebec Universities, in collaboration with their regional partners. A unique and efficient inter-university collaborative approach was developed to share equipment and services, co-supervised graduated students, and develop common protocols, from field data acquisition to maps production (Palmer et al., 2011). All projects thus used the same methodology and uniform methods for thematic maps production and databases, allowing the comparability between regions.

4. RESULTS

The Groundwater Knowledge Acquisition Projects realized in Abitibi-Temiscamingue provided an integrated portrait of the groundwater resources of the region, both in terms of water quantity and quality (Cloutier et al., 2013; 2015; Nadeau et al., 2015).

The project allowed the creation of an exhaustive inventory of the preexisting data and the acquisition of complementary field and laboratory data. The comprehensive geodatabase was used to create more than 20 regional hydrogeological maps (1: 100 000) allowing an unprecedented characterization of the region. Table 1 presents the list of the thematic maps produced during the Groundwater Knowledge Acquisition Projects in Abitibi-Temiscamingue.

Table 1. Thematic maps produced during the Groundwater Knowledge Acquisition Projects.

1. Roads, municipal limits, and place names
2. Topography
3. Hydrography
4. Watershed and sub-bassin limits
5. Vegetation cover
6. Wetlands
7. Soil cover
8. Quaternary geology
9. Bedrock geology
10. Land cover
11. Land use
12. Digital elevation model (DEM)
13. Surface slope
14. Overburden thickness
15. Topography of bedrock
16. Overburden hydrostratigraphy
17. Hydrogeological contexts
18. Regional potentiometric surface
19. Spatially distributed recharge
20. Preferential recharge and discharge zones
21. Aquifer vulnerability using the DRASTIC method
22. Potentially polluting activities

To illustrate some of the results obtained, Figures 4 and 5 present the maps of the spatially distributed recharge calculated from a discretized water budget approach and the aquifer vulnerability evaluated using the DRASTIC method, respectively, for the North part of the study region. Main recharge zones are associated with the unconfined aquifers of eskers, with calculated recharge values of aquifer estimated to be 300-400 mm/y (Figure 4). These recharge zones correspond to the areas where the DRASTIC index is the most elevated, above 146, the lowest values (<100) are associated with the presence of the Clay Belt (Figure 5).

The new groundwater knowledge is not enough for a sustainable management of the resource; strategies must be developed to optimize the adequate use of quantitative hydrogeological data in land management effort to protect groundwater resources.

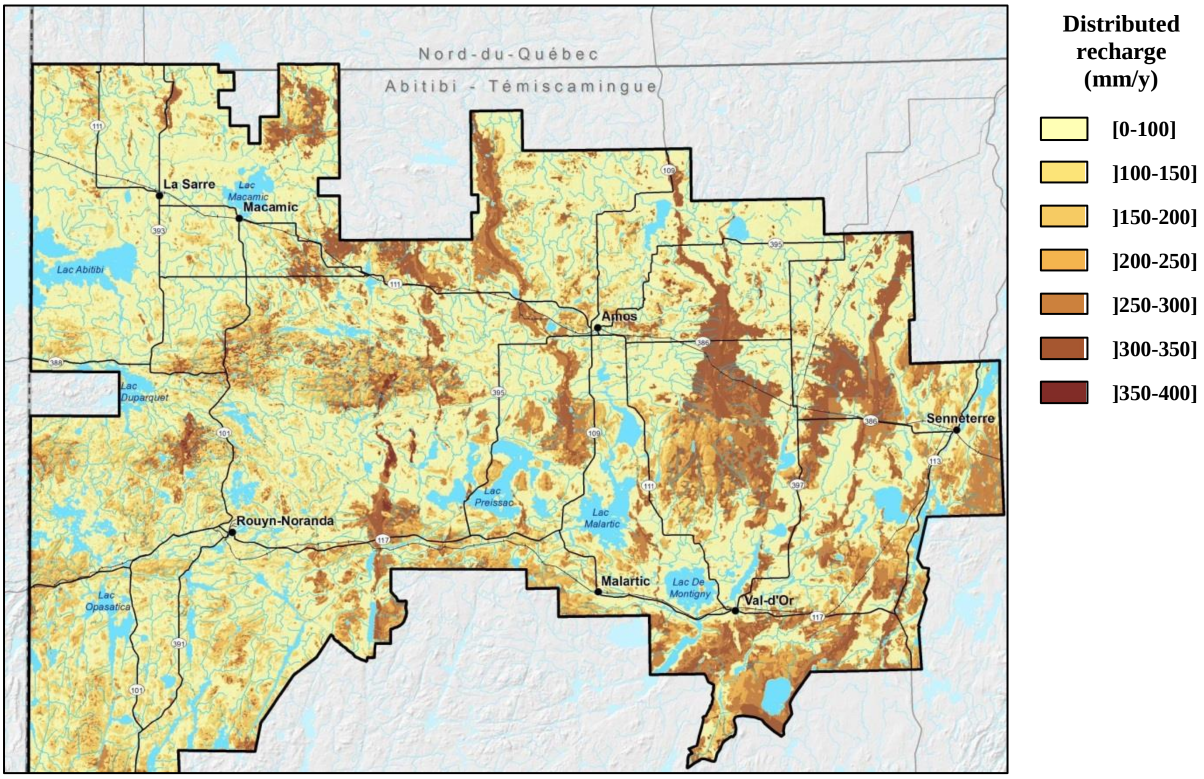

Figure 4. Map of the spatially distributed recharge calculated from a discretized water budget approach.

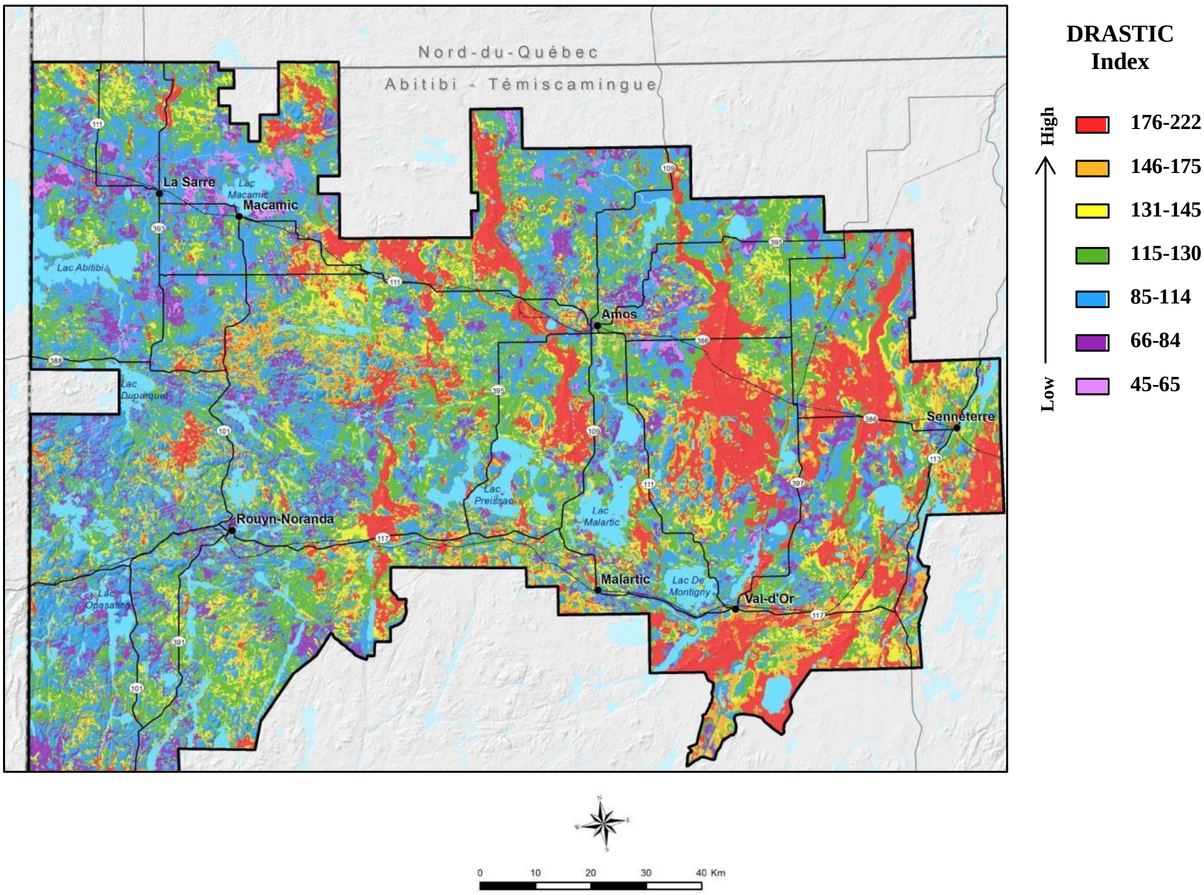

Figure 5. Map of the aquifer vulnerability evaluated using the DRASTIC method.

5. DISCUSSION AND CONCLUSION

Now that we have a comprehensive understanding of the hydrogeology of the study area, the transfer to regional stakeholders and the adequate integration and use of the hydrogeological information in land management strategies remains a major challenge. Numerous factors explain the difficulty for the regional partners to adequately use the quantitative hydrogeological data in their land management strategies, including:

(1) The availability of the data;

(2) The complexity related to the interpretation of hydrogeological data and maps;

(3) The lack of dedicated knowledge transfer endeavors.

In spite of these difficulties, knowledge transfer to project partners is critical and essential to foster sustainable land and groundwater management. As groundwater scientists, it is our responsibility to work with the stakeholders to develop efficient transfer strategies. Here, we present examples of transfer strategies that are being developed in order to create user-friendly tools and regional maps providing basic hydrogeological information.

A first example is the realization of a regional hydrogeological synthesis allowing the interpretation of the hydrogeological conditions within the defined hydrogeological contexts of the study area (Figure 6). The integration of geological and hydrogeological data allows the definition of seven hydrogeological contexts (HC) in the study area (Cloutier et al., 2013; 2015). The seven hydrogeological contexts, that were grouped based on similar hydrogeological conditions, are representative of the whole study area.

As a second example of the use of regional hydrogeological data in land management, Nadeau et al. (2015) developed a user-friendly tool based on GIS and indices to assist managers for better planning sand and gravel extraction activities to support the protection of the groundwater in eskers.

Knowledge transfer is also done during workshops with the regional partners, with the participation of the Quebec Groundwater Network (Tremblay et al., 2015) and of the SESAT (Société de l'eau souterraine Abitibi-Témiscamingue), a regional organism that promotes groundwater knowledge transfer and consultation for an integrated management of eskers and groundwater in the region.

The hydrogeological information (scientific reports, thematic maps, geodatabase) are shared with municipal, regional and provincial governments to promote the integration of hydrogeological data into prevention rather than remediation measures. This hydrogeological information is needed for the sustainable management of the resource, and it also seems much needed for allowing the evaluation of the long-term effects of climate change and human pressure on groundwater resources and groundwater dependent ecosystems.

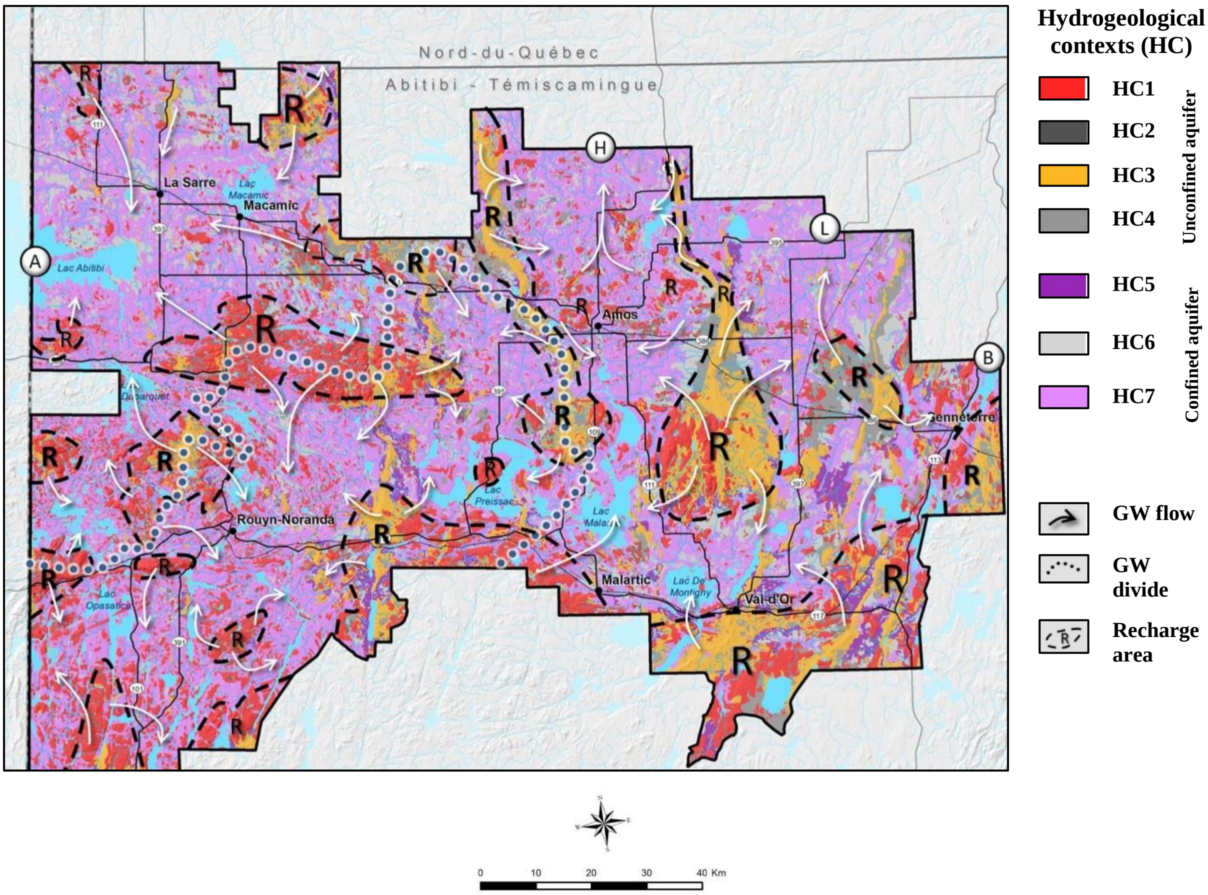

Figure 6. Regional hydrogeological synthesis of the North part of the region. Each HC were defined on the basis of their hydrogeological characteristics, including recharge, vulnerability and water quality (Cloutier at al., 2013; 2015).

6. ACKNOWLEDGMENTS

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