Volume estimate of granular deposits and groundwater reserves of the Abitibi-Témiscamingue eskers, Québec

Simon Nadeau[1,2], Vincent Cloutier[2], Robert-André Daigneault[1], Jean Veillette[2]
[1] Département de géographie– Université du Québec à Montréal, Montréal, Québec, Canada
[2] Groupe de recherche sur l'eau souterraine, Département des sciences appliquées – Université du Québec en Abitibi-Témiscamingue, Campus d'Amos, Amos, Québec, Canada

ABSTRACT
The eskers of Abitibi-Témiscamingue are known for the high quality of their groundwater. They support, however, a wide variety of activities including sand and gravel extraction and provide drinking water to several municipalities. To properly manage the resource and minimize land use conflicts more information is required. This study outlines the methodology developed to provide the first regional, volume estimate of the granular deposits contained in eskers (10.6 km^3) and to determine their aquifer potential which was classified into 4 different levels. About 70% of eskers show conditions favourable to the presence of groundwater.

RÉSUMÉ
Les eskers de l'Abitibi-Témiscamingue sont reconnus pour la qualité exceptionnelle de leur eau souterraine. Étant soumis à plusieurs activités anthropiques, dont l'extraction des sables et graviers et l'approvisionnement en eau potable de plusieurs municipalités, des conflits d'usage émergent. Dans le but d'en assurer la bonne gestion il est impératif d'améliorer nos connaissances de la ressource. Cette étude décrit la méthodologie développée pour fournir la première évaluation régionale du volume granulaire (10.6 km3) des eskers et classifier leur potentiel aquifère, lequel est subdivisé en 4 niveaux. Environ 70% des eskers présentent des caractéristiques favorables à la présence d'eau souterraine.

1 INTRODUCTION

The contribution of Quaternary studies to the economic geology of Nordic countries was convincingly demonstrated in several papers published in a special number of the journal Striae (1990). These document the expansion of the granular materials extraction industry in Scandinavian countries and stress the need for effective management of the resource to protect groundwater reserves and accommodate activities on eskers. With numerous large eskers laid out for the most part in a subaqueous environment, the Abitibi-Témiscamingue region has a glacial history similar to that of several areas in Scandinavia and consequently faces the same land use problems. Abitibi eskers support a wide variety of activities; logging, sand and gravel extraction, recreation and locally contain high-quality groundwater reserves. Several municipalities draw their supply of drinking water from wells located in nearby eskers. However, the region lacks at this time the basic information to properly manage the resource. Based on the distribution of eskers known from surficial geology maps, this study presents the first regional quantitative estimate of the Abitibi-Témiscamingue granular reserves and their groundwater potential.

1.1 STUDY AREA

It covers a large part, approximately 68 000 km^2, of Abitibi-Témiscamingue located in north-western Quebec, between the towns of Témiscaming to the south and Matagami to the north (Figure 1).

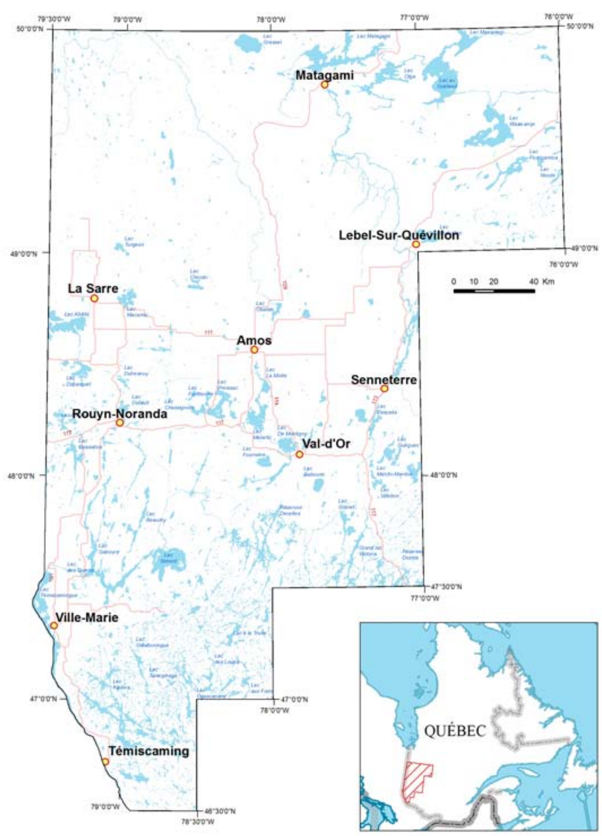

Figure 1. Study Area

2 ESKER SEDIMENTATION IN DEEP PROGLACIAL WATERS: A CONCEPTUAL MODEL

A large part of the study area was submerged by the deep proglacial waters of Lake Barlow-Ojibway. The morphology, internal structure and surficial characteristics of eskers result from a combination of glaciofluvial, glaciolacustrine and postglacial processes. Figure 2 illustrates the sequence of events that led to the formation of Abitibi eskers as they appear today. The model is derived from photo-interpretation, field observations, drill holes and published works.

(1) Subaqueous fans are formed at the emergence of a subglacial, high-energy, meltwater stream in deep water at the ice front due to the change in flow dynamics resulting from the abrupt passage of flow in an ice-confined conduit to one in relatively calm lake waters.

(2) A sequence of overlapping subaqueous fans results from the retreating ice front; icebergs are detached from the ice margin and float away; some ice blocks are trapped in granular materials along the longitudinal axis of the esker.

(3) Silt and clay (varves) settled to the bottom of the lake basin in calm waters away from the ice front. In central Abitibi the upper limit of varves rarely exceed 320 m, the basal granular parts of eskers below this level get buried below the clay.

(4) Wave actions resulting from dropping lake waters erodes and flattens the upper granular crest of the esker and redistributes the material, mostly sands, over the fine-grained deep-water deposits on the esker flanks; the melting of the trapped ice blocks in the esker produces steep-sided depressions (kettle).

(5) Wave-cut benches on the esker flanks record the lowering of the lake level; streams start to incise the young sediments, eolian processes rework the littoral sands located on the east flanks of eskers, vegetation colonizes these new surfaces.

(6) Deteriorating climatic conditions in mid-Holocene time and after probably led to a higher regional water table and to the development of extensive peatlands fed by springs coming out of eskers that give rise to streams, peat stabilizes eolian deposits, stream incision continues, vegetation expands with conifers occupying the well-drained high esker points.

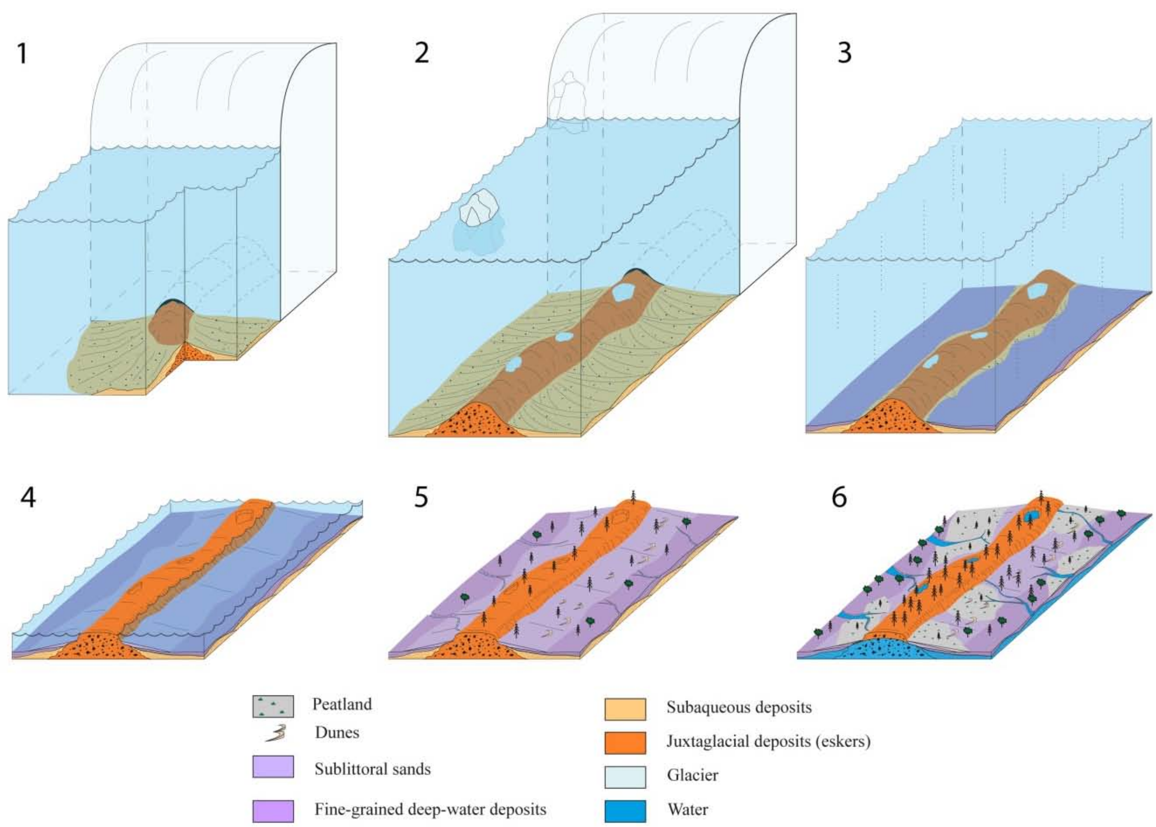

Figure 2. A conceptual model for esker formation in deep glaciolacutrine waters.

Figure 3 shows a cross-section through an esker that possesses the complete sequence of sediments shown in the preceding model (Figure 2). These eskers are typical of the central Abitibi plain characterized by a thick glaciolacustrine clay cover. Field observations indicate a strong correlation between the level of emergence of large springs and seepage zones and the upper level of the deep-water facies fine-grained deposits (Champagne, 1988: Veillette *et al*., 2004). Bedrock depressions beneath eskers and the presence of fine-grained deposits of low permeability along their flanks present favourable conditions for the retention of groundwater within them.

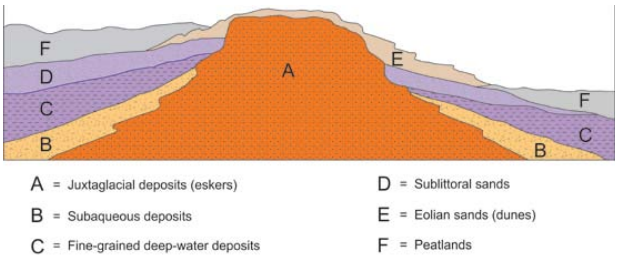

Figure 3 Idealized cross-section of Abitibi esker showing the sequence of glaciofluvial, glaciolacutrine and postglacial sediments.

3 A CLASSIFICATION OF ESKERS AS POTENTIAL GROUNDWATER RESERVOIRS

Veillette *et al.* (2004) subdivided the eskers of the region into four broad types according to their sedimentation environments, the four types may occur along the same esker (Figure 4):

(A) the esker lies above or outside the area submerged by proglacial waters,

(B) the esker was submerged but lies at a depth located above the level of deep-water fine-grained deposition (varves),

(C) the esker lies within the deep-water facies and is partly buried by fine-grained deposits,

(D) the esker is nearly or totally buried by fine-grained deposits.

Eskers of Type C contain most of the municipal and industrial groundwater facilities of the region. These eskers have the highest aquifer potential of the region. The aquifer potential of Type D esker cannot be determined as part of this study due to lack of geomorphological criteria visible on airphotos.

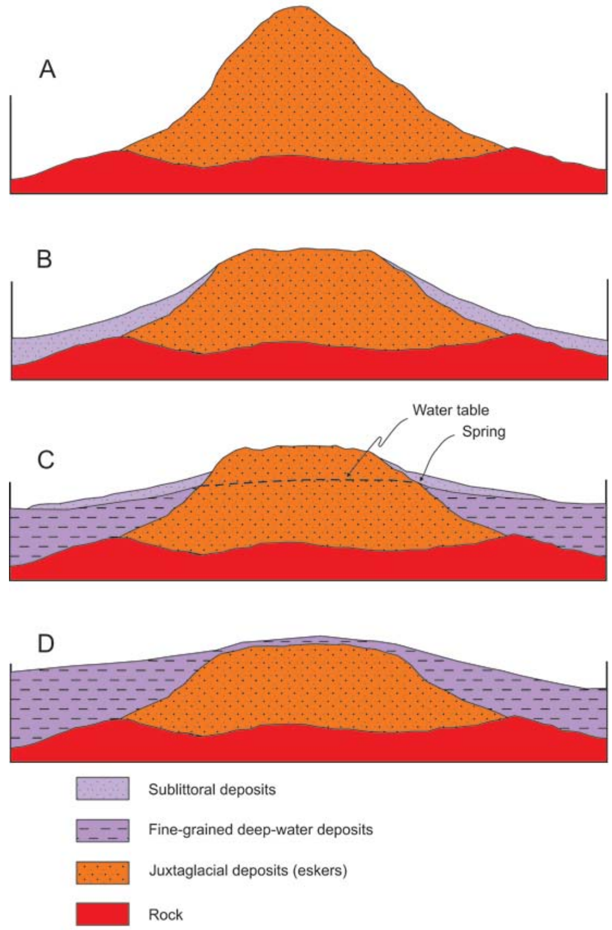

Figure 4. Sedimentation environments for eskers in Abitibi-Témiscamingue.

4 VOLUME OF GRANULAR DEPOSITS

The volume of granular deposits was estimated using GIS methods. A DEM (digital elevation model) was generated by *topo to raster* in ArcGIS 9.3 for each esker from a 1:20 000 topographic data base (Figure 5). The apparent granular mass of the esker, which is the outcropping median ridge(s), that stands above the confining littoral/eolian sands, clay or peat as depicted on surficial geology maps was measured. It follows that this volume represents a minimum value since it does not allow for the buried basal parts of eskers that may extend laterally below the confining deposits. Field observations and drilling show that sandy subaqueous fans extend well beyond the outcropping predominantly coarse-texture median part of eskers. The thicker and most extensive the confining deposits the smaller the volume estimates.

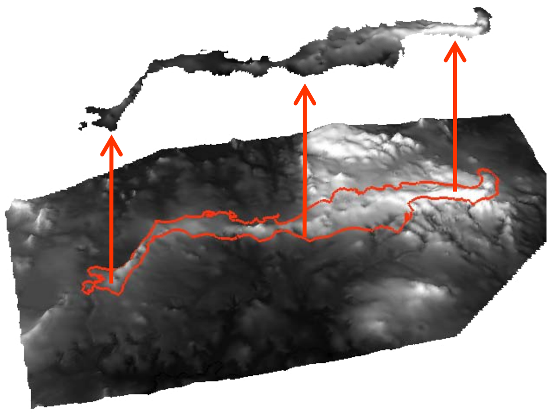

Figure 5. DEM used to estimate the apparent volume of granular material in an esker segment.

5 AQUIFER POTENTIAL

The presence of an aquifer in an esker is closely related to its sedimentation environment. Sixteen surficial geology maps produced by the Geological Survey of Canada (see References), supported locally by airphoto-interpretation, were used to identify the main granular core of the eskers and the nature and extent of the surrounding sediments. A model was derived from empirical measurements of the maximum level reached by the glacial lake to produce a map showing variations in the depth of proglacial lake waters over the region. This allowed the classification of all esker segments into one of esker Type A, B, C or D since water depth is the key factor controlling clay sedimentation. Fine-grained deposits of low permeability resting on the flanks of an esker, as is the case with Type C esker (Figure 4), confine groundwater within it.

Bedrock topography below the eskers is also a major factor affecting the aquifer potential. It was assumed for classification purposes that the presence of rock outcrops (or thin till cover) within and in the vicinity of eskers imply the absence of major bedrock depressions, hence of natural groundwater reservoirs, below the eskers. A low aquifer potential was assigned to esker segments occurring in this type of environment. Conversely the presence of springs, identified from airphoto-interpretation and field visits, emerging at the contact between the upper level of the confining clays and the granular flanks of eskers were taken as positive indicators of groundwater. Peatlands in direct contact with eskers usually correspond to seepage zones. This process is under investigation.

Depending on the influence of each of these characteristics on the presence of an aquifer in the esker, a value of 0, 1 or 2 was assigned. The value of 0 was assigned when the feature does not allow the maintenance of groundwater in the esker segment or reduce the volume. The value of 1 indicates that the characteristic influence positively the presence of an aquifer or cannot conclude that his absence. The value of 2 was assigned to the feature that indicates the presence of an aquifer. The integration of these characteristics result in four different levels of aquifer potential (table 1):

- Level 1 No geomorphological evidence of a groundwater reservoir were observed,
- Level 2 Low aquifer potential. Some characteristics suggest the possibility of a limited groundwater reservoir,
- Level 3 Good aquifer potential. Some characteristics suggest the presence of a groundwater reservoir,
- Level 4 High aquifer potential. All characteristics suggest the presence of a groundwater reservoir.

Table 1 Aquifer potential levels (4 is highest) based on weight given to the different characteristics observed on surficial geology maps and airphotos

Type of sedimentation environments (figure 4)	Outcropping bedrock in the vicinity	Springs and seepage zones	Aquifer potential level
A and B (0)	Yes (0)	Yes (2)	2
		No (1)	1
	No (1)	Yes (2)	3
		No (1)	2
C (1)	Yes (0)	Yes (2)	3
		No (1)	2
	No (1)	Yes (2)	4
		No (1)	3

6 RESULT

The volume of regional granular reserves in the region is estimated at about 10.6 km^3 (Figure 6). This is a most conservative estimate since, as discussed earlier for the large eskers located in the low areas of the glaciolacustrine basin, the basal parts of these eskers may extend below the clay for considerable distances. Eskers located outside the glaciolacustrine basin are usually of modest dimensions. In the lowest parts of the basin, such as in the thick clay plain of the Lake Abitibi area around La Sarre (Figure 6), the measured (apparent) volume of granular materials is the lowest (0.1 km^3) of the region. The same constraint applies to the area north of 49º Lat N south of James Bay. Large glaciofluvial deposits such as the Harricana Moraine and the Saint-Mathieu-Berry esker protrude 25 m or more, up to 50 m above the surrounding clay plain. This is the case for the Val d'Or area that contains about 30% of the regional granular reserves. The Amos, Senneterre and Val-d'Or areas contain about 50% of the Abitibi-Témiscamingue granular reserves.

The highest aquifer potential level (Level 4) applies to about 40% of esker segments mostly located in the deepest part of the glaciolacustrine basin (Figure 7). Grouping level 4 and level 3 segments (32% of all esker segments), even if the latter is associated with a lower groundwater potential than level 4, about 70% of eskers in the study area have a good aquifer potential. Most of these eskers lie within the clay plain. Outside the glaciolacustrine basin, as is the case for most of the Témiscamingue area devoid of clay, eskers belong to levels 1 or 2.

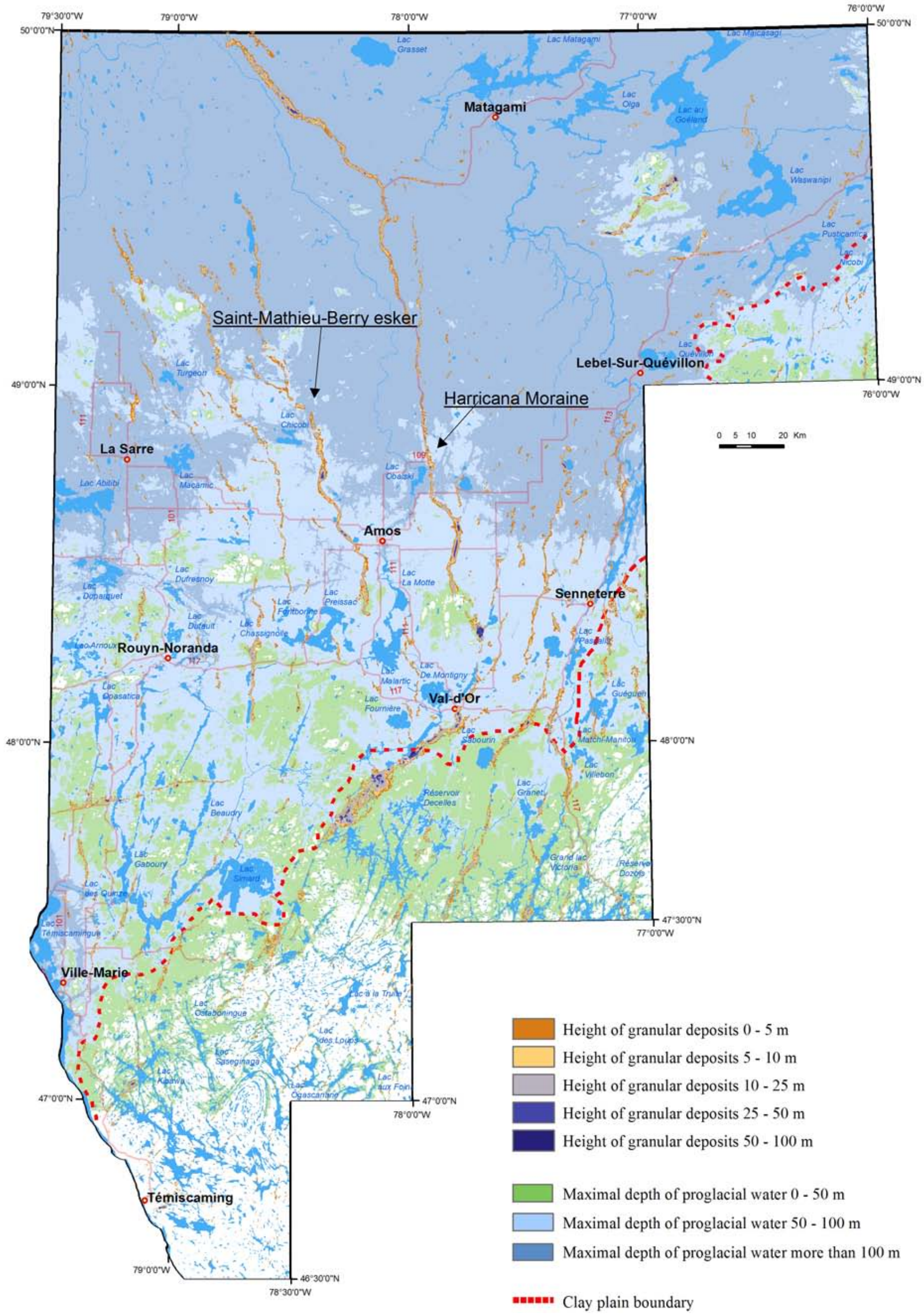

Figure 6. Height of eskers and maximal depth of proglacial lake Barlow-Ojibway in the study area.

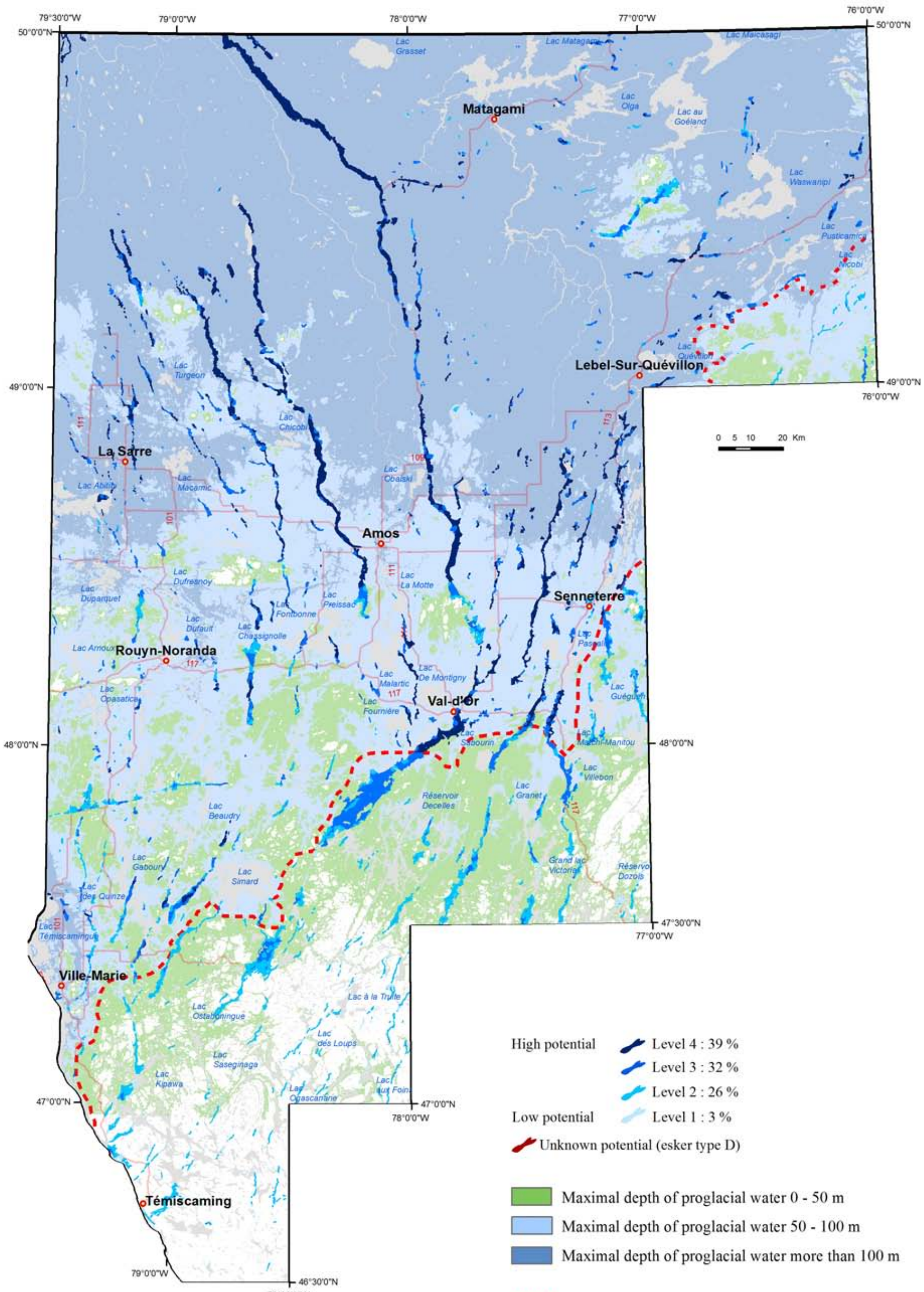

Figure 7. Aquifer potential and maximal depth of proglacial lake Barlow-Ojibway in the study area.

7 CONCLUSION

Data presented constitute the first regional conservative estimate for the volume of granular reserves in the eskers of the region. The study shows the great variations in volume, grain-size and aquifer potential that can be encountered along the same esker and as such outlines the need for subdividing eskers into individual segments possessing different physical properties and consequently different land use objectives. This knowledge will allow physical planners to discriminate between esker segments with widely different land use vocations and lead to the protection and further investigation of segments showing favourable conditions for the retention of groundwater.

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