A COMPLEX RECHARGE NETWORK, THE BARRAUTE ESKER, ABITIBI, QUEBEC

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ABSTRACT
Groundwater is the source of potable water for more than 73% of the population of Abitibi-Témiscamingue. Several municipalities of the Regional County Municipality (RCM) of Abitibi pump water of exceptional quality from aquifers located in eskers. The aquifer potential of Abitibi eskers is largely dependant on the presence of the Lake Ojibway clay that acts as a sealant retaining groundwater within the eskers. The Barraute esker, that extends over 20 km and contains an aquifer that supplies water to the village of Barraute, is buried by clay over most of its course, making recharge by precipitations from the surface of the esker problematic. This manuscript reports on possible recharge mechanisms related to regional geological conditions in the Barraute area.

RÉSUMÉ
Environ 73% de la population de l'Abitibi-Témiscamingue tire son eau potable de l'eau souterraine. Plusieurs municipalités de la Municipalité régionale de compté (MRC) d'Abitibi puisent une eau de qualité exceptionnelle d'aquifères contenus dans des eskers. La présence d'argile mise en place par le Lac Ojibway sur et au contact d'eskers retient l'eau à l'intérieur de ceux-ci et ainsi en dicte le potentiel aquifère. La recharge de l'esker de Barraute, long d'environ 20 km et source d'eau potable pour le village de Barraute, s'explique mal par l'apport des précipitations à sa surface puisqu'il est enfoui sous l'argile sur la majeure partie de son étendue. Nous examinons ici des modes de recharge probables pour cet esker compte tenu des connaissances acquises sur la géologie régionale.

1 INTRODUCTION

This paper presents an overview on the geology of eskers as groundwater reserves in a selected area of north-western Quebec with emphasis on the recharge mechanism of an aquifer located in the buried Barraute esker (Fig.1). In Abitibi-Témiscamingue groundwater pumped from aquifers in granular deposits or in fractured Canadian Shield rock, accounts for more than 73% of water used for domestic purposes (MDDEP, 2000). This proportion is substantially higher than the provincial (about 21%) (Gouvernement du Québec, 2003) or Canadian (30,3%) (Statistique Canada, 2003) average, and reaches 100% for the RCM of Abitibi which draws most of its drinking water from eskers. Eskers are usually defined as long, narrow, sinuous ridges, commonly steep-sided, composed of irregularly stratified sand and gravel that was deposited by subglacial streams flowing between ice walls or in ice tunnels emerging at the ice margin of a retreating glacier (Bates and Jackson, 1980). This definition better describes eskers deposited in a sub-aerial environment than eskers from the Clay Belt of north-western Quebec and north-eastern Ontario that were deposited in close contact with large proglacial Lake Ojibway. The deep waters at the ice front gave rise to extensive fan-shape subaqueous deposits, subsequently covered by thick fine-grained glaciolacustrine deposits laid down away from the ice front. The morphology and internal structure of eskers of the Clay Belt of north-western Quebec, reflect this sedimentological environment. The association between the granular body of eskers and the enclosing younger glaciolacustrine clay proved to be the major factor in determining the aquifer potential of Abitibi eskers and led to the classification of eskers described below.

Figure 1 Location of Abitibi-Témiscamingue region and the Regional County Municipality (RCM) of Abitibi

2 GROUNDWATER STUDIES OF ABITIBI ESKERS; A REVIEW

Several large eskers and other landforms composed of granular deposits located in the Abitibi clay plain contain aquifers, some of which supply water of exceptional quality to several municipalities and to two bottling factories. These granular deposits occupy an area of at least 1300 km^2 in the area shown in Figure 2; their volume, and the proportion of the deposits lying below or above the water table, remain to be determined. The quality of drinking water pumped from some of these aquifers was recognized by the Berkely Springs annual water tasting contest held in West Virginia, USA, that granted awards to three Abitibi municipalities and to one bottling company, since 2000. In 2003, the Université du Québec in Abitibi-Témiscamingue (UQAT), with the support of concerned citizen groups, the business and academic communities, and the public in general, initiated a regional groundwater research program to evaluate the potential of the resource and to insure its sound management and protection. The Abitibi RCM was chosen as a pilot study area because (1) it contains some of the largest eskers of the region (Figure 3), (2) of its total dependence on groundwater for domestic and industrial uses (3) of the presence of a major bottling plant and elaborate municipal infrastructures related to the use of groundwater, (4) of extensive subsurface and hydrogeological data (well logs, pumping tests and chemical analyses) acquired during the construction of commercial and municipal groundwater facilities made available for researchers.

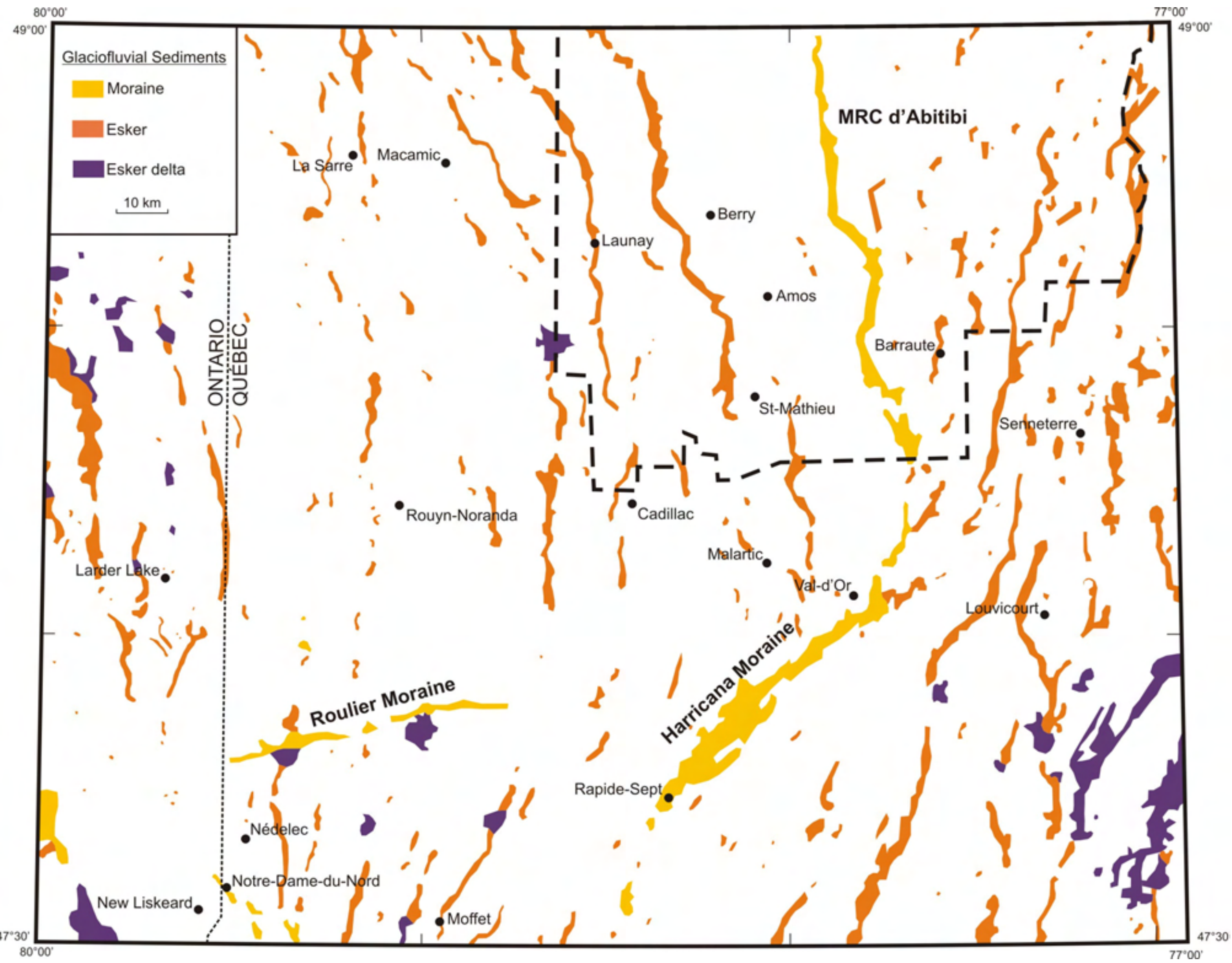

Figure 2 Major granular landforms and potential aquifers of a large portion of north-western Quebec and north-eastern Ontario, the outline of the Abitibi RCM is shown. Adapted from Veillette (1996), Baker (2000a, 2000b) and Veillette et al. (2003).

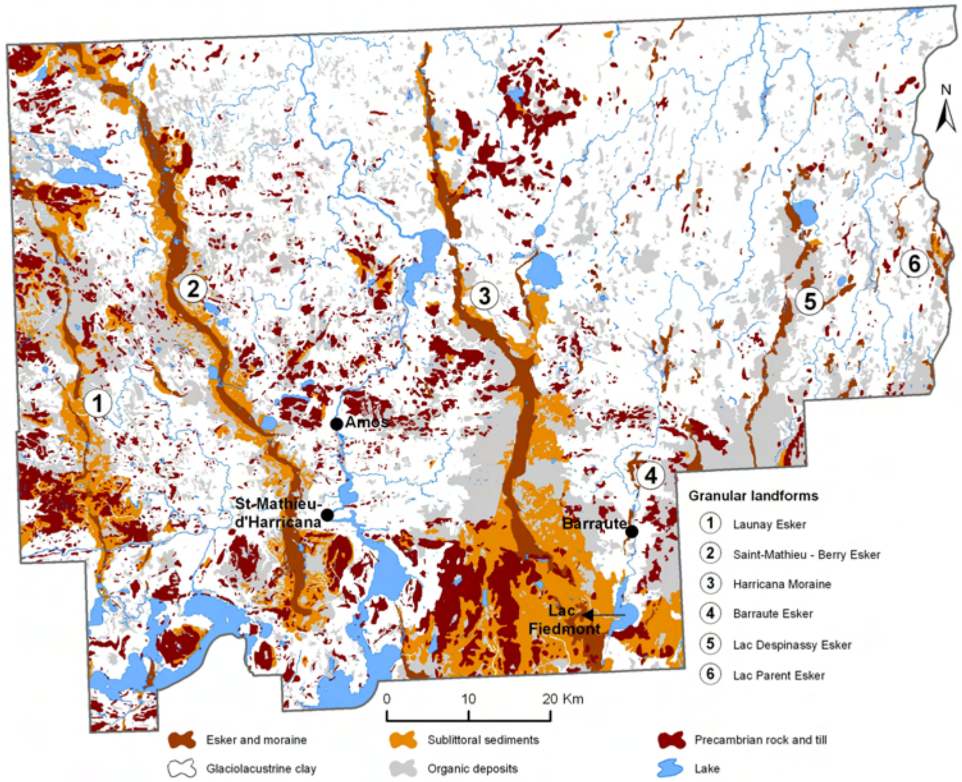

Figure 3 Generalized Quaternary geology of Abitibi RCM; six main eskers (counting the Harricana Moraine as an esker) cross the RCM. Adapted from Veillette et al. (2003)

Champagne (1988) produced the first systematic study of the physical and chemical characteristics of spring water flowing from eskers in the Abitibi RCM to evaluate the potential for fish farming. An inventory of the physical and chemical characteristics of springs and lakes on eskers was undertaken in summer 2003 by UQAT researchers (Veillette et al., 2004; Maqsoud et al., 2004). The same year the Geological Survey of Canada (GSC) in cooperation with the Institut National de la Recherche Scientifique – Eau, Terre et Environnement (INRS- ETE), Quebec, responded positively to a request made by UQAT for a thematic hydrogeological study of a segment of the large Saint-Mathieu-Berry esker near Amos (Fig. 3) The objectives were to reconstruct the stratigraphy and internal structure of this esker segment and develop a 3D geological model to characterize and establish the groundwater flow dynamics in the aquifer system, and to provide a model for further investigation of other eskers in the region. The municipalities of Amos and the Esker bottling water company (now Eska), established near St-Mathieu d'Harricana, provided GSC and INRS researchers with pumping test results, stratigraphic logs and geophysical data. UQAT took charge of the regional hydrogeological characterization of the Abibiti RCM to understand both the hydrodynamics and hydrogeochemistry of the aquifer systems associated with eskers with the ultimate objective of assessing their aquifer potential and to support their sound management.

This cooperative effort and multi-disciplinary approach led to a first assessment of the Saint-Mathieu-Berry esker (Bolduc et al., 2006; Riverin, 2006). In 2004, a regional water well sampling program and the compilation of stratigraphic information, involving about 800 water wells throughout the RCM, was completed. It was followed in 2006 by a systematic hydrochemistry study undertaken to evaluate water quality throughout the RCM (Cloutier et al., this volume). A hydrogeological atlas (Cloutier et al. in preparation) summarizes the research realized to date by UQAT and by some of its research partners.

3 CLAY BELT ESKERS AS POTENTIAL AQUIFERS: A CLASSIFICATION

The study conducted by Champagne (1988) on springs flowing out from eskers in Abitibi revealed that glaciolacustrine clay deposited on the flanks of eskers acted as a sealant that confined groundwater within the pervious body of the esker. Field work in 2003 and 2004, carried out by UQAT researchers, showed that most of the major springs flowing out of the Saint-Mathieu-Berry esker were located at, or in the vicinity, of the maximum level reached by Ojibway clay, which, in the study area, is about 320 ± 5 m (Veillette, 1994). The Saint-Mathieu-Berry esker and the Harricana Moraine show large granular surfaces lying above the highest level reached by the clay, through which recharge from precipitations can occur (fig. 3). On the other hand, eskers deposited at lower elevation in the region, such as the Launay, Barraute, and Lake Despinassy eskers are partially or totally buried by clay making recharge by precipitations alone from the surface of the eskers difficult to explain, since only narrow, discontinuous, crests emerge from the surrounding clay plain, and in some locations the eskers are totally buried (fig. 3). This characteristic led to a classification of Abitibi eskers into four types according to their elevation relative to the level of proglacial Lake Ojibway, and to the maximum level reached by the clay blanket (Fig. 4). In 2005 a study of the Barraute esker (Type D) was undertaken and followed through in 2006 with the objective of comparing geological and hydrogeological conditions with the Saint-Mathieu-Berry esker (Type C). Both eskers present stratigraphic relationships and sedimentological characteristics that are representative of a broad range of sedimentary environments of Abitibi eskers that are presently used as aquifers by the local population.

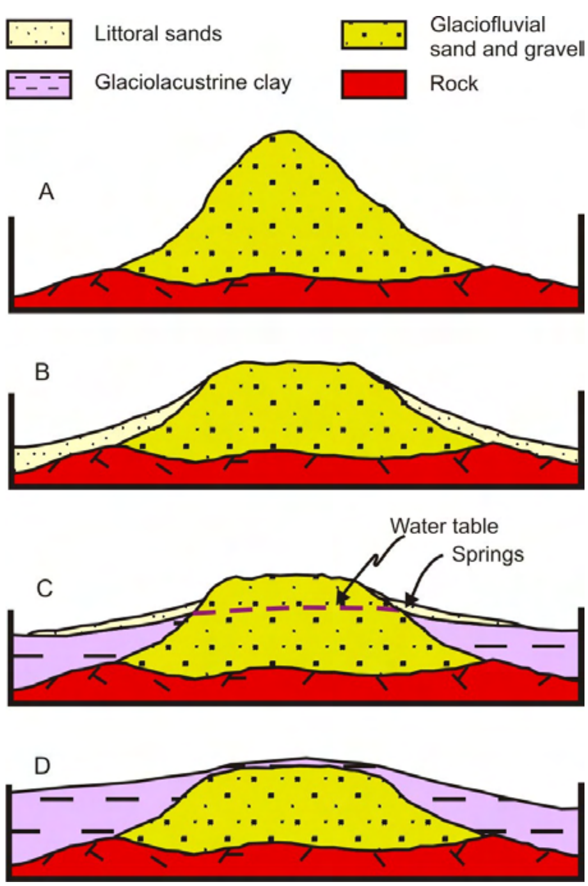

Figure 4 Classification of eskers according to the maximum level reached by Lake Ojibway clay as proposed in Veillette et al. (2004). Eskers found on interfluves located above the maximum level reached by the lake (Type A), eskers, reworked by Lake Ojibway waters at lower elevation but located above the maximum level reached by the Ojibway clay plain (Type B), eskers partially buried by the clay cover (Type C) and eskers totally buried by the clay cover (Type D).

4 QUATERNARY GEOLOGY OF THE BARRAUTE AREA: THE BARRAUTE ESKER

The Harricana Moraine (Figs. 2 and 3) is an imposing interlobate glaciofluvial landfrom composed of stratified sand and gravel that extends well beyond the limits of the Abitibi RCM (Veillette, 1996). Because of its granular composition it possesses hydrogeological properties similar to those of nearby eskers. It is interpreted as an interlobate feature because it marks the zone of separation between two major ice-flow and associated landform systems; one retreating toward the NW west of the moraine, and the other retreating toward the NE, east of it (fig. 3). Minor recessional moraines in the Barraute area, striations and the orientation of eskers, testify to a retreating ice front toward the NE, east of the Harricana Moraine (Paradis, 2005). The Saint-Mathieu-Berry esker belongs to the NW lobe and the Barraute esker to the NE lobe. The Barraute esker branches off from the moraine in the vicinity of lake Fiedmont (fig. 5).

Over 60% of the Abitibi RCM is covered by clay, about 20% by peat mostly located along eskers, and only about 4% by the granular deposits of eskers and those of the Harricana Moraine. The rest of the area is occupied by near-shore sands, till and bedrock outcrops. The results presented below describe some of the current research done by UQAT on the geological conditions governing the recharge of the Barraute esker. The esker lies in the lowest part of a linear, structural depression oriented northeast- southwest, along a fault zone (Avramtchev and Lebel-Drolet, 1981) and is overlain by a nearly continuous varved clay cover (Figure 5). The alignment of discontinuous outcrops of esker gravel through the clay shows the general orientation of the esker but not its extent. The esker is much more extensive below the clay due to the subaqueous style of sedimentation of glaciofluvial sediments laid down in large bodies of standing water (Rust and Romanelli, 1975).

The village of Barraute, partly built on the esker, draws a high-quality water that has a total dissolved solids content of 188 mg/L from a well in the esker, south of the village. The Laflamme River runs parallel and close to the esker, but is an unlikely source for recharge since the river bed is carved entirely in clay with no apparent connection with the granular core of the esker. The exposed granular surfaces of the Barraute esker were mapped in details during summer 2006 and appear too limited in extent to account for the recharge required to sustain the 600 U.S. gal/min capacity of the municipal well.

Given these conditions, the investigation into the recharge of the esker was directed toward the interaction between the surface water and groundwater at various locations along the esker and its presumed extent below the surface (fig. 5). A prerequisite for this study was a better understanding of the topography of bedrock and the Quaternary geological units overlying it.

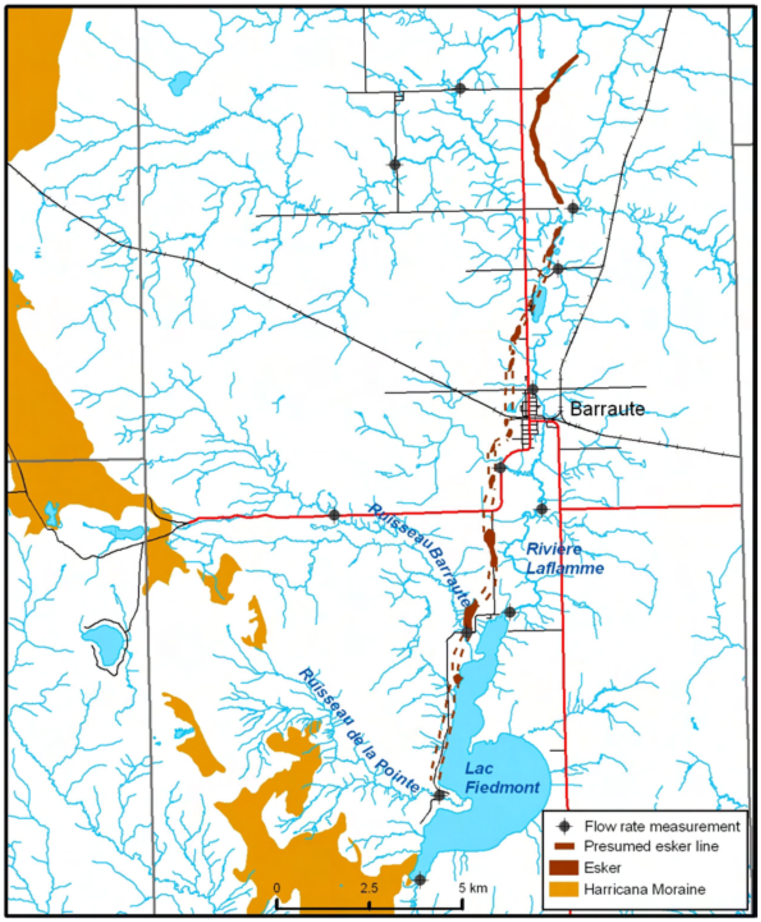

Figure 5 Map showing the hydrographic network, areas where the Barraute esker emerges through the clay plain, and the probable location of the esker trend beneath the clay. Almost all the esker lies below elevation 320 m

5 LAKE FIEDMONT; AN INDICATOR OF REGIONAL GROUNDWATER FLOW

Early in the investigation, the possibility was considered that a groundwater connection between lake Fiedmont, which forms the headwaters of the Laflamme river and the Barraute esker, may be present. The western shoreline of the lake, in contact with the esker, the presence of this large lake in the upstream part of the Laflamme River hydrographic basin, and the apparent smaller volume of water entering into the lake from surface streams compared with the larger volume of water coming out of it via the Laflamme river, raised questions about the discharge of groundwater into the lake from surrounding granular deposits. The following directions of research were followed to verify these assumptions (1) an acoustic survey using a Knudsen 320M (profiling transducer 28 kHz, depth transducer 200 kHz) instrument was completed in 2005 to map the bathymetry of the lake and the nature of the bottom sediments, with the purpose of detecting morphological conditions indicative of discharge or exit of groundwater below the surface of the lake, (2) probing and sampling from the frozen surface of the lake into bottom sediments was carried out to validate the acoustic data, (3) measuring groundwater temperature profiles below the ice near the end of winter using thermistor cables, to detect temperature differences at depth that could be related to discharge of groundwater at the bottom of the lake, (4) stratigraphic drilling at selected points on the west side of the lake and the installation of a network of piezometers to map the water gradient were carried out and (5) stream flow measurements on streams entering the lake and at the mouth of the Laflamme river were taken in late winter in an effort to quantify the groundwater contribution to the lake.

6 OBSERVATIONS AND RESULTS

Results from the different field methods outlined above point out to a substantial contribution of groundwater into the lake from the granular deposits west of it. The most obvious indication is provided by numerous springs and seepage zones found along the western shore of the lake (figure 6a). The springs discharge groundwater all year around into the lake and prevent freezing for continuous sections up to 300 m long along the shoreline (figure 6b). The acoustic survey showed that the lake bottom is everywhere underlain by clay even in the deepest parts. Probing and sampling from the frozen surface of the lake support the acoustic data. Augering in lake bottom sediments at 11 sites from the frozen lake surface in the southern half of the lake penetrated up to 13 m of clay without encountering refusal. In the deepest parts of the lake, in about 30 m of water, an organic mud indicative of reworked clay was found overlying distinctly varved clay. The level of the varved clay reaches 325 m west of the lake, well above the lake level at about 302 m, but the clay was eroded along most of the western shoreline in contact with the lake. Above elevation 320 m the varved clay occurs as discontinuous patches and extends westward below littoral sands derived from the Harricana Moraine (see figure 5).

The outstanding feature revealed by the acoustic survey is a channel-like depression carved in the clay, that extends along the western shore (Fig. 7). It varies in depth from 30 m in the southern part of the lake to 5-7 m along most of its course and is deflected by the delta protruding into the lake from ruisseau La Pointe. The erosion of this channel in the lake bottom is tentatively associated with groundwater discharge in the southern part of the lake (water depth 30 m) and possibly at other locations along its western shore as suggested by springs. There, the lake is in direct contact with extensive granular deposits. Year-round discharge of groundwater along the western shore and its movement toward the Laflamme outlet, would prevent sedimentation of clay in winter, under the ice cover, and thus maintain the channel open.

A further indication of northward flow in the lake is indicated by the deflection toward the north of deltaic sediments for the two deltas formed by ruisseau de la Pointe and ruisseau Barraute (Fig. 6a). Depth of water in the large circular bay (a morphology typical of erosion in clay deposits), located in the southern half of the lake, decreases gently eastward from a depth of 3m, a few 100s meters east of the ruisseau de la Pointe delta, to 0 m depth along the eastern shore. Flow toward the Laflamme outlet in this bay is less obvious than along the western shoreline and is not indicated by lake bottom morphological features.

Significant groundwater discharge into the lake is revealed by preliminary flow measurements recorded near the end of winter in 2006 (Table 1), showing that the streamflow at the mouth of the river, the only outlet for the lake, greatly exceeds the combined flow of streams flowing into the lake from the west (Fig. 6a). Streams along the east shore of the lake are intermittent and most do not flow in winter; only one small spring was identified along the eastern shoreline (Fig. 6a). This large imbalance (0.48441 m3/s) between the volume of water flowing out of the lake (0.81730 m3/s) versus the volume flowing in (0.33289 m3/s), after months without any input from precipitations, is attributed to groundwater seeping in from the western and southern shorelines of the lake. This monitoring program will be pursued in coming years.

Table 1 Streamflow data, Lake Fiedmont, winter 2006.

Station ID	Date	Cross-section area (m^2)	Stream-flow (m^3/s)
06EAFG0001	2006-02-28	19.40	0.81730
06EAFG0002	2006-02-24	4.07	0.07264
06EAFG0003	2006-02-28	1.46	0.21534
06EAFG0004	2006-02-28	1.27	0.04491

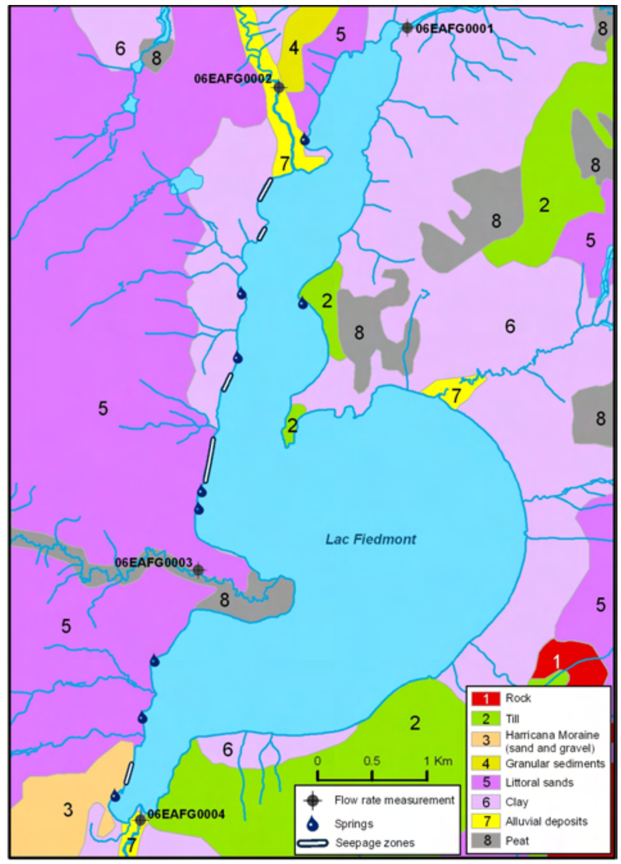

Figure 6 a Location of springs, seepage zones and gauging sites along the west shore of Lake Fiedmont .

Figure 6 b. Unfrozen seepage zone in winter, groundwater emerged at 5.5º C and lake water was at 2.2º C.

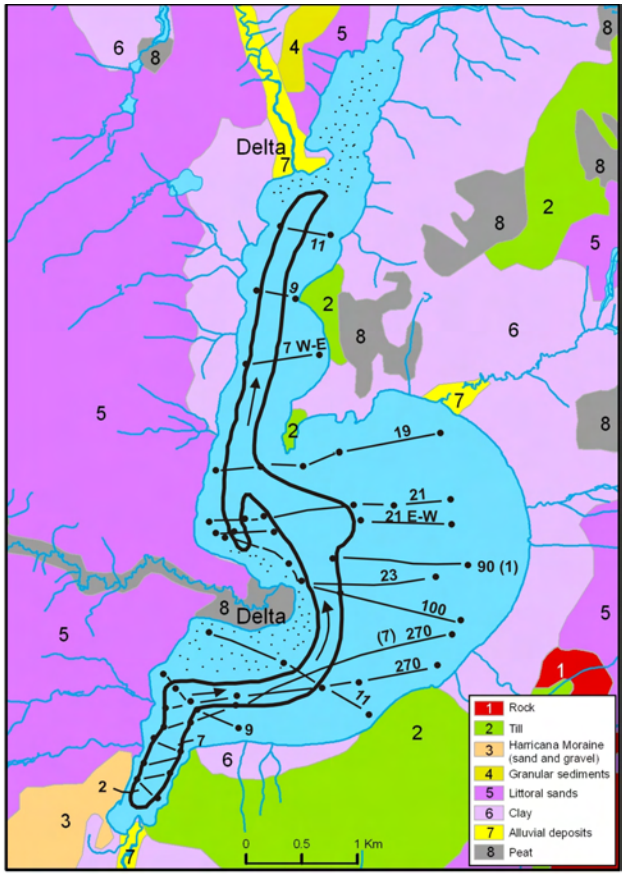

Figure 7 Map showing the location of a channel incised in the fine-grained sediments at the base of Lake Fiedmont by groundwater discharge and acoustic profiles ran in fall 2005.

7 A TENTATIVE STRATIGRAPHIC MODEL TO ACCOUNT FOR RECHARGE OF THE BARRAUTE ESKER

A detailed surficial geology map (1:15 000 scale) and stratigraphic information derived from boreholes drilled for mineral exploration, water wells, and from a network of piezometers suggest that the Harricana Moraine, a prominent glaciofluvial landform, located about 10 km to the west of the esker, is a likely recharge area for the Barraute esker (Figure 8). High hydraulic conductivity measurements using the Guelph permeameter were recorded within a 50- km^2, water-saturated blanket of littoral sand covered by eolian sands and peat, that slopes gently eastward from 340 m asl near the source to 320-325 m at the contact with the clay plain located at about 3 km from the esker (Fig. 8). The lack of well-developed podzolic horizons in the widespread and well-sorted eolian sands favours recharge from precipitations. Subaqueous granular deposits derived from the moraine probably serve as conduits for groundwater toward the buried esker located at lower elevation in the Laflamme River valley. The contribution of wetlands and peat plateaus to the recharge remains to be determined as some are underlain by impervious clay and others by well-sorted granular deposits. We observed at some locations in the general area, that overflow from peat plateaus locally recharges the eskers (Ex: Launay and Lake Despinassy eskers, Fig. 3) with probable impact on the groundwater chemistry of these eskers.

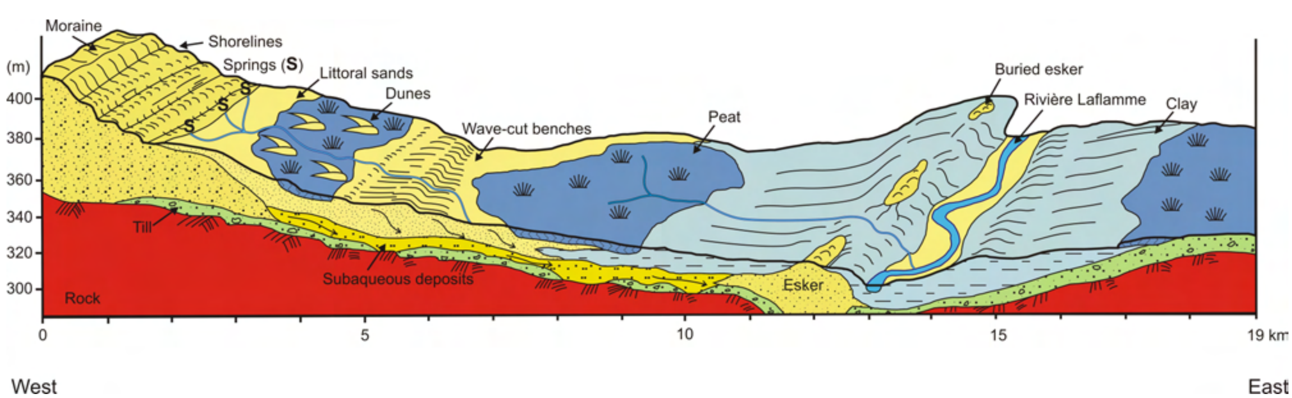

Figure 8 Surficial geology and idealized cross-section through Quaternary sediments between the Harricana Moraine and the Barraute esker at the level of Barraute village.

7 CONCLUSIONS AND FUTURE WORK

The subsurface data acquired to date on the geology and hydrogeology of the Barraute area are insufficient to draw definite conclusions regarding recharge for the buried Barraute esker. This difficulty appears to be characteristic of eskers elsewhere that lie buried by thick deposits of impervious fine-grained deposits (Cummings and Russell, 2007). However, groundwater flow from the Harricana Moraine to the southern segments of the Barraute esker in the Lake Fiedmont area, argues for a similar process further north along the Barraute esker. A better understanding of the bedrock topography underneath the esker is required to map rock basins that may contain individual aquifers along the esker. The application of the seismic reflection method and control drilling that proved to be successful to map the outline of a buried esker and bedrock topography in the Ottawa area (Cummings and Russell, 2007) will be necessary to accurately assess the full aquifer potential of the Barraute esker.

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