



## Building a geodatabase for mapping hydrogeological features and 3D modeling of groundwater systems: Application to the Saguenay–Lac-St.-Jean region, Canada

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### ABSTRACT

Understanding and managing groundwater resources require the integration of a large amount of high-quality data from a variety of sources. Due to the limitations in accessing information related to groundwater and subsurface conditions, the gathering of available existing information is of crucial importance when conducting a successful hydrogeological study. Here, we present an approach for the development of an exhaustive and comprehensive groundwater database through (1) the gathering of relevant sources of information relating to groundwater, and (2) the application of a quality control process in order to screen the data for accuracy and quality. This hydrogeological database is then implemented within a GIS (geographic information system) framework coupled to a Relational Database Management System (RDBMS) as a personal geodatabase (ESRI format) GIS technology. Once established, the spatial database allows a user to request the relevant data required for a specific hydrogeological study. In addition, stratigraphic data stored within the spatial database may be utilized for constructing 3D subsurface hydrostructural models. In order to achieve this objective, the software Arc Hydro Groundwater combined with the ArcGIS spatial database is shown to be appropriate for the 3D structural representation of aquifers (groundwater reservoirs). The innovative contribution of this approach in building 3D hydrostructural subsurface models from a spatial database resides in simplifying the required step-by-step processes by considering a unified compatible combination of "RDBMS–ArcGIS–Arc Hydro Groundwater" technologies. The proposed methodology is illustrated using data from an ongoing project aimed at developing an inventory of the groundwater resources of the Saguenay–Lac-Saint-Jean region, Quebec (Canada).

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### 1. Introduction

Sustainable management of groundwater resources is a very complex task; the main challenge is that information related to the subsurface is rare and often not easily accessible. Furthermore, the acquisition of groundwater data is costly. The numerous means used for collecting data, e.g., drilling operations for installing wells, geophysical investigations, groundwater sampling and water chemistry analyses are expensive although necessary for the characterization of aquifer systems. Hence, the proper recording of these data and ensuring their availability within a unified spatial database have become critical for hydrogeologists in order to maximize the utility of cost-intensive datasets. Knowledge of the existence of previously collected

information can also avoid costly duplication of previous investigations. Accessing a spatial database may also assist in the planning of future hydrogeologic investigations through the effective use of all preexisting information. Furthermore, databases allow researchers and practitioners to have easy access to a large pool of data from which they can draw upon for research or industrial projects.

One of the first comprehensive GIS-based hydrogeological databases was presented by Gogu et al. (2001) who implemented a groundwater spatial database for the Walloon region of Belgium. Gogu et al. (2001) illustrate that following time and spatial queries, the hydrogeological data stored in the database can be easily used for different purposes. Similarly, Murray et al. (2003) developed a coupled GIS-spatial database for assessing groundwater recharge in the Palouse Basin in the United States. More recently, McCarthy and Graniero (2006) highlighted how compilation and effective management of large amounts of data by use of computationally efficient software maximize efficiency and

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increase research productivity. As the computational efficiency of computers and software increases, larger amounts of data may be recorded, treated, and then coupled with GIS software for rapid georeferencing and spatial representation of the data. For example, Strassberg et al. (2007) illustrate the advantage of displaying and analyzing data assimilated from various sources within a geospatial context based on GIS. Bonomi (2009) presents an application of a groundwater database for the construction of a 3D model of an unconsolidated aquifer located in the Milan Plain in Italy and Elewea et al. (2010) apply a GIS-based approach for determining priority areas for hydrogeological development in the Western Desert in Egypt. This use of a GIS-based approach for implementing groundwater databases and characterizing groundwater systems has been explored by other authors including Chang and Park (2004), Steward and Bernard (2006), De Dreuzy et al. (2006), Kaufmann and Martin (2008), Lin et al. (2009), and Strager et al. (2010).

More specifically, over the last decade there has been extensive use of RDBMS such as the personal geodatabase format from ESRI software for the compilation of data as well as ArcGIS software for visualizing the spatial context of the data. Indeed, the utility and efficiency of the geodatabase format used by ArcGIS have been largely demonstrated and this software has already contributed to many geoscience investigations (see references listed above). Recently, new advanced software has been developed for the specific visualization of groundwater data. Best and Lewis (2010) propose GWVis software as a useful tool for the presentation of a simplified view of hydrogeological systems for decision makers and a broader audience.

The implementation of a spatial database has been mandated by the Quebec Ministry of Sustainable Development and Parks (MDDEP) for seven different regions of the province. This provincial project, known as the *Programme d'Acquisition des Connaissances sur les Eaux Souterraines* (PACES), is being conducted in partnership with the regional municipal counties, the MDDEP, and several universities in the province. The spatial database is intended to provide a regional picture of groundwater resources in terms of both their quantity and their quality. This work involves the compilation of existing hydrogeological data as well as the collection of new data to complete existing information gaps. The final objective of the database implementation consists

of characterizing regional aquifers and understanding associated groundwater flow systems (Robins et al., 2005; Ross et al., 2005). This provincial-scale project should improve our knowledge of regional hydrogeology and provide decision makers with additional information for the sustainable management of groundwater resources.

The methodology that has been established in order to reach these goals is presented in this paper, which initially consists of describing the nature of the gathered information, listing the different accessible sources of information from which relevant hydrogeological data may be extracted and illustrating data collection and organization when designing the database. A second aspect of the methodology illustrates the utility of the database for presenting aquifer systems at multiple scales such as the construction of georeferenced 3D hydrostructural domains. This approach also illustrates an original preliminary data processing method, which can be conducted from the database.

For this paper, we focus on the populated area of the Saguenay–Lac-Saint-Jean region (SLSJ; one of the seven regions involved in the larger provincial project). The SLSJ region encompasses a large area of 13,210 km<sup>2</sup> with a population of approximately 277,000 inhabitants (Fig. 1). Granular aquifers, aquitards, and fractured rock aquifers constitute the dominant hydrogeological entities present in this region. Groundwater resources represent about 30% of the potable domestic water supply to the regional population. In the western half of the region, groundwater drains to the large (1041 km<sup>2</sup>) Lac-Saint-Jean, which constitutes the main discharge zone of the surface and subsurface waters around the lake (Fig. 1). Important granular aquifers (Quaternary deposits) are found around the lake, formed in the deltas of the major discharging rivers. The granular deposits are underlain by Precambrian crystalline bedrock; aquitard layers composed of silt and clay are found within the Quaternary deposits and sometimes over the bedrock of the Canadian Shield.

Prior to this current PACES project, very little work had been undertaken regarding groundwater management in the SLSJ region even though many pumping wells have been installed since the 1970s for individual, municipal, and industrial supplies. An assessment of the overall groundwater resources of the region has never been conducted and there is a critical need for gathering available information related to the quantity and

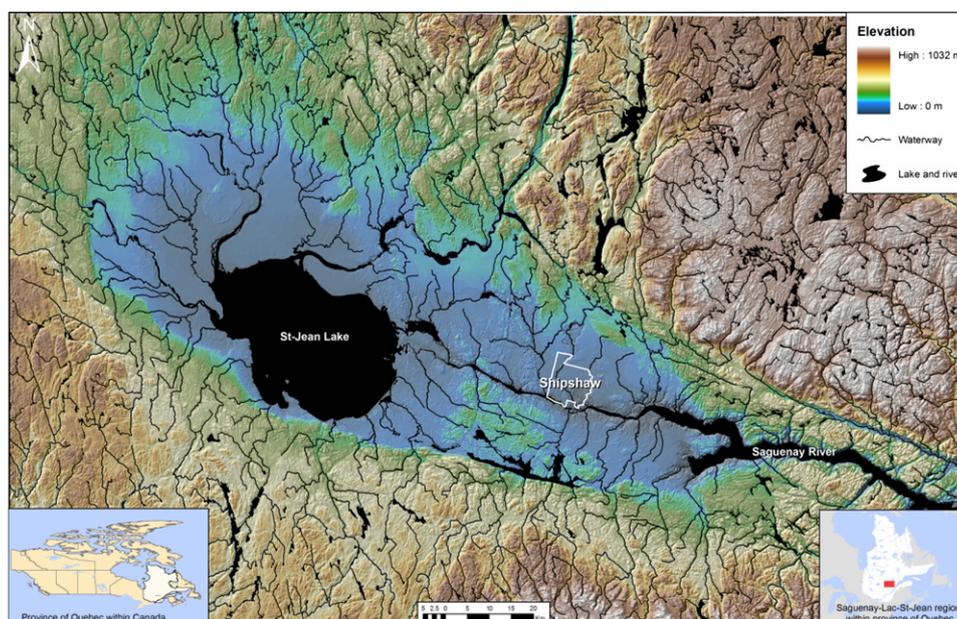


Fig. 1. Location and digital elevation model (DEM) of the Saguenay–Lac-Saint-Jean (SLSJ) region of Quebec.

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