Regional Groundwater Management in Ontario Canada

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Abstract

The Oak Ridges Moraine (ORM) Groundwater Management Program presents a unique case in Ontario where, since 2000, a partnership of the municipalities of York, Peel, Durham, and Toronto (YPDT) and the nine Conservation Authorities (watershed management bodies) with jurisdiction on the Oak Ridges Moraine (collectively known as the Conservation Authorities Moraine Coalition (CAMC), recognized a deficiency in coordinated groundwater management, and partnered for the purposes of establishing a groundwater management program across a broad geographical extent of south-central Ontario. Supporting the initiative to various extents are Provincial Ministries (Ministry of Northern Affairs and Development (Ontario Geological Survey), Ministry of Natural Resources, and the Ministry of the Environment) as well as the Federal Government (Geological Survey of Canada (NRCAN)). The program, known as the YPDT-CAMC Groundwater Management Program, has the Oak Ridges Moraine as a common physiographical element of interest to all partner agencies.

The Oak Ridges Moraine stretches some 160 km across southern Ontario from the vicinity of Trenton in the east to the Niagara Escarpment in the west (Figure 1). The moraine serves as the height of land separating southward flowing drainage towards Lake Ontario from northward flowing drainage into Lake Simcoe and other northern Kawartha Lakes. The moraine is recognized as a regional groundwater recharge area, providing a source of groundwater to numerous aquifers and to the streams having headwaters on the flanks of the moraine.

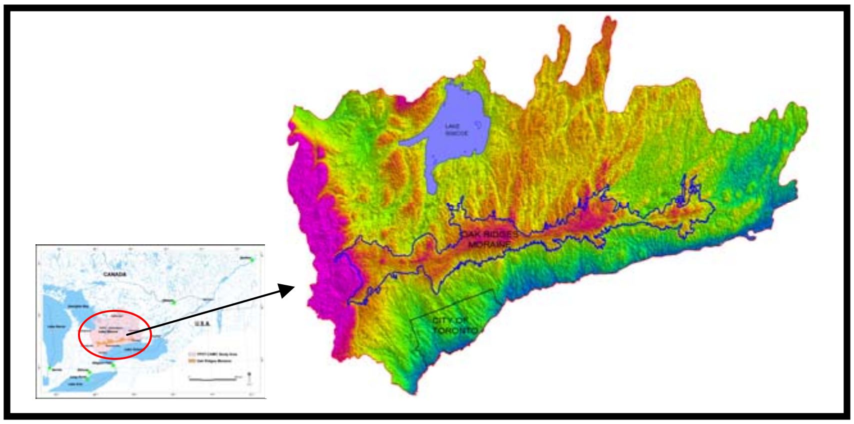

Figure 1. Location and DEM of the Oak Ridges Moraine, Toronto, Canada.

From a groundwater perspective, the Moraine has long been the focus of significant attention by municipalities, conservation authorities and the Provincial Government, as well as by the public owing to:

- the recognition of the moraine as a naturalized area where hydrologic processes are seen as an important part of Ontario's natural heritage;
- the extensive use of groundwater in the area for municipal and other uses;
- pressing development encroaching onto the moraine from the rapidly growing communities surrounding Toronto that has the effect of reducing groundwater recharge and degrading groundwater quality; and
- the numerous groundwater dependant, cold water streams emerging from the moraine flanks.

The culmination of this attention led finally to the passage of the Oak Ridges Moraine Conservation Act and the accompanying Oak Ridges Moraine Conservation Plan, both of which were released by the province in late 2001. These legislative pieces not only significantly curtailed development on the Oak Ridges Moraine, but were significant in the context of Ontario water legislation as a result of requirements to use modeling to develop water budgets for watersheds originating on the moraine and for the first time in Ontario put in place Provincial land use restrictions in wellhead protection areas.

Since 2001 the central focus of the YPDT-CAMC groundwater management program (Holysh *et al.*, 2003) has been on the understanding of flow systems (both groundwater and surface water systems) originating on the Oak Ridges Moraine, for the purposes of making effective water management decisions. The study has produced three key products: 1) a comprehensive water-related database; 2) a detailed geological model (Kassenaar *et al*., 2003); and 3) a calibrated numerical groundwater flow model (Wexler *et al*. 2003). Each of these products is now being used by the partner agencies for numerous practical applications. The products continue to be refined to meet the growing needs of the partnership.

Comprehensive Database

In initiating the project, and from experience with previous studies within the Province, it was apparent that data, and in particular ready access to data, was a limiting factor restraining advancements in water resource management. In Ontario, as in many jurisdictions in North America, data, and in particular water and environmental data, have been neglected. Historically, water-related studies have been required for a wide variety of land development projects by government agencies at Provincial, Regional and local levels, and each study generally has a data acquisition component. Although hydrogeological data are constantly being collected in Southern Ontario, and at a considerable cost, the information has never been assembled into a comprehensive, centralized database that can be used for future reference. Rather, data is collected by consultants, reported through various studies, and then simply lost in archived paper reports within the various agencies. In a similar fashion, individuals at many partner agencies have, as part of their on-going daily duties, collected water related data that now resides in files stored on one or two computers unknown and unavailable to others in the organization.

One of the first YPDT-CAMC projects set out to assemble a comprehensive digital database that would not only support groundwater flow model construction, but also form the foundation for long term groundwater management. A key element of the database construction approach was to bridge both agency and disciplinary boundaries by compiling an integrated, comprehensive database covering geology, groundwater, surface water and climate related information across a wide regional area. This broad scope recognizes that water management cannot stop at municipal boundaries and that a broad range of data sources need to be tapped in order to establish the foundation for credible groundwater decision making and effective long term resource management.

Processes have been established with the partner agencies to transfer new information to the database as it is acquired. For example, data logger files of water levels from monitoring wells are being added to the database on an ongoing basis. With the growth of the database, access to the data has become more complicated and front-end interactive database tools have been developed to facilitate queries and general access to the database. Database synchronization between partner agencies and the central database is a critical component of the database management work and has proven to be challenging.

Conceptual Understanding and Detailed Geological Model

The second major product from the YPDT-CAMC program has been the construction of digital geological layering at a regional scale to represent subsurface geological and hydrogeological units. The Geological Survey of Canada (GSC) undertook a multi-year investigation of the Oak Ridges Moraine through the 1990's and highlighted the need for an understanding of the regional Quaternary sedimentology in groundwater investigations (e.g. Russell et al, 2001). As a result of their lead, a considerable effort was expended in building upon the GSC's work to construct a digital geological model that would directly integrate into groundwater flow modeling.

The glacial sediments laid down across south-central Ontario constitute the primary aquifers in the area and an understanding of their morphology is critical to understanding groundwater flow patterns on a number of scales. The glacial sediments are complex in nature, transitioning from aquifer to aquitard material over short distances. Understanding the depositional setting at a regional scale assists in developing an understanding of changes encountered at a local scale. As an example, knowing that sediments are associated with deltaic deposition with feeder channels coming from the northeast, provides a model for considerable variation in grain size (and therefore hydraulic conductivity) in moving from east to west, while at the same time providing a model for continuity of grain size in a north-south direction associated with channelization.

Typically, groundwater studies carried out within the Oak Ridges Moraine area characterize subsurface aquifers as either "upper", "middle" or "lower" without any reference to a broader understanding of the geological package. Of course the "upper" aquifer from one study might be several tens of metres higher or lower than the "upper" aquifer from an adjacent study. The absence of a rigorous regional framework into which local studies can be set, provides an opportunity for those undertaking local studies to be casual and inconsistent in their geological interpretations and therefore these studies fail to advance the overall understanding of the subsurface geology. It has been recognized in Ontario that geological information from water well records (generally mud rotary drilling with little sampling) can be of poor quality, which makes interpretations difficult to begin with. Despite this, however, observations of a rapid transition in grain size or sediment type lead to the immediate conclusion that the well records are "suspect", without any due consideration of the regional depositional setting in which the sediments were laid down. A goal of the groundwater management program is to provide a regional geological context into which local studies can be more effectively interpreted, thereby advancing the overall understanding of the geological setting.

A key aspect of the interpretation process was a focus on understanding the depositional setting and the geological processes of the Quaternary deposits. In addition to simply kriging hard geological data from well records to construct geological surfaces, an emphasis was placed on incorporating "expert knowledge" into the kriging process, in the form of digitized interpretation lines. This ensured continuity of valley systems, and allowed for layer pinch-outs to be effectively represented (Kassenaar *et al*., 2003). The selected approach was to resist from automating the geologic interpretation. The incorporation of geological knowledge and/or interpretation, allowed for considerable refinement of the original contoured surfaces. The 3D lines constrained the gridding process, and ensured that the resulting surfaces honoured both the well picks and the geologically inferred valleys and channels. Figure 2 shows the application of this approach with respect to the bedrock surface. Figure 2a (left side) shows the bedrock surface constructed for an area extending north and west of the City of Toronto using only hard well picks. Figure 2b (right side), on the other hand, shows the same bedrock surface after a sub-aerial fluvial erosional system was interpreted to have eroded the bedrock surface. Although Figure 2a strongly hints at a topographical low on the bedrock surface extending northwestwards from Toronto (near the Lake Ontario label on the figure), it is only in Figure 2b that the river system is fully developed through the use of the 3D polylines. When incorporated into the numerical flow model this fully developed Laurentian River bedrock system allows groundwater flow systems to develop in deeper aquifers that partially infill the bedrock valley. The exact location of the channel thalweg and the slopes of the channel walls, even though they are based on the available hard data, could be subject to question due to the lack of hard data in particular areas. It is the intent of the project to update and improve the surfaces as new data is made available.

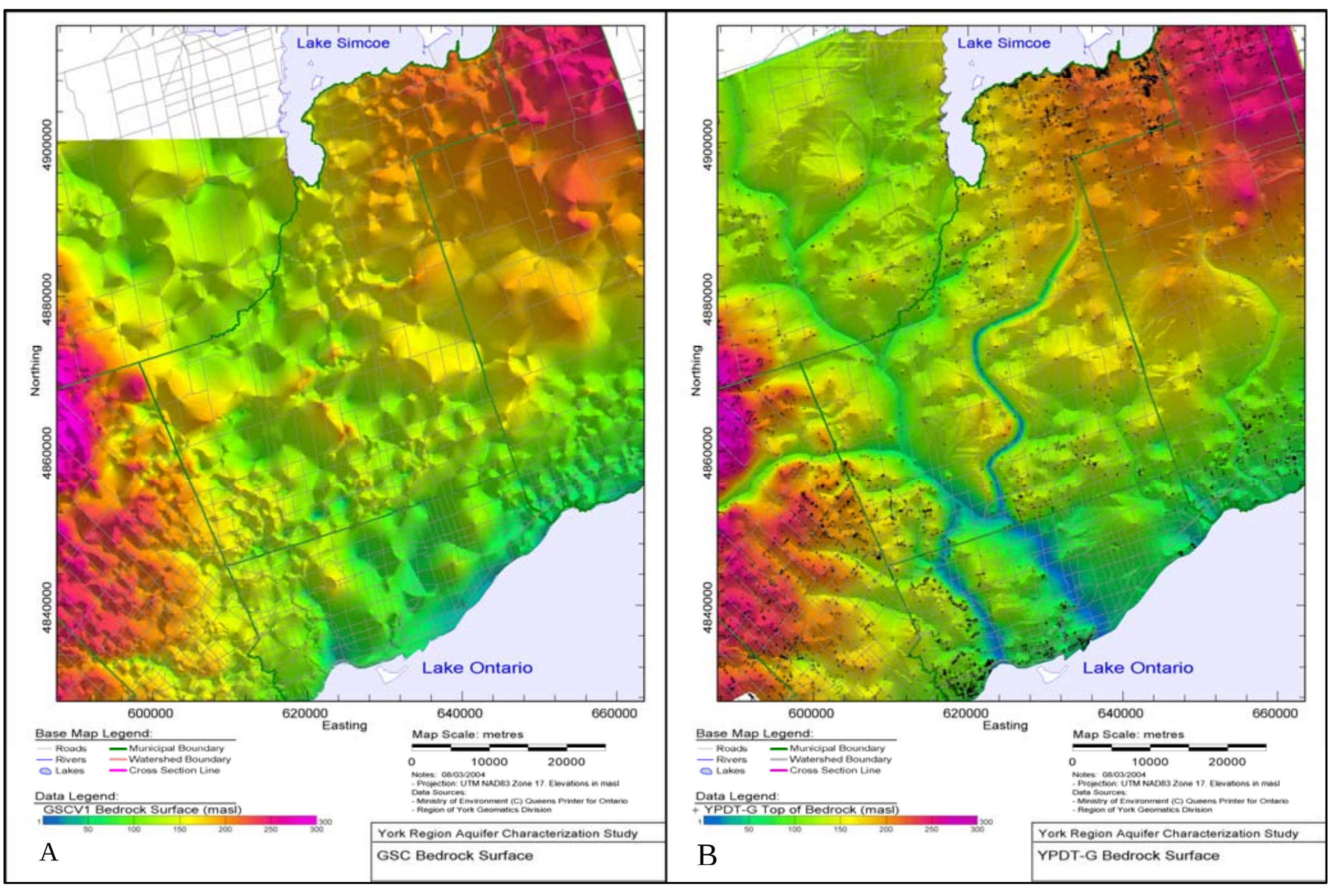

Figure 2: Comparison of unconstrained (left) and constrained (right) bedrock surface.

Numerical Groundwater Modeling

A third focus of the program was to use the database and geological layering as key inputs to develop a numerical groundwater flow model across the area to assist in water management decision making. Initially the program called for modeling at two scales; i) a "regional" scale whereby the entire ORM area would be modeled; and ii) a "local" scale, centred on Toronto and York Region, and stretching between Lake Ontario and Lake Simcoe. Although challenging in terms of optimizing computer capabilities, the successful development of the five layer regional model, consisting of some 3.3 million 240 m x 240 m cells, showed that some computer modelers were capable of developing the type of regional groundwater management models that the project was seeking.

Until recently, regional groundwater assessment studies were rarely undertaken in southern Ontario. Traditionally, of the agencies comprising the partnership, municipalities have focused on local groundwater supply investigations surrounding well fields, while conservation authorities have focused on surface water management for flood control purposes, generally paying little attention to low flows and groundwater discharge into the surface water system. In the 1960s and 1970s, the Ministry of the Environment undertook some excellent work in terms of integrating groundwater and surface water understanding however, structural changes within the Provincial Government put an untimely end to the good work that was progressing. It is only recently that water managers are starting to again recognize the need for groundwater flow models to focus on stream/aquifer interaction, and this was a key focus of the YPDT-CAMC modeling. The strong linkage between groundwater and surface water systems in southern Ontario, as evidenced by the strong influence of streams on groundwater levels and flow directions, demands that both resources be managed in an integrated manner.

The "local" scale model was particularly tailored to better evaluate groundwater – surface water interactions. The 8 layer model consists of 7.1 million 100 m x 100 m cells. The cell size was selected to better represent: i) stream-aquifer interaction since each small tributary would be separated by several model cells; and ii) drawdowns around the municipal wells. To assist in better representing the surface water system in the groundwater model several unique tasks were undertaken in the YPDT-CAMC modeling:

- Incorporation of the numerous smaller stream reaches, including the headwater tributaries that emerge on the flanks of the moraine, rather than just the larger-order streams that discharge south into Lake Ontario and north into Lake Simcoe. These numerous small tributaries represent a significant "wetted area" of contact between the groundwater and surface water system. Because headwater streams only partly penetrate the water table, they tend to be extremely sensitive to small changes in the groundwater system, such as those caused by changes in land use. A water table decline, for example, as a result of increased pumping or a decrease in recharge due to urban development, can shift the "start-of-flow" location in these streams by tens of metres, thus decreasing the habitat potential for many of the moraine's freshwater organisms. With over 25,000 Strahler Class 1 stream reaches in the study area, it is clear that the cumulative impact on small streams can be significant.
- Small, upper-reach tributaries were simulated as MODFLOW "drains", only allowing for one way movement of groundwater from the ground into the drains, while larger tributaries were simulated as MODFLOW "rivers" and could lose water back to the aquifers.
- Stream-aquifer geometry was also considered a critical factor controlling GW/SW interaction. The controlling stream level, or stage, was estimated from a high resolution 10 m Digital Elevation Model that had been hydrologically corrected.
- Hundreds of cross sections were "cut" under the rivers to evaluate the stream-aquifer geometry. Stream conductance and interaction parameters were adjusted based on the insight provided by these cross sections.
- The 100 m uniform cell size allowed local groundwater flow systems to develop between the streams and results in a more realistic representation of the interaction between the groundwater and surface water system.
- To effectively calibrate the groundwater model, both static groundwater levels and estimates of groundwater discharge (obtained from streamflow hydrographs) were set as targets for the model to match.

Once calibrated, the model indicated that most groundwater discharges to streams rather than to the large lakes (Kassenaar and Wexler, 2006). Thus, an increase in groundwater withdrawals or a decrease in recharge will result in an eventual decrease in baseflow (once local aquifer storage is depleted). Figure 3a shows the predicted discharge (color coded) to each of the 100 m cells along headwater tributaries within a portion of the model area under baseline conditions. Simulated discharge to streams under different land use and pumping conditions can be compared on a cell-by-cell basis to produce maps of predicted per-cent change and predicted absolute change in streamflow. Figure 3b shows the predicted percent change in the flux to the streams after increasing pumping at a nearby municipal well. Only by incorporating all streams into the model and calibrating to observed baseflows is this level of stream impact evaluation possible. Conservation Authorities, armed with this information, can target specific tributaries or reaches of streams for further investigation, monitoring, and sensitivity analysis to assist in determining the significance of the predicted changes.

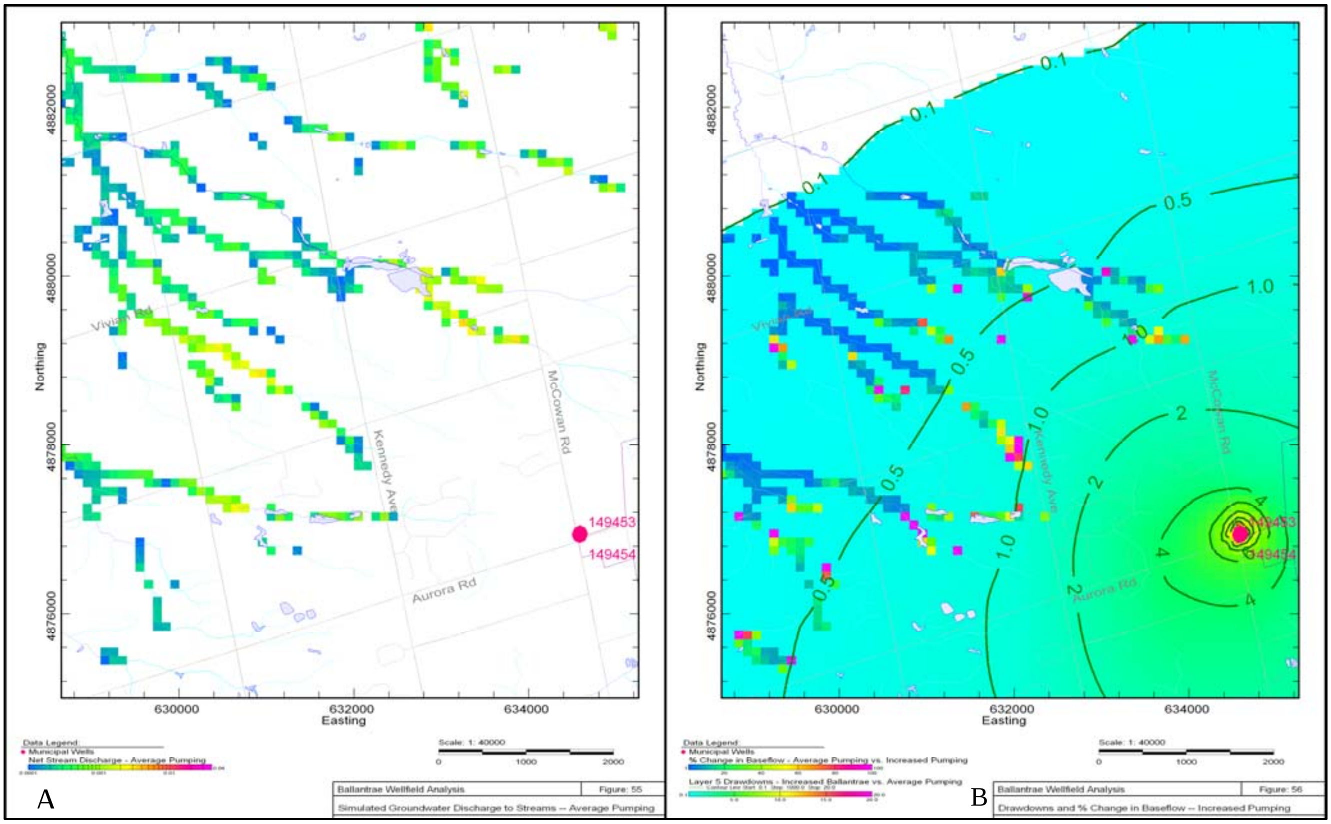

Figure 3: (A) Stream baseflow, (B) Percent change in baseflow due to pumping.

Summary

The study provides an example of how local government agencies can combine limited resources to foster strong ties and achieve a sound technical understanding of the groundwater resource across a significant geographical area.