APPLYING A NUMERICAL GROUNDWATER MODEL FOR MUNICIPAL GROUNDWATER MANAGEMENT ON THE OAK RIDGES MORAINE IN YORK REGION

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ABSTRACT

Approximately 25% of the population of York Region continues to obtain water supply from groundwater sources, either through municipal systems or directly from private wells. In addition, groundwater and surface water (from streams) are used for agriculture, industry (sod-farming), and recreation (golf courses) activities. The overall water-taking stress has the potential to adversely affect the the groundwater and surface water flow system both in terms of quality and quantity. Until recently, the complexity of the underlying groundwater system and the lack of understanding of groundwater-surface water relationships have proven to be a substantial challenge to efforts to understand the effects of water taking.

A regional-scale three-dimensional numerical groundwater flow model has been constructed to assist in understanding the effects of water taking and to provide guidance in managing groundwater resources in York Region. The paper provides examples of the application of the regional scale groundwater model to the analysis and understanding of the effects of local scale pumping on the groundwater flow system.

Specifically this paper will touch on:

- The combined effects of known water takings (permitted and non-permitted) in multiple aquifers;
- An assessment of well-field sustainability;
- Estimates of change in groundwater discharge to streams for different water taking scenarios; and
- Estimates of time-of travel within estimated capture zones of municipal wells.

York Region plans to continue to refine and use the numerical model as a tool to provide input into overall groundwater understanding and to direct groundwater management activities.

RÉSUMÉ

1. INTRODUCTION

Groundwater provides the primary water supply source for approximately 25% of the residents of York Region (Figure 1) and is the sole source for many of the communities and rural residents. Approximately 40,000 m^3/day is withdrawn from groundwater to meet the average daily needs of the towns of Newmarket, Aurora, Holland Landing, Sharon, and Queensville. Beginning in December 2002, water from Lake Ontario has been available to supplement groundwater supplies to approximately 10% of the demand for Aurora.

Use of existing groundwater sources has increased through the years to keep pace with growth. As withdrawal rates have increased, attention has been drawn to the changing aquifer levels and concern regarding sustainability of the existing and future water taking plans.

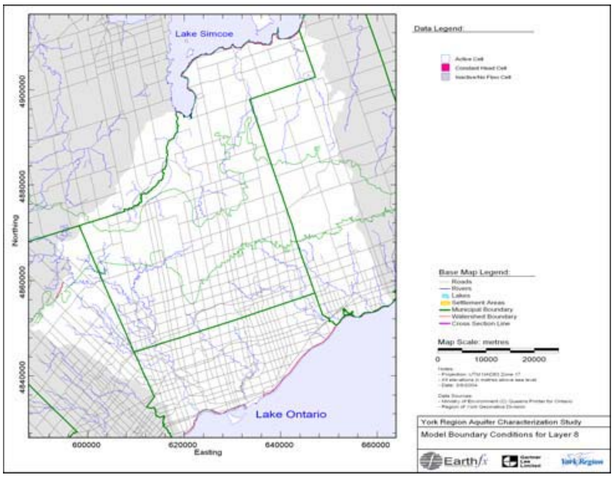

Figure 1: York Region and Numerical Model Area.

State-of-the-art tools have been developed to improve understanding of groundwater conditions in York Region.and to assist in making water management decisions. The most valuable of these tools is a three-dimensional regional-scale numerical groundwater flow model. This paper will provide a brief overview of the numerical groundwater flow model and provide examples of application of the model to:

- Assess the combined effects of known water takings (permitted and non-permitted) in multiple aquifers;
- Assess the sustainability of municipal wells;
- Estimate changes in groundwater discharge to streams due to existing and future pumping; and
- Estimate time-of travel to municipal wells and to delineate capture zones surrounding the wells.

2. HYDROGEOLOGICAL SETTING

York Region is underlain by a relatively complex series of interbedded glacial and glaciofluvial/glaciolacustrine sediments. Glacial history has also imparted some significant structural features on this landscape in the form of deeply incised and subsequently infilled erosional channels. Many of the most productive aquifer units within York Region lie within or beneath these channel features.

On a regional basis, three horizontally extensive aquifers are recognized. These are referred to as the Oak Ridges Moraine Aquifer, the Thorncliffe Formation Aquifer, and the Scarborough Formation Aquifer and correspond with the geological strata shown in Figure 2. The thickness and relative permeability of granular sediment within each of these aquifers varies spatially. Historical observations indicate that the most productive aquifer formations follow northeasterly trending gravel channels.

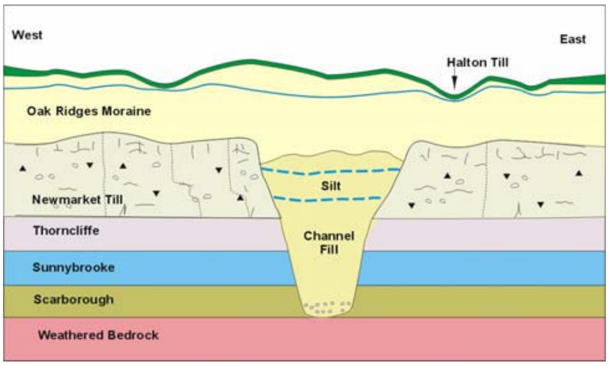

Figure 2: Conceptual Stratigraphic Profile

The Newmarket Till forms an aquitard that plays a very important role in the groundwater flow system beneath York Region. This formation is laterally extensive and relatively thick and is generally a very dense silt till. The Newmarket Till restricts the vertical movement of groundwater between the upper Oak Ridges Moraine Aquifer and the deeper Thorncliffe Formation Aquifer. Available evidence suggests that erosional channels have removed some, or all, of the Newmarket Till at various locations. These channels are typically filled with sequences of coarse to fine-grained sediments. Further work is required to improve understanding of these features and their influence on the groundwater flow system.

3. GROUNDWATER MANAGEMENT TOOLS

The need to improve available tools to promote understanding and enable improved management and protection of groundwater systems was recognized as a priority by the York Peel Durham Toronto Groundwater Management Strategy Study (YPDT Study). The YPDT Study partners include The Regional Municipalities of York, Peel, and Durham, and the City of Toronto as well as the six Conservation Authorities that are active within the area encompassed by these municipalities. Historically, issues such as whether water takings can deliver the expected capacity or whether water takings would have an undesired effect on the environment and/or other users of the resource have been based on local studies only. They YPDT Study team recognized that tools were needed to enable these issues to be understood and assessed on a regional scale.

The study team determined that a numerical groundwater flow model would provide the ultimate tool that would help scientists to interpret available data and provide opinions regarding the effects of various water taking scenarios on a regional basis. In order to develop an effective numerical groundwater flow model tool that could be applied universally to address multiple concerns, a need was recognized to develop a shared system for storage of water-related data (climate, surface water and groundwater) and an approach for understanding regional scale geology in a manner that can be improved over time as new data becomes available. These tools were integral in the development of the numerical groundwater flow model.

3.1 York Region Groundwater Information Management System

The YPDT Study contracted Earthfx, Inc. to develop a workable system for managing groundwater related data that can be shared by all of the partner agencies based on their SITEfx™ data model.

An abundance of relevant geological and hydrogeological data was recognized as being available from several sources including: York Region, the Ontario Ministry of the Environment, Ministry of Natural Resources, Ontario Geological Survey, Geological Survey of Canada, Environment Canada, Lake Simcoe Region Conservation Authority, Toronto and Region Conservation Authority, and private sources.

The data model for management of data within the YPDT Study area was introduced in 2002 and all agencies now have access to a centralized database that contains information such as:

- Borehole and well information (locations, names, construction details);
- Geological information;
- Water level data;
- Water Quality data;
- Water Use data (primarily municipalities);
- Climate data (temperature/precipitation);
- Surface water flow data; and.
- Scanned electronic copies of reports and maps.

3.2 Digital Geological Model

A substantial effort has been placed in developing a three-dimensional digital model of the geological systems beneath the YPDT Study area and particularly beneath York Region. This work involved creating a representation of the distribution of the key stratigraphic formations based on drilling and geophysical records. The relationships of stratigraphic units are illustrated schematically in Figure 2.

The starting point for this work was the Version 1.0 surfaces as developed by the Geological Survey of Canada. These surfaces were then refined using a manual process that involved using the VIEWLOG ™ mapping tools to view borehole information in cross-section and to manually define the distributions of the units. The resultant "picks" were then contoured to produce a series of layers representing each unit. VIEWLOG™ has proven to be a very effective tool for interpreting, revising and representing geological information in three-dimensions.

3.3 Numerical Groundwater Flow Model

The regional-scale numerical groundwater flow model was constructed using the digital geological model as a base and applying hydrogeologic properties to each of the identified stratigraphic units. The domain of the model was selected to encompass the area from Lake Simcoe to Lake Ontario and a sufficient distance to the east and west of York Region to minimize the potential for any boundary effects in the core of the model domain (white area in Figure 1).

The U.S. Geological Survey MODFLOW code (McDonald and Harbaugh, 1988; Harbaugh and MacDonald, 1996) was selected for use in the numerical groundwater flow model. The model is three-dimensional and comprises a uniform grid of 100m x 100 m cells and 8 vertical layers. The thickness of vertical layers is variable and conforms to stratigraphy. Hydraulic conductivity properties are variably distributed through the cells based on available data. Recharge is variable through the upper layer of the model and distributed according to surficial geology, land use and vegetated cover, topographic slope, and direction of vertical hydraulic gradients.

The model has been calibrated to reproduce observed groundwater elevations in all aquifers and the water table using historical pumping rates for municipal wells and other permitted water supplies. The model has also been calibrated to the estimated groundwater discharge component from historical stream flow records. A third calibration target involved matching the spatial distribution of groundwater discharge as determined from low flow streamflow surveys.

Figure 3 illustrates the ability of the model to match the observed groundwater elevation pattern for the Oak Ridges Moraine aquifer.

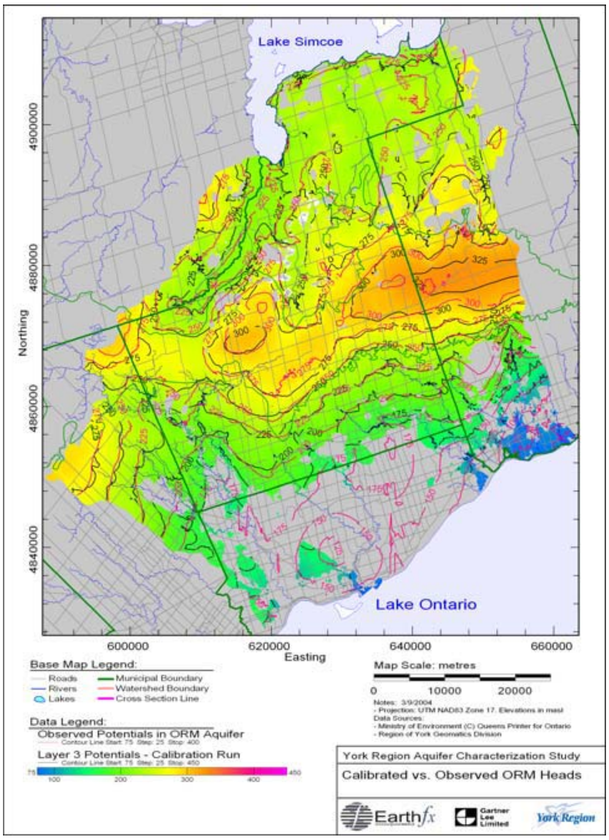

Figure 3: Modelled versus Observed Groundwater Elevations

4. APPLICATION OF NUMERICAL MODEL

The complexity of the hydrogeology beneath York Region had raised many questions regarding the regional effects of groundwater taking, both for municipal use by York Region and by other permitted users. Some key concerns were the potential for takings from one community to affect groundwater levels in other communities, as far as 15 km away.

The numerical groundwater flow model is a key tool for assisting in resolving concerns related to understanding the groundwater flow system beneath York Region. The first test of the model was calibration to reasonably reproduce regional groundwater flow patterns and stream discharges. Once a satisfactory calibration is achieved the model can be applied to evaluate various specific water-taking scenarios. Some examples of the model applications to date include:

- Assessing the hydraulic influences of water taking from municipal wells;
- Evaluating the sustainability of municipal wells;
- Predicting changes in groundwater discharge to streams; and
- Delineating wellhead protection areas.

4.1 Combined Effects of York Region Water Taking

A key application of the numerical groundwater flow model is to predict the likely influence of municipal wells. The numerical model is ideal for this type of assessment as it incorporates the effects of using all municipal wells and known permitted wells. This ensures that cumulative effects of withdrawals from neighbouring municipalities are being considered. The model also allows the effects to be assessed simultaneously for each stratigraphic layer.

The influence of pumping is evaluated by comparing the predicted groundwater elevations and discharge for a base case (typically the calibration case) with a test case. Figure 4 illustrates the predicted additional change in groundwater elevations that could result in the Oak Ridges Moraine Aquifer if the extraction rate for all municipal wells was to increase to the maximum permitted rate from the historical rate used for calibration. Figure 5 provides the same information for the underlying Thorncliffe Aquifer layer.

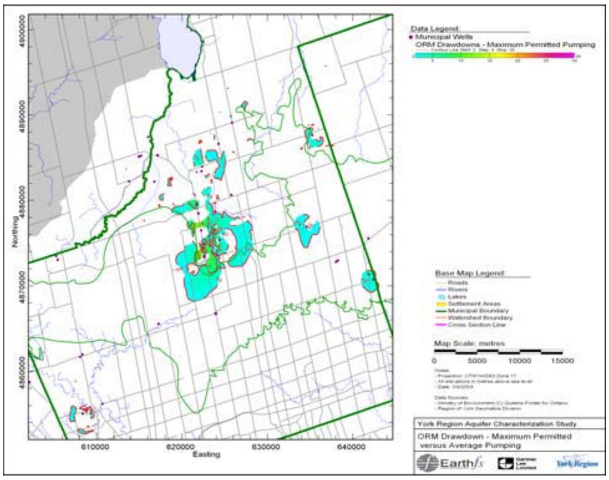

Figure 4: Predicted Hydraulic Influence - Oak Ridges Moraine Aquifer

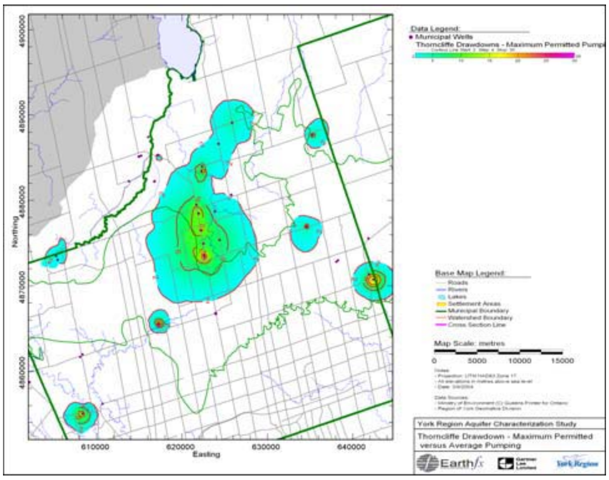

Figure 5: Predicted Hydraulic Influence - Thorncliffe Formation Aquifer.

4.2 Sustainability of Municipal Wells

One of the key groundwater management issues in York Region is the potential capacity of the groundwater supplies that can safely be withdrawn without resulting in an undesirable effect on the environment or on other users of the resource.

To date, the capacity of individual production wells has been assessed primarily based on hydraulic testing performed during well construction and development and to some extent on operational experience. While this approach is valid for individual wells, it does not consider the combined effects of numerous wells operating together (either simultaneously, or in an alternating fashion).

The first method in which the steady-state groundwater flow model was applied to assess the capacity of the municipal production wells was to operate the model using the maximum permitted withdrawal rates. The maximum permitted rates are typically determined using a safe yield approach from individual wells. The maximum permitted rates overestimate the actual steady-state average extraction rate for an individual well by up to a factor of two. In a larger system, lead wells may be operated at or near this rate for extended periods of time. The model demonstrated an estimate of the extents and changes to the flow system that extracting this increased amount of water from the wells would generate.

4.3 Predicted Change in Groundwater Discharge to Streams

In recent years, one of the key issues that has developed with respect to understanding the influence of groundwater extraction is the potential effects on stream flow or on wetlands. The groundwater management tools provide an opportunity to assess what could happen to streams under different pumping scenarios.
The model is constructed to represent discharge to surface water via individual grid cells in various layers of the model. The use of a 100m x 100 m grid allows the model to be reasonably precise in predicting where stream flow starts (i.e. headwater areas) and produces good matches in calculated discharge flows relative to known data points.

Figure 6 shows an illustration of the predicted change in discharge to the stream "per grid block" for an example scenario relative to a base case. This tool helps to identify where streams are most likely to be effected. Caution must be used in interpreting these types of plots since a large percent change in discharge can be predicted in cells that actually have a minor contribution to the overall stream flow. Taken together, a plot of the predicted flux, and the percent change relative to a base case, can effectively identify the potential magnitude of change in surface water and more importantly provide valuable direction for designing monitoring programs.

In this case, the modelled scenario is predicted to only potentially have effect in the uppermost reaches of the streams.

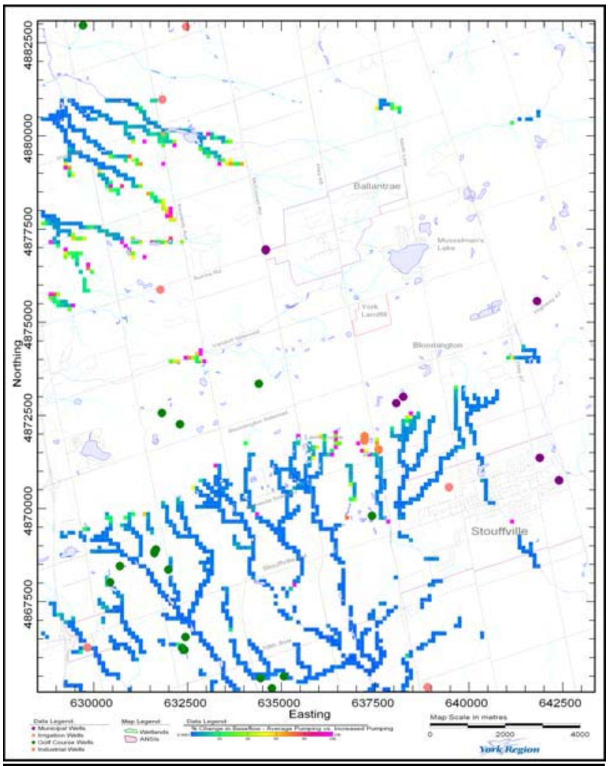

Figure 6: Predicted per cent change in groundwater discharge to streams.

4.4 Wellhead Protection Area Delineation

The regional-scale numerical groundwater flow model was applied to delineate wellhead protection areas for all municipal production wells within York Region. The advantages of applying a regional model for this purpose include:

1) A consistent modelling approach has been used for all areas and uncertainties related to assumptions of boundary conditions are minimized.

2) The influences of all municipal and permitted water taking in York Region have been considered.

3) Conservative assumptions through development of the model and use of maximum permitted pumping rates will ensure that delineated capture zones are conservative.

4) A factor of safety has been included (universally) to address limitations related to use of a steady-state model to account for temporal influences, such as potential variations in pumping patterns, and seasonal recharge.

The wellhead protection areas delineated for municipal wells serving the communities of Stouffville and Ballantrae are illustrated in Figure 7.

The numerical model has been and will continue to be a valuable flow system assessment tool and future work includes plans to improve the knowledge base on which the model is constructed, address uncertainty in the model, and to continue to improve tools that will allow the model to be more accessible to end users

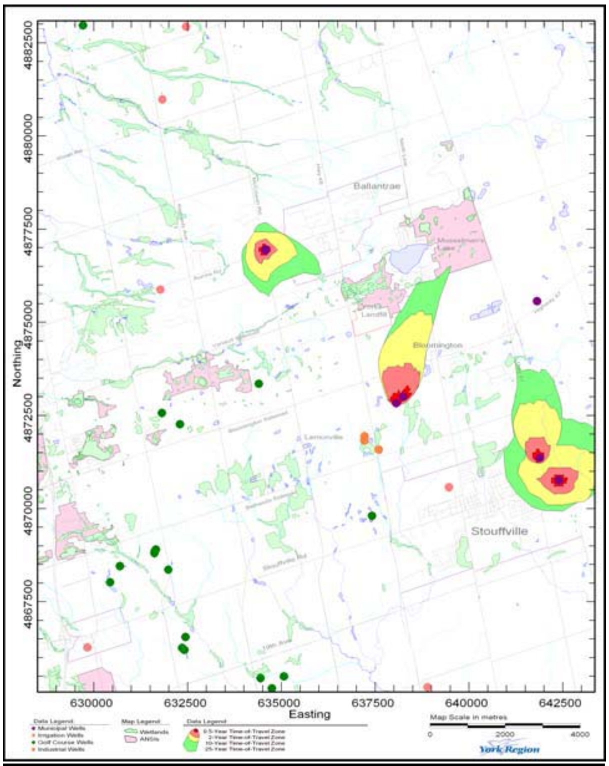

Figure 7: Municipal well capture zone examples.

5. SUMMARY

The tools created to assist with groundwater resource management in York Region have greatly improved overall understanding of groundwater systems beneath York Region and provide valuable insight for assisting with groundwater management and protection decisions.

The key components of the management system include:

- A database of water related information including climate, streamflow, borehole and groundwater records;
- A three-dimensional conceptual and digital geologic model; and
- A three-dimensional conceptual and numerical groundwater flow model.

The numerical models allow for all historical information to be incorporated and considered in water management decisions. The database and models are also constantly being refined as new information becomes available.

6. ACKNOWLEDGEMENTS

The work presented in this paper is a culmination of efforts from staff of York Region, contracted consultants, and partners in advancing the understanding of groundwater systems. Key partners include the York Peel Durham Toronto Groundwater Management Strategy Study team, Lake Simcoe Region Conservation Authority, Toronto and Region Conservation Authority, Geological Survey of Canada and the Ontario Ministry of the Environment. Consulting firms contributing to these studies include Gartner Lee Limited, Earthfx Inc., Azimuth Environmental Consulting Inc., Gerber Geosciences Inc. and Morrison Environmental Limited.

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