Merging Conceptual Insight and Secondary Indicators into the Hydrogeologic Modelling Process: Example from the Oak Ridges Moraine, southern Ontario

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Construction of 3-D aquifer and aquitard layer geometry is one of the most challenging aspects of ground water modelling. Simple interpolation of sparse point data (well picks) rarely produces layer surfaces that realistically represent the structure and, more important, the continuity/discontinuity of complex hydrogeologic features. Three areas where aquifer interconnection is particularly critical include bedrock valley systems, aquitard breaches, and stream-aquifer interconnection. Without geometric continuity, realistic flow patterns cannot develop within the groundwater model.

Keefer (2002) discussed the importance of adding synthetic values into the gridding process, including imaginary wells and manual (hand-drawn) contouring. Logan (2001) discusses the challenges of incorporating partially penetrating well data (push-down conditions) into the model construction process. The objective of this paper is to address these issues and report the methodology developed to blend well picks, 3-D conceptual stratigraphic understanding (expert intuition), secondary hydrogeologic indicators, and a confidence-priority based surface checking rule system.

Central to this methodology is the process of capturing expert insight and conceptual understanding by blending 3-D horizon line drawing tools with on-section picking functions. The gridding algorithm still honours each well pick, but push-down conditions, pinch-outs and other complex conditions are represented by constraining the gridding process, between boreholes, with 3-D horizon lines. The majority of the 3-D drawing is performed on cross sections that are dynamically extruded, or pushed, through the model domain. Plan view hand-drawn contours can also be incorporated, but plan view contouring is a somewhat more indirect method for constraining complex features. Extruded sections, both parallel and perpendicular to the geologic features, can be used even if the feature is sinuous.

The objective of this approach is to automate everything but the interpretation. Database integration, flexible visualization, efficient layer picking tools, and a conceptual understanding of the key sedimentological processes are all critical inputs to the process. The result is a hydrostratigraphic model that not only honours the borehole and well data, but also the conceptual understanding of the processes that formed the system. This process can be considered as an extrapolation process to expand between and beyond hard or reliable data points.

This approach has been used to construct a sub regional flow model of the Oak Ridges Moraine (ORM) in southern Ontario, Canada. The project began with the construction of a 5-layer MODFLOW model of the entire ORM, using the extensive stratigraphic framework and digital model surfaces developed by the Geological Survey of Canada (GSC) (Russell et al., 2002). Following the calibration of the 5-layer GSC model, the central third of the GSC study area was selected for refinement using the process outlined in this paper. The goals of the refinement from 5 to 8 layers were to better represent the deep Laurentian River bedrock valley
systems, fining upwards patterns infilling sub glacial erosional valleys, and further subdivide the lower sediments within the major wellfields. Secondary data indicators, including well screen position, water levels and water found comments, were also incorporated into the refinement process.

**Data.** A solid database foundation (and comprehensive data model) was required for both the primary lithologic data and secondary information (well screens, water levels, etc.). A single relational database containing over 140,000 wells, 600,000 lithologic descriptions, 2 million water level readings, plus millions of surface water and climate data was assembled. The database structure was based on the Earthfx Data Model, and standardized data entry, reporting, and database validation were performed with the Sitefx Groundwater Data Management System. In addition, over 1,500 hydrogeologic reports and 2,400 large format maps and drawings were scanned. The entire database system and report library is hosted online using the VIEWLOG/Webserver product, which provides interactive maps, well logs, cross sections, and hydrographs.

Water well driller’s logs form the majority of the borehole information, supplemented by high quality data from the GSC (Sharpe et al., 2003) and an additional 12,000 geotechnical boreholes. The reliability of individual MOE water well driller’s logs is frequently suspect. However, as a group, the logs provide significant, yet biased, subsurface information. This bias is because most drillers are hired simply to “find water”, so they frequently stop drilling as soon as they breach the top of a significant aquifer. As a result, the logs are primarily a record of aquitard materials, with only the bottom most screened sand or gravel unit representative of the significant aquifer. So, despite the apparently large number of wells, there is still limited information on the deep valley systems, and data quality is highly variable.

The success of the interpretation task was highly dependent on the integrated, interactive visual presentation of a large volume of data, and the efficient capture of the conceptual insights. Interactivity and display flexibility were critical, allowing the interpreter to view fine details and identify subtle patterns, yet continue to understand the broader context. The VIEWLOG 3D Borehole GIS software was used for all visualization; synthesis and interpretation tasks (Figure 1). The software directly connects to the relational database (Figure 1, A) to allow for dynamic filtering and queries. The software provides an integrated set of GIS mapping functions (B, F, and G), dynamic cross sectioning (C), real-time 3-D fly-through (D), and borehole data display, editing and picking functions (E).

![Figure 1. On-screen interpretation required the visual integration of large volumes and types of information.](image)
A total of over 67,000 borehole unit boundary picks were made by the interpretation team. An additional 12,000 3-D polyline vertex points were made on sections that were dynamically pushed through the complex geologic features and valley systems. Polylines represent lines of hydrostratigraphic contact or plan view manual elevation contours. Well screens proved particularly valuable as an effective indicator of aquifer position. Bedrock valleys were represented as continuous aquifer systems (Figure 2). Sub-glacial tunnel channels were interpreted as breaches in the Newmarket

Figure 2. Comparison between constrained gridding bedrock surface (left) with the same surface gridded using kriging and push-down approach.

aquitard, yet were also modeled with an upper silt zone representative of the fining upwards sediments postulated in the GSC’s conceptual models.

Results. The hydrostratigraphic units were input into a MODFLOW model covering the sub-regional ORM core model area (84 x 106 km). A cell size of 100 m was selected to represent detailed stream-aquifer interaction, and over 4,400 Strahler classified stream reaches were represented in the model. The MODFLOW model grid has 840 rows, 1,056 columns, and eight layers, for a total of approximately 7.1 million cells.

The calibrated flow model results clearly demonstrate the importance of aquifer continuity and geometry. Sensitivity analysis simulations with uniform aquifer properties demonstrate that aquifer geometry explains many of the regional water level patterns. The influence of deep bedrock valleys on the spatial distribution of groundwater discharge to streams can also been seen. Model calibration indicates that the erosional valleys or tunnel channels are
not open windows interconnecting the upper and intermediate aquifer systems, but that the silt infilling in the channels is likely about one order of magnitude more permeable than the tight Newmarket Aquitard.

**Conclusion/Summary.** This interpretation methodology has proven effective in dealing with the complex geology and variable data quality encountered in the ORM study area. The constrained gridding process produces conceptually accurate surfaces with fewer illogical “bullseyes”. Drawing in three dimensions is difficult, but the dynamic cross section approach has proven effective. Maintaining consistency between sections can be a challenge, but perpendicular tie-lines can be used. An integrated combination of plan view, cross section, and 3-D visualization tools are needed. Cross sections provide a precise “reference frame” drawing environment (Figure 3), while real-time 3-D fly-through (Figure 4) is more suited to qualitative error checking and not precise 3-D drawing.

![East-west cross section under the moraine perpendicular to tunnel channels.](image)
Figure 4. Bedrock surface and fence diagram of overburden layers. View from Toronto looking northwest. Width of 3-D viewport is approximately 150 km.

The methodology shows that it is possible to move beyond a simple layer-cake system, even on a regional scale. Complex larger scale features, such as the tunnel channels and infill sequences, can be accurately represented; however, good conceptual models are essential to guide the interpretation process. Data gaps (lack of deep boreholes), and data quality issues are universal problems, and our view is that constrained gridding with good conceptual models and secondary data should become the preferred model construction approach.

References


