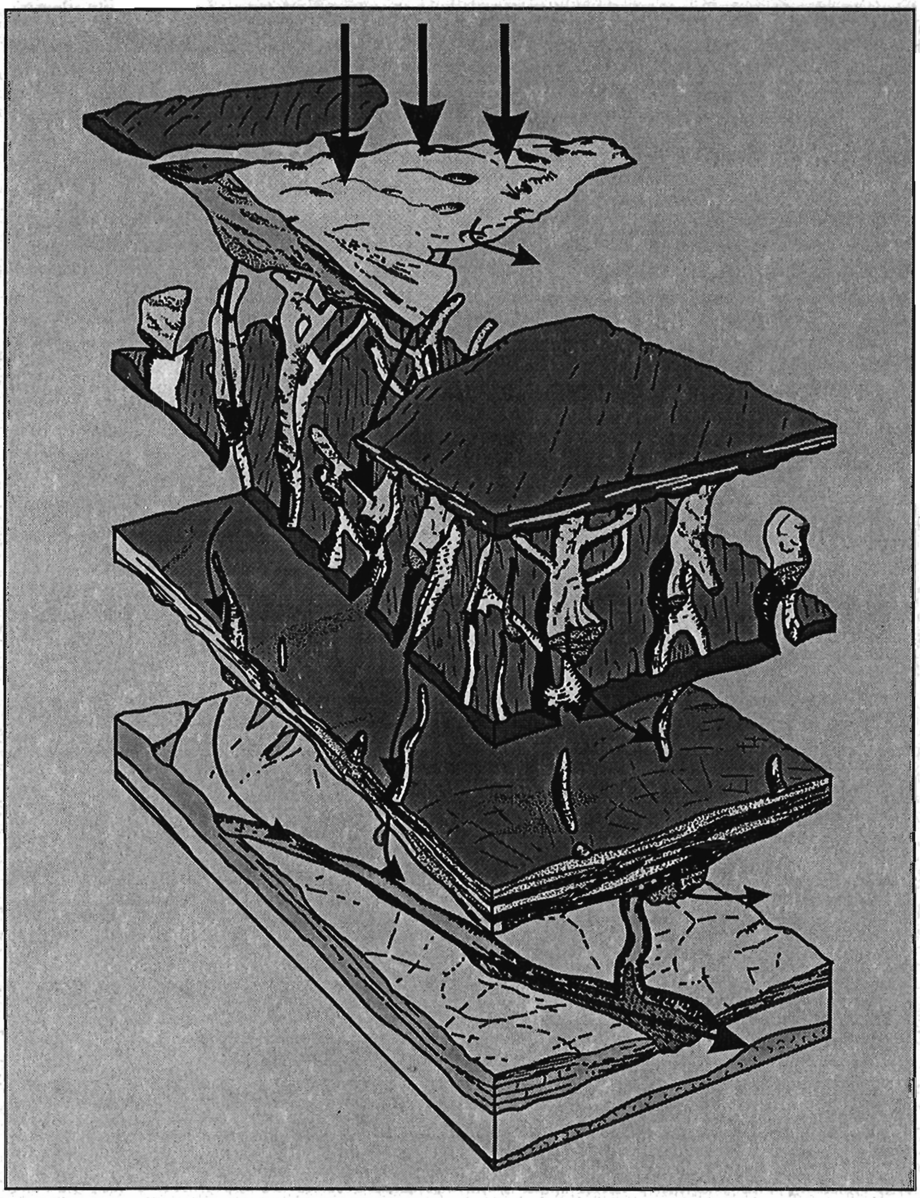
WATER RESOURCE INVESTIGATIONS OAK RIDGES MORAINE, ONTARIO GEOLOGY AND HYDROGEOLOGY



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Water Resource Investigations of the Oak Ridges Moraine, Ontario:

Geology and Hydrogeology

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OPENING REMARKS
Setting The Stage to Advance Groundwater Knowledge

In June of 1990, the Government of Ontario released an expression of interest on the Oak Ridges Moraine. It recognized that the Oak Ridges Moraine plays an essential role in preserving the quality of life for residents in the most populous part of Canada, the Greater Toronto Area. It seemed clear that, without a better understanding and stronger land use stewardship, ongoing development pressure in this area could:

- degrade both the quality and quantity of water resources, including streams, lakes and groundwater supplies
- reduce the diversity and health of the native wildlife and wetlands
- seriously alter the unique visual character of the moraine

In a related development, the Canadian Geoscience Council, representing a group of 16,000 geoscientist from across Canada, produced a report: "Groundwater Issues and Research in Canada". (Morgan, 1993). This report concluded that current efforts in groundwater inventory, protection, and research were fragmented and lacked direction from federal and provincial governments. The number one priority was the need to establish broad linkages and partnerships concerning groundwater resources. The International Joint Commission echoed this concern with respect to surface water - groundwater interactions in the Great Lakes area.

In 1991, the province began working in earnest on an Oak Ridges Moraine Planning Study which was to lead to the development of a provincial strategy to protect the ecological integrity of this landform. Some of the key objectives of this effort were to better understand how water moved through this complex ecosystem, who used these water resources and how could the anticipated new development be designed to ensure sustainable water use? Although this Oak Ridges Moraine study began as a focused land use planning exercise, it became a catalyst for some ambitious and innovative integrated earth science and water resource studies.

As part of the ORM planning study, Garry Hunter and Paul Beck were retained by the Ministry of Natural Resources, with the support of the Ministry of Environment and Energy, to develop a broad hydrogeological review of the Oak Ridges Moraine. What emerged was the development of a comprehensive water resource database, as well as many insightful recommendations that challenged society's conventional views of water resource management. For example, as a general planning principle the report advised: limit lake-based water supply expansion to Oak Ridges Moraine areas below the ~275 m asl elevation contour.

To complement the MNR effort, the Ontario Geological Survey (Cam Baker and Peter Barnett) was able to carry out detailed (1:20,000 scale) geological mapping of over half of the moraine. This work has resulted in a basic re-evaluation of how the ORM formed.

A team from the Geological Survey of Canada used the provincial initiative as a springboard for an extensive, five year project to examine the geologic framework and the hydrologic role of the moraine. This work, for example, has increased our understanding of the hydrostratigraphy and improved the techniques of how to find new water resources. A significant by-product has been the development of a comprehensive digital database for the geology of the Greater Toronto Area and environs. The work was carried out with a broad network of partners from the GTA, and thus partly fulfilled a concern of the Canadian Geoscience Council report on national groundwater problems.

At the same time, the Ontario Ministry of Environment and Energy (including Irmi Pawlowski, Maurice Goodwin, Gary Bowen and Sam Singer), in part through the extensive landfill investigations by the Interim Waste Authority, and through funding some of the research at the University of Toronto, lead by Ken Howard and Nick Eyles, has advanced geologic and hydrogeologic understanding at the site and watershed scales. The U of T work has yielded integrated hydrologic and geologic data through groundwater modeling, particularly in Duffins Creek and the Seaton lands.

Using the basic foundations and resources provided by these projects, other workers from federal, provincial, municipal (e.g. Halton Region) and conservation authority offices (e.g.. Credit Valley) as well as several universities were able to undertake much-needed research using a variety of hydrogeologic, geologic, digital and remote sensing techniques. In less than six years, these partnerships have resulted in an extensive 'regional scale' examination of hydrology and geology, exceptional by Canadian standards. It is, however, by no means complete.

Ironically, the original catalyst for this collaborative work, the Oak Ridges Moraine Planning Study, has yet to bear fruit. However, many remain optimistic that the government will release at some future time a strategy for the long-term management of the Moraine, including its water resources. Regardless of the outcome, one of the most enduring legacy of the ORM Planning Study will be the high quality information and growing databases we now have at our disposal with which to plan and manage the land and water resources of the moraine.

It is my honor and pleasure to have played a role, albeit a minor one, in affording these scientists the opportunity to bring their skills to bear on unraveling the complexities of water resources of this area. Today's session will provide a brief overview of their research, discuss some of the practical applications that are currently underway and will discuss future research and data management challenges.

Fred Johnson
Team Leader, Municipal Planning
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Overview of GSC ORM Hydrogeology Study

An Oak Ridges Moraine hydrogeology study was initiated by the Geological Survey of Canada (GSC), in 1993 in response to water and environmental management issues identified by the Ontario government. The study began following wide consultation and was carried out in collaboration with the Ontario Geological Survey (OGS) and a number of other provincial, municipal, university and local groups. The work was sponsored by the Hydrogeology program and the National Mapping Program (NATMAP) of the GSC and by resources of collaborators.

The Oak Ridges Moraine (ORM) is a large (160 x 20 km), complex landform north of Lake Ontario, and is one of the most heavily used groundwater resources in Canada. However, further expansion of the use of this resource and decisions relating to land use planning (e.g. watershed management and cold-water fishery) in a growing urban area were being hindered by a poor understanding of the regional hydrogeology. Thus, the primary objective of the ORM hydrogeology program was to understand the moraine's interior structure in enough detail to identify the geologic elements which control groundwater recharge, flow and discharge.

This ORM hydrogeologic study was designed to complement and to provide a regional geologic context for existing work of the Ministry of Environment and Energy (MOEE), Ministry of Natural Resources (Hunter-Raven/Beck study), the former Interim Waste Authority and the University of Toronto. The GSC's ORM program focused on broader regional issues and methods of hydrogeology that needed to be brought to the fore. As a result, the combined ORM studies establish a background for evaluation of an emerging regional hydrostratigraphic model of the Oak Ridges Moraine area. Throughout the study, the emphasis has been placed on the use of innovative field and digital mapping techniques, on initiating and maintaining broad partnerships, and on the timely communication of results to stakeholders on all levels. To this end, an interdisciplinary team of scientists was assembled and includes experts in: geophysics, glacial geology, sedimentology, hydrogeology, geochemistry, remote sensing, GIS, databases and digital cartography.

Accomplishments of the ORM hydrogeology program include;
i) development of techniques and methods for conducting regional hydrogeology,
ii) formulation, development and testing of a regional hydrostratigraphic model
iii) development of a comprehensive relational database of ~100,000 records

The major impact of this regional investigation is that it is changing the way in which these studies are carried out in the ORM. The simple layered stratigraphic model that was assumed prior to this work has be replaced with a new more complete and accurate regional model. The development of a successful strategy for identifying new groundwater targets based on an efficient sequence of geophysical surveys interpreted in terms of the geological model, has set a new stage for groundwater searches and assessment that is being evaluated by the municipalities and the private sector. The GSC/OGS involvement in groundwater issues in the ORM region, along with the efforts of MNR, MOEE and the University of Toronto has helped renew discussions, cooperation and collaboration among all interested parties.

Regional Hydrogeological Methodologies: Developments from the Oak Ridges Moraine, Southern Ontario

Introduction

The GSC's Oak Ridges Moraine hydrogeological study has been under way in the Greater Toronto Area, since 1993. This region supports one of the largest groundwater user groups in Canada yet, no regional hydrostratigraphic model exists. Hydrogeologists have not expanded site-specific studies to a regional context while geologists have been slow in providing the necessary geological information to water resource engineers and planners (e.g. Eyles, 1997; Sharpe et al., 1994). A geological model has been developed that can serve as a framework for building a regional hydrostratigraphic model and integrating site-specific studies, generally from the private sector. The ORM work has attempted to achieve this objective through a multidisciplinary investigation and through the development of a conceptual geologic model (Sharpe et al., 1996; Barnett et al., submitted; this vol.; Sharpe et al., this vol.). The work also attempts to partly address a national research need, identified by the Canadian Geoscience Council (Morgan, 1993), to carry out aquifer mapping and resource assessment.

Regional water resource investigations seek to advance the understanding of surface and groundwater interactions across varied terrains. To improve the understanding of the role of groundwater requires the collection and integration of hydrologic (e.g. stream base flow) and geologic (e.g. structure) data so that recharge, flow and discharge patterns may be better understood (e.g. Boyce et al., 1997). The GSC's regional approach emphasizes geologic and terrain mapping, geophysics and hydrogeology, with selected integration of hydrology (Fig. 1). Regional water level data are sparse and require considerable effort to assemble (e.g. Howard et al., 1997). To date the effort to collect these regional water level data, has not been comparable to that used to assemble the hydrostratigraphic data discussed here. A few watershed scale summaries of hydraulic data have been attempted recently (Hunter/Raven-Beck, 1996) and have been well integrated with the hydrostratigraphy in the Duffins Creek watershed (Boyce et al, 1997; this vol.).

Hydrogeology and geology

The close relationship between hydrogeological properties and geology, particularly sedimentary deposits is well recognized (e.g. Stephenson et al., 1988; Liu et al., 1996). For example, sediment texture and bedding style greatly affect permeability. Hence, attempts have been made to synthesize geological and hydrogeological information and provide working models for hydrogeological studies (Stephenson et al., 1988; Anderson, 1989). Knowledge of sedimentary architecture and textural composition improves the assessment of groundwater movement. These syntheses however, are incomplete where recent advances in the understanding of glacial sediments and processes have been omitted or overlooked (e.g. subaqueous fans, Rust, 1977; large bedforms, Shaw and Gorrell, 1991). Developing geological and sedimentological models are advanced enough that realistic predictions of the scale, structure, arrangement and textural gradations in sediments can be made. There is a need for more integration of geologic concepts so that hydrogeologists can develop stronger conceptual regional hydrogeological investigations, particularly in glaciated terrain such as southern Ontario where the subsurface structure is complex. For example, watershed and groundwater divides often bear little relationship to each other within and adjacent to the Oak Ridge Moraine. As a result, most existing water budget and stream base flow estimates determined using surface watershed boundaries should be regarded as suspect (e.g. Hunter-Raven/Beck, 1996).

The complexity of glacial sediments results in a high degree of lithological heterogeneity, and this is the major determinant affecting hydrostratigraphy (Stephenson et al., 1988). As a result, hydrologists and geologists need to work in partnership. However, the emphasis in hydrogeology on site-specific and numeric hydraulic characterization (modeling) has often worked against such collaboration. Geologists have traditionally operated in a non-quantitative environment where conceptual models and extrapolation are paramount. In contrast, hydrogeologists have developed empirical approaches to site investigations at the expense of understanding the geologic context. Fogg (1986) summarized the common lack of interaction between the two groups in three points; a) sufficient geological information may not exist, b) modelers may lack a geological background or access to geologists, c) modelers may be unaware of the potential gains to be made from geological (conceptual) and geophysical analysis. Therefore a key purpose of this meeting is to promote interactions between the geological and hydrogeological communities. The prime purpose of the meeting is to present a broad group of users with results of increasing hydrogeologic knowledge in the GTA, while reviewing progress in regional groundwater activities in the Oak Ridges Moraine.

Approach

Conceptual models provide a valuable tool for analysis of any complex earth science phenomenon. The value of geological models as an aid to exploration is well established in the petroleum and mineral industries. In fact, it is the need within the petroleum industry for such models that is the key stimulant to the evolving understanding of sedimentary processes, and how this understanding can aid hydrogeologic research (e.g. Lui et al., 1996). Hydrogeologists have been less enthusiastic in adopting this approach to understanding controls on and the behaviour of groundwater (e.g. Van der Kamp, 1997). The ORM project adopted a model-driven scientific approach to investigating the ORM aquifer complex. The moraine-area structure was formulated in the fashion of an architectural event-sequence model (Fig. 2; Sharpe et al., 1996). To investigate the validity of this model an integrated multi-disciplinary investigation was initiated and included geologic mapping, geophysics, and sedimentology. This basin analysis approach (e.g. Eyles et al., 1985; Sharpe et al., 1992) is particularly valid in areas where subsurface features (e.g. buried valleys) may exceed the scale of site-specific studies and remain unidentified (Fig. 3). The approach recognizes a hierarchy of architectural elements to be identified in glacial landscapes (e.g. Miall, 1984).

Model Development

A geological model for the ORM (Sharpe et al., 1996; Fig. 2) was constructed using mapping, terrain analysis and basin analysis concepts, particularly subsurface investigations. The model was built on an understanding of the regional geology of southern Ontario (Barnett et al., 1991), detailed

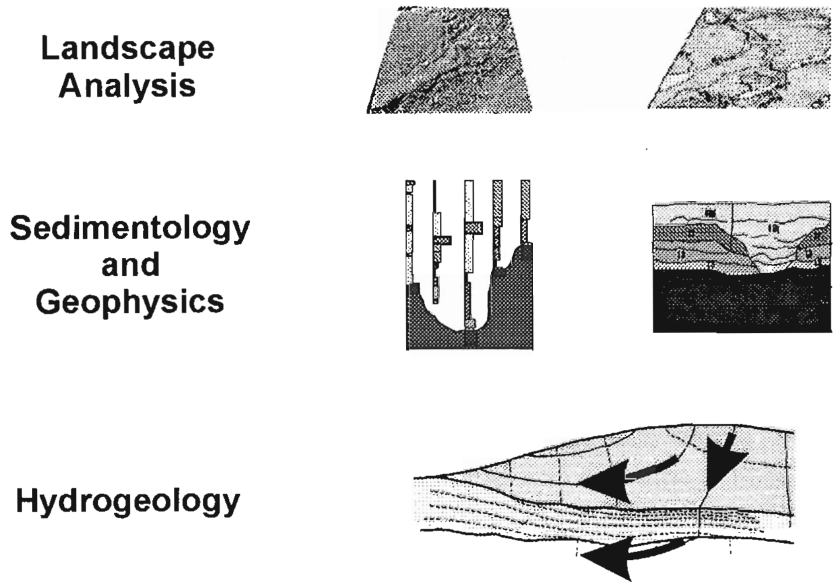

Figure 1. Methodology integration in the ORM hydrogeology project.

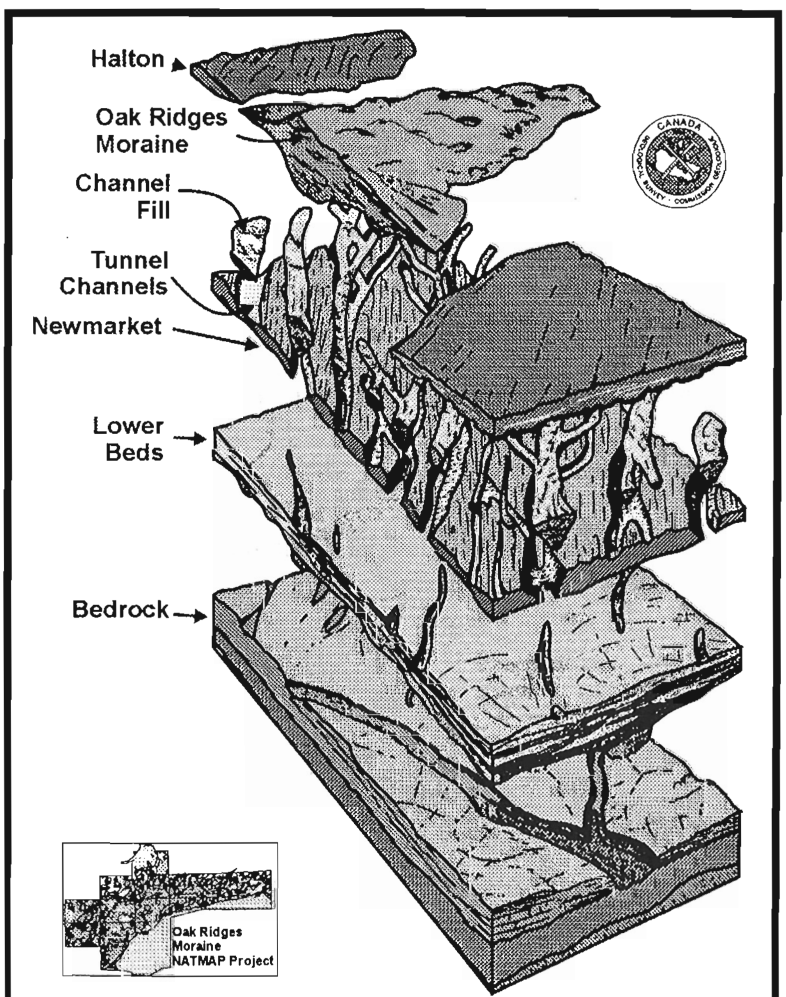

Figure 2. Conceptual geologic model of the Oak Ridges Moraine area (from Sharpe et al., 1996)

ARCHITECTURAL HIERARCHY

(basin - fill complex)

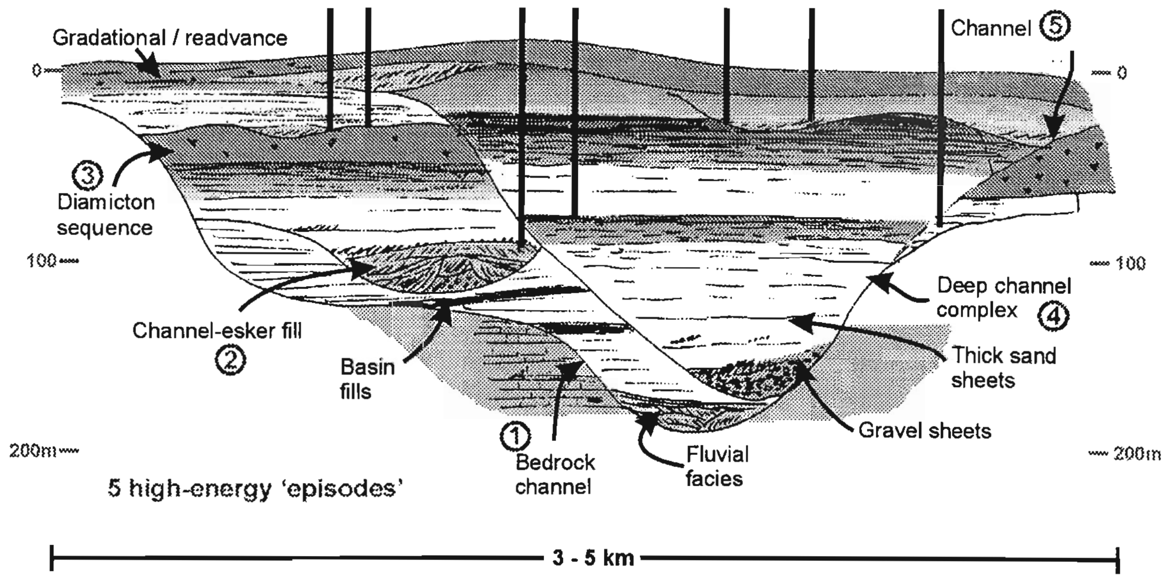

Figure 3. Conceptual representation of architectural hierarchy in sediments of the ORM area. If a site investigation drilled a set of holes (vertical black lines), it is unlikely the large channel (episode 4) or smaller channels (episode 2) and their sediment fills would be identified.

mapping (e.g. Karrow, 1967; Barnett, 1995; this vol. Sharpe and Barnett, 1997a), published studies (e.g. Sibul et al., 1977), shallow seismic reflection profiles (Pullan et al., 1994; Pugin et al., 1996; Fig. 4), and, logging of sediment exposures and recent drill cores (Barnett, 1993; GSC unpublished). The model best applies to the area between Uxbridge and Nobleton where these high-quality data are most abundant; however, it seems to have regional application (e.g. Sharpe and Barnett, 1997b).

The model comprises four units and channels that dissect these units (Fig. 2). Channels in sediment were eroded through a regional till sheet and aquitard, Newmarket Till, thus providing hydraulic connection between upper ORM aquifers and lower aquifers. Seismic profiling and drill core results show the geometry of NNE-SSW-oriented buried channels and their fills of silt, sand and gravel. Gravel sequences within these channels may be targets for high-yield wells. Sedimentological studies of cores and exposed channel fills in particular, and additional subsurface mapping, will help advance concepts for groundwater prospecting.

The ORM model also benefited from incorporation of key new principles from other geologic models e.g. glacial meltwater concepts (e.g. Barnett, 1990; Shaw and Sharpe 1986, Shaw and Gilbert, 1990; Brennand and Shaw, 1994) and glacial depositional models (Rust, 1977; Shaw and Gorrell, 1991; Brennand, 1994).

Three elements important to developing a regional hydrogeologic model are discussed: 1) terrain analysis and surficial mapping, 2) basin analysis, and 3) hydrogeologic methods, elements that can be united through a regional geoscience database.

Terrain Analysis and Surficial Geological Mapping

Glaciated terrains contain complex landscape information on the formation of landforms and the deposition of associated sediments. Investigations of such terrains are commonly completed by aerial photographic and topographic map analysis in conjunction with supporting field investigations (Mollard, 1982; Mollard and Janes, 1983; see poster, Sharpe et al., this vol.). Recent developments in computing hardware and software now provide new opportunities for data collection and analysis of the terrain, such as remote sensing (TM, RADARSAT, thermography; see posters by Kenny and Dyke et al., this vol.) and digital elevation models (DEM). For synoptic and intermediate scale analysis, DEMs provide considerable improvements for terrain analysis (Shaw et al., 1996; Rains et al., 1996, Kenny et al., 1996;) by highlighting landform relationships not apparent by traditional methods (Fig. 5; Kenny, this vol.).

While some new methodologies have been developed and applied to hydrogeological investigations (e.g. land-systems mapping; Anderson, 1989; Randall, 1997) they need to be supplemented by sediment-landform-process relationships, particularly for areas where sediments may be 200 m thick. Nevertheless, while there is emerging information on glacial processes, there is incomplete knowledge of landform-sediment relations in many complex terrains (Shaw, 1995).

A DEM developed for the ORM area (Kenny et al, 1996) is used in synoptic and intermediate scale analysis (Skinner and Moore, 1997; Skinner and Moore, this vol; Kenny this vol.). The DEM also allows one to do more detailed terrain analysis, 3-D viewing, by providing, for example, "fly-through" and other enhanced terrain viewing tools. The DEM, a digital product, is ideally suited for data integration and use in geological and hydrogeological modeling (e.g. Cheng, this vol.).

The use of 1: 10 000 and 1:30 000 air photographs (Barnett, this vol.; Sharpe et al., this vol.) allows for more detailed terrain analysis during landform and sediment mapping in the ORM area. When supplemented with more than 1000 ground observation points per 1:50,000 map sheet (e.g. Sharpe and Barnett, 1997a; Russell and White, 1977), this technique permits the description of more detailed landform-sediment links across the ORM area. However, detailed airphoto analysis is more time-consuming and less efficient at yielding synoptic understanding. For example, the major network of channels present in the ORM went un-recognized despite earlier attempts at detailed mapping and air photo interpretation (Fig. 5). This set of channels can be readily identified on TM images and DEM models at scales based on 1:250,000 data or smaller. Furthermore the network can be readily compared to a digital geology map drape to assess its local relationships to sediments. With the large numbers of ground points and point to area transformations in GIS (neighbour-area plots) rapid mapping can be completed, perhaps more effectively than with traditional air photo methods.

Basin Analysis

Basin analysis refers to an integrated investigative approach to sedimentary basins with the objective of defining the architecture, depositional processes, and paleobasin configuration (Fig. 3). This is commonly achieved through a variety of sedimentological (sediment-facies and paleoflow analysis) and geophysical (seismic, downhole geophysics) approaches (e.g. Fligg, 1983; Eyles et al, 1985). With this three-dimensional dataset, (Chung, this vol.) one can use a series of "sliced-views" or surfaces (Brennand, this vol.) through the basin sediments to reproduce surfical mapping, which employs lithofacies and paleoflow analysis at shallow depths (1-3 m). This process, if sucessful, improves hydrostratigraphic and hydrogeological understanding (e.g. Boyce et al., 1997; this volume).

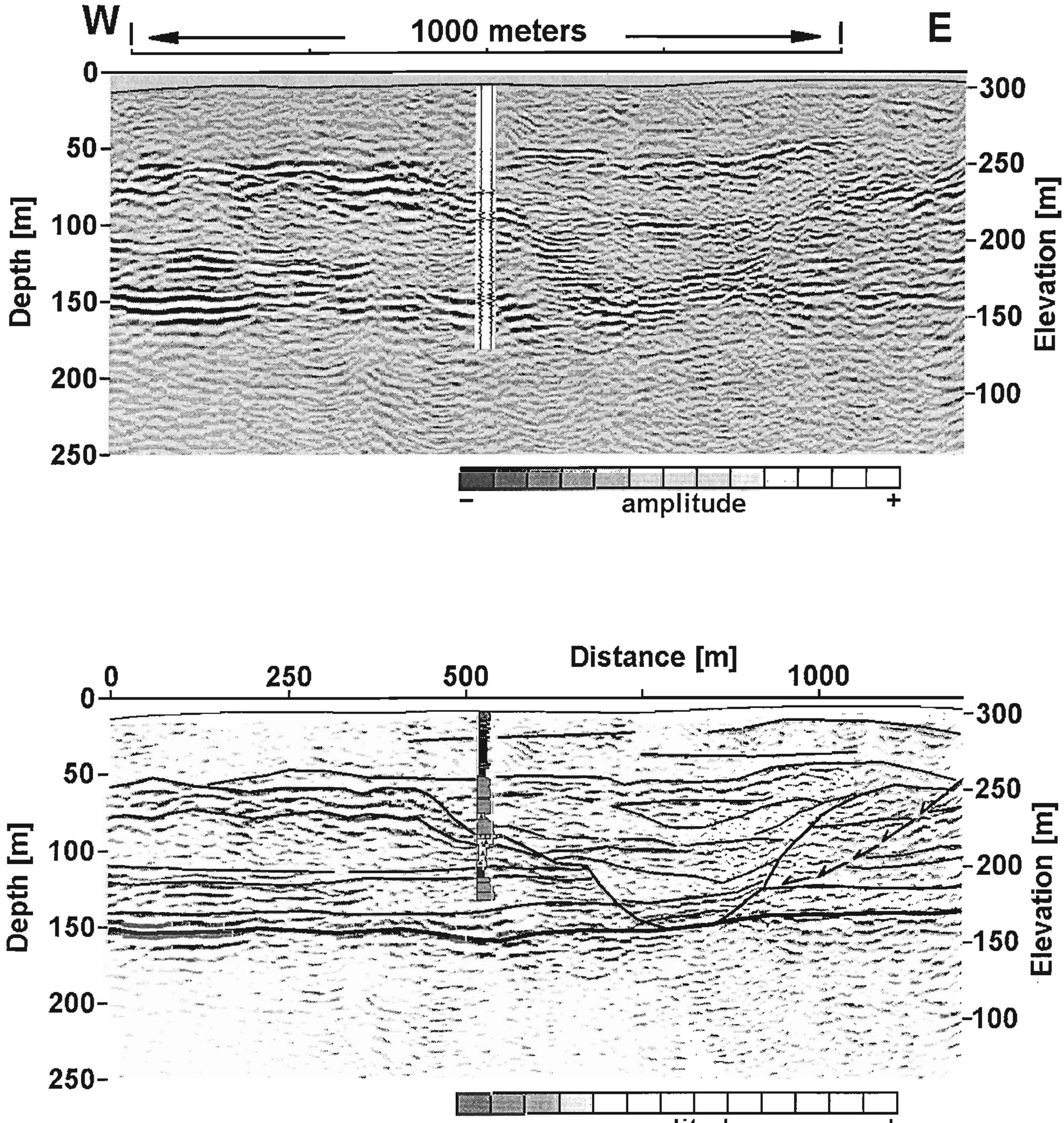

Figure 4. Seismic profile showing typical structure beneath and within the ORM (Pullan, this vol; Pugin et al., submitted)

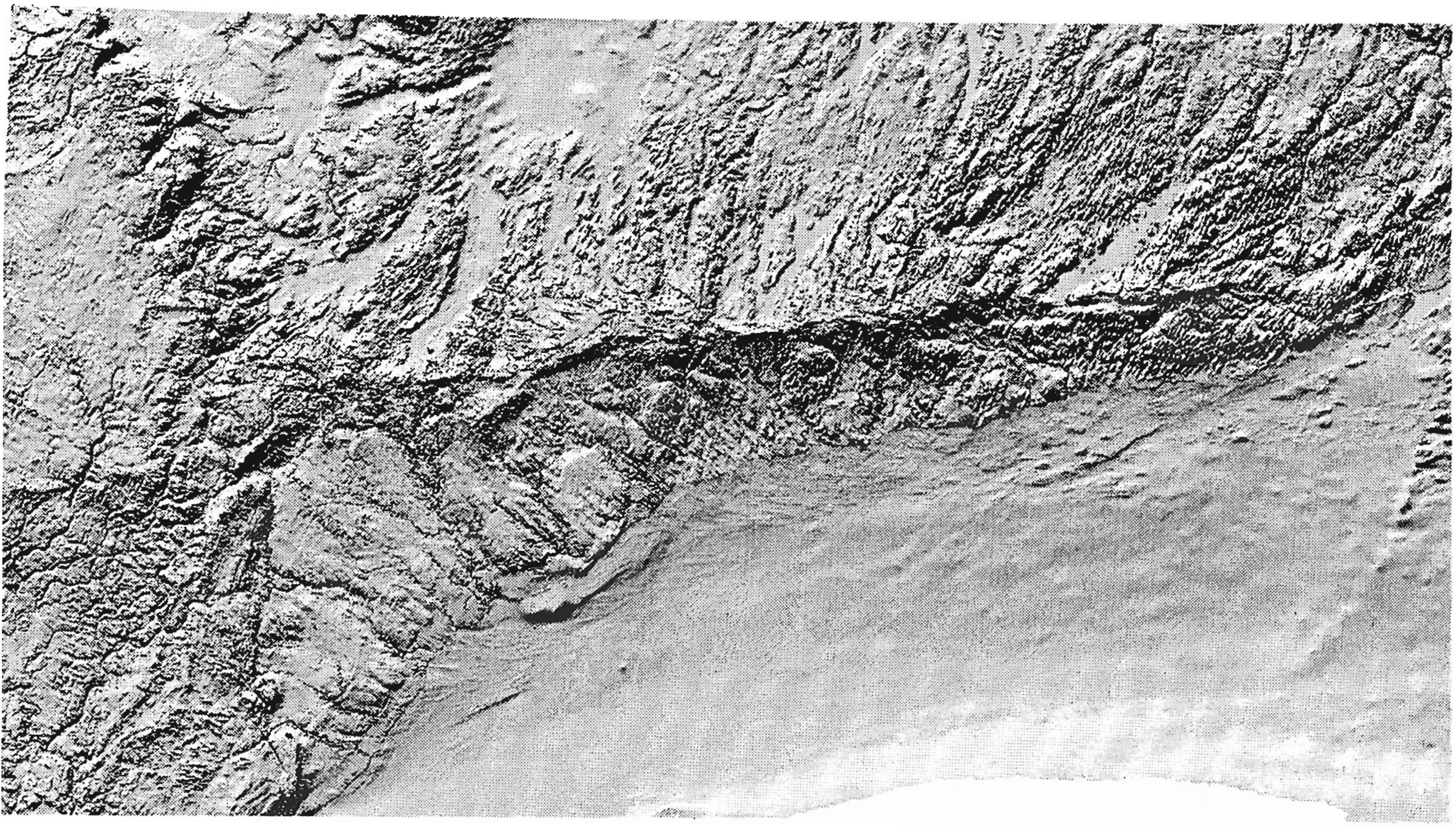

Figure 5. Hill-shaded Digital Elevation Model (DEM) of ORM area.

Within the ORM area, sedimentological logging has been completed along river (Boyce et al., 1995; Sharpe, 1997) and lake bluff sections (Brennand, 1997), gravel pits (Duckworth, 1979; Paterson, 1994; Barnett, 1997), drill core; and analysis of archival data (Russell et al. 1996; this volume). The sedimentary architecture has been extended by use of reflection seismic profiles (Pullan et al., 1994; Boyce et al., 1995 and Pugin et al., 1996). Many studies have emphasized a facies mapping approach (sediment or geophysical building blocks, cf. Miall, 1985) to describe the strata. Large sections and seismic profiling allow architectural or structural elements to be defined (Miall, 1985; Pugin et al., submitted; Boyce, et al., this vol.). These new data and a wealth of archival data from geotechnical and hydrogeoloic studies need to be integrated and synthesized with the MOEE water well database (Hunter and Raven-Beck, 1996; Brennand 1997; Russell, this vol.) to advance regional, basin-wide understanding.

The key progress in the application of basin analysis in glaciated terrain is shallow geophysical methods (Pullan, this vol.). Advances in the application of existing technology (e.g. seismic surveys) and advances in microprocessing technology have opened the door for improved subsurface mapping using: 1) seismic profiling and 2) downhole geophysical surveys (Hunter, J.A. and Burns, R.A. 1991; Pullan et al., 1994; Hunter et al. 1997). These techniques extend the sedimentogical information gathered in the near-surface to deeper parts of the basin. The methods generally have been used for years in oil exploration, and are now being applied to shallower, engineering and environmental applications such as aquifer mapping.

Collection, processing and interpretation of reflection seismic data is relatively time-consuming and expensive. However, the data breadth and resolution in the ORM area (e.g. Boyce et al., 1996; Pugin et al., 1996; Pugin et al., submitted), in the depth range of 20-200 m below surface with lateral and vertical resolution of 1-2 metres, pays dividends in the high-quality framework (stratigraphic and conceptual) that can be established for future work. Experience has shown that local knowledge in optimizing data collection and an understanding of glacial sedimentatary processes for data processing, markedly improves the interpretation of the results. Seismic profiling, particularly when coupled with borehole logging and downhole geophysics, have provided information on the nature and depth of bedrock, the presence and nature of lower drift, the Newmarket Till geometry, the composition of channels and channel fills, and the geometry of the Oak Ridges Moraine complex.

Hydrogeologic Methods

Hydrogeologic methods used in the ORM study focused on regional approaches important to area-wide water resource assessment, planning and management. Some site-specific surveys such as drilling, borehole installations and water well monitoring were also conducted. Regional datasets include stream baseflow surveys, groundwater and surface water chemistry and thermal imaging. The methods in use are discussed with respect to groundwater recharge, flow and discharge.

Groundwater recharge
The amount and distribution of groundwater recharge in the Oak Ridges Moraine area is an important aspect of regional water resource management, yet is poorly understood. A modest effort to investigate and quantify groundwater recharge is under way at two sites where vertical hydraulic gradients are monitored and groundwater age dating will be performed. Piezometer nests were also installed at 10 kettle lakes to determine vertical hydraulic gradients and examine the recharge role of the lakes. Several sites have downward flow which indicates that these depressions contribute to groundwater recharge.

More extensive work on groundwater recharge has been carried out at the University of Toronto (Eyles and Howard, 1988; Gerber and Howard, 1997). Gerber (1994) estimated the recharge in seven watersheds using water balances and stream baseflow analysis. More recent, site specific research investigates groundwater recharge mechanisms through tills using piezometric and isotopic methods. These isotopic data indicate higher bulk hydraulic conductivities (and hence recharge) in the Newmarket/Northern Till than would normally be anticipated from laboratory or field tests of hydraulic conductivity (Gerber and Howard, 1996).

Groundwater flow
Whereas results from recharge studies, stream baseflow surveys, water chemistry surveys and deep piezometer nests have direct implications for groundwater flow, no specific studies examining groundwater flow directions and rates have been undertaken (e.g. Haefeli, 1970). Maps of hydraulic head that indicate the direction of groundwater flow within several watersheds have been presented by Sibul et al. (1977), Ministry of Environment (1978), Smart (1994), Hunter (1996). Smart (1994), and Boyce et al. (1997) have also developed regional groundwater flow models that quantify groundwater flow.

Groundwater discharge
Groundwater discharge was assessed remotely and by field measurements. Under appropriate weather conditions, airborne thermal imagery can be a useful tool for the preliminary assessment of groundwater discharge (Dyke et al., 1996, poster this vol.). A derived map shows potentially significant discharge zones across the south flank of the ORM. These data could help in the delineation of the discharge boundaries of prominent aquifers in the Oak Ridges Moraine, or identify key habitat for the cold-water fishery.

Regional groundwater discharge is most commonly estimated using stream baseflow measurements in the dense stream network draining the ORM. Groundwater discharge estimated from Environment Canada streamflow records varies greatly between watersheds and ranges between 130 and 440 mm/yr (Gerber, 1994). These differences are used to assess some of the potential controls on groundwater discharge including surficial geology and topography. The highest baseflow generally occurs in watersheds with a greater proportion of exposed ORM sediments and with steeper slopes (Gerber, 1994, Dyke, unpublished results).

New surveys of stream discharge collected during low-flow conditions provide minimum estimates of groundwater discharge and improve our understanding of the spatial pattern of groundwater discharge within individual watersheds (e.g. Duffins, Soper, Wilmot, Humber, East Holland, Pefferlaw, Uxbridge, Rouge and Little Rouge) and sub-watersheds (e.g. Hinton and Bowen, G., 1997). These surveys provide insight into the geological and topographic controls on groundwater discharge and provide key data for the sustainable management of streams. Groundwater discharge from small upland areas (<10% of the basin area) may be responsible for a large proportion (up to 40%) of the total watershed discharge in this geological setting. The locations of discharge zones suggest some stratigraphic and permeability controls on groundwater discharge. High groundwater fluxes occur predominantly where surficial deposits are of glaciofluvial or glaciolacustrine origin whereas low groundwater fluxes are located in areas where till is present at the surface.

Groundwater chemistry
The quality of groundwater has been of interest in the area since the early studies by the Geological Survey of Canada (e.g. Hainstock, 1948a, b, 1952; Gadd, 1950; and Watt, 1968). Since then, the Ontario Ministry of Enviroment and Energy has collected a considerable amount of stream and groundwater chemistry data, though few of these data have been summarized or integrated to improve hydrogeological undertanding, except the synthesis by Hunter-Raven/Beck (1996). Beck and Howard (1986) significantly advanced hydrogeologic understanding in the area with their assessment of groundwater chemistry in the Rouge-Duffins Creek watersheds. Additional documentation of the impacts of land-use on water quality have been provided by Howard et al. (1993) and some examples are provided in the program (Bowen et al. this vol., and Freeman, this vol.).

Two water chemistry surveys were conducted in the ORM study in an attempt to improve regional data and develop regional methods. In the first, water samples from across the entire study area were taken from 400 wells and 150 stream sites to gain a general indication of groundwater quality and determine if chemical changes are taking place on a scale that would indicate regional groundwater flow (Dyke, this vol.). Moderate sulphate in recharge areas on the crest of the moraine and very low sulphate in wells below 300 m asl suggest a gradual evolution towards reducing conditions in regional flow systems. In the second survey, 400 stream samples were collected during low-flow conditions from individual watersheds to examine spatial differences in groundwater discharging to the streams. Such surveys can provide information on regional baseline groundwater chemistry and can help locate both point and non-point sources of contamination.

Databases and Geographic Information Systems

Data collected during the ORM project, with some exceptions, has been entered into either a relational database or GIS database (Russell et al., 1996). This database has been developed to integrate a large amount of varied data collected over a long period of time (40 years) and to synthesize the various datasets (Brennand et al., 1997). In this format the data are ready for database querying and export to a GIS for interpolation and the generation of geological surfaces (e.g. bedrock Moore et al., 1997; Brennand et al., this vol.).

A major source of data has been from archival sources, such as government agencies (MOEE, MTRCA, MOT, Regional Municipalities of Durham, Peel and York), universities and the private sector (e.g. Consumers Gas and CNR). Field data from existing geological mapping and from new mapping has contributed ~ 25,000 ground sites in the area (see posters, Sharpe et al., this vol; Barnett, this vol.). Other point data come from geochemcial surveys and from hydrogeological surveys (e.g. baseflow surveys and water chemistry sampling).

Borehole data are of three main types based on data quality: a) boreholes with continuous core, b) boreholes from geotechnical reports, and c) boreholes from the MOEE water well database. Boreholes with recovered continuous core provide the highest quality data by allowing sedimentological logging. This is crucial to reliable interpretation of sedimentary processes and depositional models (see above). The GSC and OGS have cored ten deep boreholes (~60-190 m) in the ORM area. Whereas, 80 continuously cored boreholes have been drilled by the IWA, though very few have been logged to capture sedimentological detail (e.g. Dillon, 1994; Golder and Associates, 1994; Boyce et al., 1995). Boreholes from geotechnical reports (5-30 m in depth) have not been continuously sampled and have been described primarily for engineering purposes (e.g. sediment texture, standard penetration testing, "N" values, grain size analysis, water levels, Atterberg limits, and shear strength). While providing valuable information on sediment properties the descriptions have limited use for interpreting sedimentary processes.

The water well data reported in the MOEE database have limited applications due to the absence of sediment sampling. The sediment descriptions rely on washings brought to the surface during the drilling process and do not describe solid sediment core. Individual boreholes from this dataset have low reliability (Kenny et al., submitted); however, as an ancillary dataset and as a group, they are a useful subsurface mapping tool.

The MOEE water well material codes provide a unique opportunity to expand regional sediment mapping from sites of high quality data (Brennand, 1997; Russell et al., this vol). This dataset is particularly important for defining the bedrock surface as it is the only dataset to with regional penetration to bedrock (e.g. White et al., 1971; Eyles et al., 1993; Brennand et al., this vol.).

GIS Layers

Information in this category includes both archival data (e.g., original Landsat TM) and thematic data layers (e.g., interpreted TM, geology). The number of thematic layers will increase as data are interpreted and interpolated from point to spatial datasets (e.g. field points via airphoto interpretation to surface geology maps) (see Sharpe et al., this vol.). A hydrologically conditioned DEM with a 30 m grid resolution has been developed from 1:50,000 NTS vector contour data with the assistance of MNR (Kenny et al., 1996; Kenny, 1997; Skinner and Moore, 1996; two posters this vol., Kenny, Skinner and Moore) (Fig. 5). This DEM will provide an elevation datum for hydrologic data, permit landform analysis, and aid watershed mapping and stream pattern analysis (Cheng et al., 1997; Cheng, this vol.).

Remotely sensed data provide extensive coverage of the study area e.g. Landsat TM, SPOT, ERS-1 and RADARSAT. These data are proving to be invaluable for terrain analysis, wetland, and landcover mapping. A thermal image flown along the south side of the ORM by MNR has been incorporated into the database (Dyke et al., this vol.). These data highlight open water on a cold March night in 1994 and are providing insights concerning spring locations and related geological correlations.

Summary

The goal of this meeting is to review progress toward understanding the regional hydrogeology of the Oak Ridges Moraine area. Focus is on the work of the Geological Survey of Canada, partners and other groups attempting to unravel the complex hydrostratigraphic structure of the moraine and beneath the ORM. Conceptual geologic models are emphasized in an attempt to direct effort towards regional scale approaches to hydrogeology and thus complement and provide context for site-specific studies.

The need for credible geologic models illustrates the way in which geologists and hydrologists may work together more closely on hydrogeologic problems. This approach also emphasizes the importance of geological context to advancing hydrogeological understanding in a stratigraphic complex area.

Regional geologic and hydrologic methods are briefly evaluated. Regional water-quality datasets, with a few exceptions are poor. Some important work on groundwater recharge has been carried out and new surface mapping should aid moisture-balance estimates. However, the spatial variation of recharge is poorly understood and regional water resource management is hampered as a result. New stream discharge data collected during low-flow conditions provide insight into geological and topographic controls on groundwater discharge and management of streams. Groundwater discharge from small areas can account for a large proportion of the watershed discharge, including capture from adjacent basins and sub-watersheds.

At the same time there is a lack of regional hydraulic (water level monitoring) data to test emerging hydrostratigraphic models. Modeling efforts to date can only advance if both the hydrologic and stratigraphic datasets are improved, particularly for the deep channel systems beneath the ORM. This should allow the current reliance on surface watershed water budgeting to include the significance of subsurface controls on the flux of groundwater across watershed boundaries.

Regional geologic methodologies are emphasized as a means of providing new insights to approaches beyond those used at the site-specific scale. These methods involve the use of basin analysis techniques (sediment mapping, reflection seismic surveys, continuous deep drilling and borehole geophysics) and the capture and synthesis of archival 3-dimensional data. An important adjunct to these field-intensive and office techniques is the integration of remote sensing, GIS and database management methods to more efficiently advance regional water resource knowledge.

How to obtain additional information

Further information concerning ORM and related studies and products can be found at the following outlets:

1. GSC
   Oak Ridges Moraine website:
   http://sts.gsc.nrcan.gc.ca/page1/envir/orm/orm.htm

Maps and report can the purchased at the following outlets:

GSC Publications
Geological Survey of Canada Bookstore
601 Booth St., Ottawa, ON, K1A 0E8, Canada
Tel: (613) 995-4342 Fax: (613) 943-0646
Internet: gsc_bookstore@gsc.nrcan.gc.ca
http://www.nrcan.gc.ca/gsc/gicd/pubs/publish.html

2. OGS
   OGS web site: http://www.gov.on.ca/MNDM/MINES/OGS/MMDOGSE.HTM

OGS Publications
Publications of the Ontario Geological Survey and the Ministry of Northern Development and Mines are available from the following sources.

a) Mines and Minerals Information Centre
M2-17 Macdonald Block
900 Bay St.
Toronto, Ontario M7A 1C3

Toll-free long distance: 1-800-665-4480

b) Publications Ontario
880 Bay Street
Toronto, Ontario M7A 1N8
Telephone (local calls): (416) 965-5300

Toll-free long distance: 1-800-668-9938

c) Publication Sales
Ministry of Northern Development and Mines
Willet Green Miller Centre
Level B3, 933 Ramsey Lake Road
Sudbury, Ontario P3E 6B5
Telephone: (705) 670-5691
Fax: (705) 670-5770

3. MNR publications:

Hunter and Associates and Raven /Beck, 1996. Hydrogeological evaluation of the Oak Ridges Moraine area: technical report. *Prepared for* the Oak Ridges Moraine Technical Working Committee.

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Land Use Planning Branch
Ministry of Natural Resources
300 Water Street
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4. MOEE publications: http://www.ene.gov.on.ca/envision/index.htm

Ministry of Environment
Public Information Centre
135 St.Clair Ave. West.
Toronto, Ontario
M4V 1P5 Phone: 416 -323-4342

5. University of Toronto Hydrogeology in the GTA.
See papers and contained references in:

Environmental Geology of Urban Areas, Geological Association of Canada, edited by N. Eyles, 1997. Available from Geological Association of Canada, c/o Department of Earth Sciences, Memorial University of Newfoundland, St. John's Newfoundland A1B 3X5.
709 737-7660; Fax: 709 737-2532; E-mail: GAC@sparky2esd.mun.ca
GAC web site: http://www.esd.mun.ca:80/~gac/

U. of Toronto geology web site: http://www.geology.utoronto.ca/

Geology publications: http://www.geology.utoronto.ca/publications/publications.html

6. Oak Ridges Moraine fieldguide books:

Sharpe, D.R., and Barnett, P.J. (Compilers). 1997. Where is the water? Regional geological/hydrological framework, Oak Ridges Moraine area, southern Ontario. Geological Association of Canada – Mineralogical Association of Canada, Joint Annual Meeting, Ottawa '97, Field Trip A1, Guidebook, 49 p.

Sharpe, D.R., Barnett, P.J., Dyke, L.D., Howard, K.W.F., Hunter, G.T., Gerber, R.E., Paterson, J., and Pullan, S.E. 1994. Quaternary geology and hydrogeology of the Oak Ridges Moraine area. Geological Association of Canada, Mineralogical Association of Canada, Joint Annual Meeting, Waterloo, 1994, Field Trip A7: Guidebook.

(Fieldguide books are available for viewing at Queen's Park (M2-17 Macdonald Block) or can be purchased from the GAC, see address above).

7. GSC / OGS ORM bibliography -Appendix to this volume

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Regional Municipality of Peel
Regional Municipality of York

Water Resources Investigations of the Oak Ridges Moraine-Geology and Hydrogeology

Oral Program

Date: October 29th 1997

		Presentation schedule	Presenter
	8:00-8:20	**Coffee**	
	8:20-8:30	Opening Remarks	- Fred Johnson, OMNR
Geological Setting			
1.	8:30-8:50	What is the Oak Ridges Moraine?	- Peter Barnett, OGS
2.	8:50-9:10	Regional geology / hydrogeology of ORM	- Dave Sharpe, GSC
3.	9:10-9:30	Glaciolacustrine basin analysis of Humber watershed	- Hazen Russell, U. of Ottawa
	9:30-10:20	**Coffee and Poster Session**	
Hydrogeology and hydrology			
4.	10:20-10:40	Hydrostratigraphy and hydrogeology of Duffins watershed	- Ken Howard, U. of Toronto
5.	10:40-11:00	Stream baseflow surveys, ORM	- Marc Hinton, GSC
6.	11:00-11:20	Application of the Agricultural Non-Point Source Model, Oak Ridges Moraine	- Gary Bowen, MOEE
7.	11:20-11:40	Watershed planning-forty steps to a new Don	- Adele Freeman, MTRCA
	11:40-13:00	**Discussion, lunch and Poster session** (lunch on site)	
Techniques -field and office			
8.	13:00-13:20	Groundwater and stream water chemistry Oak Ridges Moraine	- Larry Dyke, GSC
9.	13:20-13:40	Seismic profiling and water resource, ORM	- Sue Pullan, GSC
10.	13:40-14:00	DEM applications in the Oak Ridges Moraine	- Frank Kenny, MNR
11.	14:00-14:20	Stream pattern analysis in the ORM	- Qiuming Cheng, York U.
	14:20-15:00	**Coffee and Poster Session**	
Data management, analysis, and resource management			
12.	15:00-15:20	The ORM database and quality control	- Hazen Russell / D. Sharpe
13.	15:20-15:40	Resource management in the ORM	- Gary Hunter / Beck Cons.
14.	15:40-16:00	ORM groundwater: our legacy for the next generation	- Brian Beatty, OGWA
15.	16:00-16:30	**Discussion, Posters and Summary**	

On the origin of the Oak Ridges Moraine

Barnett, P.J.[1],Sharpe, D.R[2]., Russell,H.A.J[3]., Brennand,T.A[4].,Gorrell, G[5]., Pullan, S.E[2]., and Kenny, F.M[6].

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Landscape analysis, mapping, sedimentology, shallow geophysics and borehole data have been integrated to aid understanding of the complex landform-sediment geometries and event sequences of the Oak Ridges Moraine (ORM), southern Ontario. Landscape analysis using a digital elevation model of the moraine area illustrates regional relationships at a synoptic level. Sedimentological study of sediments and drill cores shows a composition, structure and environment of deposition dominated by meltwater sediments and processes that were much more important than the direct action of glacial ice. Integrating these data with results from shallow geophysics defines seismic facies and subsurface geometry that can be linked to surface landform elements. Large glaciofluvial bedforms observed in channels near the moraine can be observed in profile in channels beneath the moraine, perhaps marking the inception of moraine building.

The current model for the extent and origin of the Oak Ridges Moraine is based on the recognition that the moraine is built on a high-relief, erosional surface consisting of drumlin uplands and a network of deep, steep-walled, branching valleys (tunnel channels). Moraine development can be traced in four stages, from a glaciofluvial core to flanking glaciolacustrine-dominated wedge sediments. The model reflects the transition from subglacial to proglacial conditions during moraine formation and may represent sedimentation patterns through time, although more synchronous sedimentation may not be ruled out. It is thought that the initial stages of moraine construction are better exposed in the east and that the later stages bury the initial stages in the west.

Groundwater Prospects In The Oak Ridges Moraine Area, Southern Ontario: Application of Regional Geologic and Sedimentologic Models

Sharpe, D.R[1]., Barnett, P.J.[2], Brennand, T.A[3]., Russell, H.A.J[4], Gorrell, G[5], Dyke, L.D[1]., Hinton, M.J.[1], and Pullan, S.E[1]., and Pugin, A[6].

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It is well recognized that conceptual geologic models play a key role in successful exploration for mineral and petroleum resources. Groundwater is a major resource exploited for domestic, industrial and agricultural uses in the glacial deposits of the Oak Ridges Moraine area in southern Ontario. It is a major aquifer system of national importance in terms of the total population reliance on the resource. However, no regional conceptual models have been proposed for the sediments composing this ~200 m thick, areally-extensive sequence.

A geologic model is discussed that contains three distinct, yet related, elements: stratigraphy; depositional facies; and event-sequences. The stratigraphic model contains a number of hydrostratigraphic units, several of which have regional extent and influence (e.g. till sheets/ aquitards). Depositional facies comprise subaqueous fan and/or deltaic facies that show systematic changes in sediment geometry, style and texture away from source on the scale of 10's of kilometres to 10's of metres. These features are indicated by detailed mapping, seismic reflection profiles and drill core analysis. Event-sequences of regional hydrogeologic interest include, cutting of a widespread channel network, channel filling, and rapid sedimentation events.

The model, with two successful case studies, has significant implications for groundwater resource evaluation in the Greater Toronto Area. Where channels have eroded through regional aquitards there may be increased hydraulic connection between the aquifers of the overlying Oak Ridges Moraine and those of the underlying lower drift. Gravel sequences within channels may be targets for high-yield wells. Secondary aquifer connection may be laterally extensive.

Similar glacial sequences are found across glaciated terrain in North America and Europe and similar conceptual geologic/sedimentologic models may be developed to aid regional hydrogeologic investigations in these areas.

Glaciolacustrine Basin Analysis, Humber River Watershed, Southern Ontario

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Hydrogeological investigations and terrain evaluation for land use planning require more complete geological information than is commonly collected. As part of a surficial mapping program within the ORM NATMAP project, a four-stage approach has been tested to define the geological history of the glaciolacustrine basin in the Humber watershed. This is focused on understanding the 3-D nature of the basin fill, by: i) integration into a regional framework, ii) surficial geological mapping, iii) sedimentology, iv) GIS data integration.

The basin sediments onlap the Niagara Escarpment and occur down-flow of the surface expression of drumlins and tunnel channels associated with a regional unconformity. At only one location does the truncated Newmarket till crop out within the basin; other outcrops within the basin record the unconformity through truncation of lower deposits (e.g. Scarborough Fm.).

Surficial geological mapping involved landform analysis and sediment mapping. This provides a correlation between surface features beyond the study area and features within the watershed. Mapping of landforms and surficial sediments facilitated the preliminary identification of tunnel channel locations, the glaciolacustrine character of the ORM, and the character of the Halton Drift.

The sedimentological investigation involved three components; i) sediment description, ii) paleoflow measurements, and iii) architectural analysis. Six end-member lithofacies are defined from outcrop and drill core studies, i) bedrock, ii) diamicton, iii) gravel, iv) medium to coarse sands, v) fine sand to silt, and vi) clay. Paleoflow measurements indicate flow was predominately toward the northwest with a late stage flow reversal toward the northeast. Using lithofacies associations sediments were assigned to one of four regional stratigraphic packages. Within the watershed the regional unconformity is buried by stratigraphically younger sediments (Oak Ridges and Halton).

Having defined a conceptual geological model and the architecture, a GIS allows integration of archival data. This involves analysis of archival and field data to produce both structural and isopach maps of stratigraphic units. The individual units will be further characterized by integration of data on physical parameters, hydraulic conductivity, and geochemistry. This will allow an improved understanding of the basin architecture and facilitate the use of the geological data for regional planning issues and hydrogeological studies.

Hydrostratigraphy And Hydrogeology Of An Urbanizing Catchment On The South Slope of The Oak Ridges Moraine, Southern Ontario

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The Greater Toronto Area of southern Ontario is experiencing rapid urban growth with the current population expected to double by 2020. Urbanization is currently focused along the southern margins of the Oak Ridges Moraine (ORM; 1400 km^2), a provincially-significant groundwater recharge area and aquifer complex. The University of Toronto, in conjunction with the provincial government, has initiated a long-term research programme to establish the hydrogeologic function of the ORM and its susceptibility to urban pressures. Recent work has focused on evaluating the hydrogeology of a rapidly-urbanizing catchment (Duffins Creek Basin) on the south slope of the moraine prior to development of a large community for 90,000 residents (Seaton: 2800 ha).

The Duffins Creek study involved detailed reconstruction of the subsurface Quaternary geological framework, a water balance study and numerical groundwater flow modeling. Quaternary units were mapped as a series of surfaces and isopachs using a large subsurface GIS database (>7000 boreholes). The basin geology consists of a thick sequence of Late Wisconsin tills (Halton and Newmarket tills), intervening interstadial deposits (Oak Ridges Aquifer Complex; ORAC) and older glaciolacustrine and glacial sediments overlying Ordovician shale bedrock. Hydrostratigraphic units were identified through a spatial query of water well data and contoured geologic surface. This analysis reveals the presence of three principle aquifer systems including an upper sand and gravel complex (ORAC; 240-340 m asl), an intermediate aquifer (120-240 m asl) and a lower aquifer defined between bedrock and 140 m asl.

A 3-D groundwater flow model (Visual MODFLOW) incorporating the hydrostratigraphy was calibrated to water well hydraulic head data and stream baseflow estimates throughout the catchment geostatistical analysis (variography, kriging) was employed to evaluate aquifer heterogeneity and the spatial variability of hydraulic conductivity (K). Simulations show that deeper aquifer systems are recharged by the ORAC close to the moraine crest, but also by recharge through confining till units (Halton and Newmarket tills) on the moraine flanks. In the vicinity of the Seaton development, recharge through surface tills accounts for up to 60% of total groundwater flux. This finding has significant implications for managing the extent and density of urban development on the flanks of the ORM.

Stream Baseflow Surveys to Identify Regional Groundwater Discharge and Chemistry in the Oak Ridges Moraine

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The locations of groundwater recharge and discharge, aquifers and aquitards are important elements of regional groundwater studies. Often, field data at the regional scale consist of stream discharge records at a few locations, water well records and detailed local studies. Although these data are extremely useful, they are often insufficient to characterize hydrogeologic systems across a region. Stream baseflow surveys, which involve gauging stream discharge and collecting water chemistry samples at many locations within a watershed during a short period of time, provide additional field data that are used to characterize spatial changes in groundwater discharge and chemistry. Detailed stream baseflow surveys were conducted in 1995 and 1996 in four watersheds (Soper, Wilmot and Duffins creeks and Humber River) that drain the Oak Ridges Moraine. These watersheds range in size from 80 to 900 km^2.

Groundwater discharge is highly variable within each watershed but is related to geology and topography. Discharges are largest along the steep slopes of the Oak Ridges Moraine and smallest where the Newmarket, Halton and Kettleby Tills form the surficial sediments. Discharge zones that occupy relatively small areas can account for a significant proportion of the total groundwater discharge from the watershed. Areas of high discharge are probably associated with aquifers that pinch out or intersect streams. Smaller, but locally significant discharge zones are formed in coarse sediments at the edge of the former glacial Lake Iroquois shoreline. In all cases, stream baseflow surveys help in defining the existence and boundaries of aquifers and aquitards.

Baseflow water chemistry surveys were conducted principally to characterize regional differences in groundwater chemistry. Although the spatial and temporal variations in natural baseflow water chemistry are small, there are local differences in some parameters. These surveys also have other uses in considering the influence of chemical point and non-point sources on downstream water chemistry. For known sources, these surveys may be used to quantify downstream removal or dilution of pollutants. The surveys may also help in locating previously unknown sources of either point or non-point water pollution.

Application of the Agricultural Non-Point Source (AGNPS) Model on a Catchment Draining the Oak Ridge Moraine.

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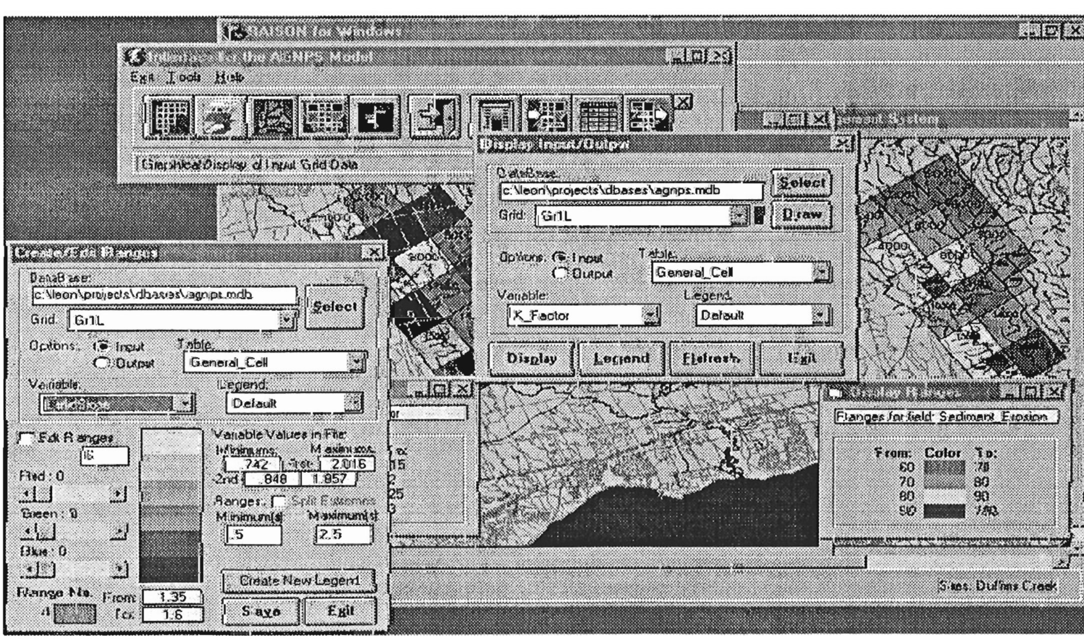
Non-point source pollution (NPS) is one of the major components that must be considered in watershed management. In the Duffins Creek watershed, we wanted to examine the impacts of future urbanization and changing agricultural practises. Stouffville Creek and Ressor Creek subwatersheds were selected as test catchments, since they have both urban development and agriculture. Located in the northwest corner of Duffins Creek, these subwatersheds arise on the Oak Ridges Moraine.

One solution to NPS pollution is to implement Best Management Practises (BMPs), such as conservation tillage, fertilizer application, animal-waste management on agricultural lands. Since there are many BMPs to select from, it is necessary to compare the effectiveness of these practises. The Agricultural Non-Point Source Model (AGNPS) is an event (precipitation) based model, which simulates surface run-off, sediment and nutrient transport. The AGNPS model was chosen for this study due to its ability to simultaneously simulate water quantity and quality in different parts of the catchment.

Environment Canada has developed a decision support software package (RAISON). One of the important features of RAISON, is its ability to incorporate modelling tools into the system. A lot of the information needed to run the AGNPS model, can be abstracted from digital maps (DEM, soils, land use). The RAISON/AGNPS interface assembles the required input data automatically from the GIS database and intercepts the output from AGNPS (Figures 1).

Based on the results from this and related studies by the authors, it appears that the RAISON/AGNPS is an effective tool for evaluating agricultural BMPs for southern Ontario. The capability to undertake rapid, "what if " scenarios in defining and managing future land use will be critical in maintaining the ecological function of Oak Ridges Moraine watercourses.



Watershed Planning - Forty Steps to a New Don

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In 1992, The Metropolitan Toronto and Region Conservation Authority (MTRCA) initiated the development of a watershed plan for the 380 square kilometre Don River Watershed, one of the nine watersheds within its jurisdiction. The internationally recognized plan "Forty Steps to a New Don" was developed by a task force representing the citizens of the watershed in partnership with the municipalities and agencies involved in activities that affect watershed health. A variety of consultants were engaged to provide technical, writing and process support for the task force in addition to the resources provided by the MTRCA and other agencies. Throughout the development of the vision, principles, protection and regeneration strategies (the forty steps); the identification of sub-watershed needs and opportunities; and the development of concept sites; the residents of the watershed were invited to participate in a variety of forums. The experience within the Don and the MTRCA's other watersheds supports the observation that community involvement is fast becoming a hallmark of watershed and river regeneration in North America.

Following the release of Forty Steps, the Don Watershed Regeneration Council was established to assist in its implementation and to act as an advocate for the Don in a variety of contexts. Four subcommittees were formed to undertake specific projects including a recently published Don Watershed Report Card. The MTRCA continues to provide staff and technical support to the Don Council whose members provide leadership in a number of areas. Local and regional partners, senior levels of government, private foundations; businesses, schools, community associations and individuals provide both resources and volunteer time to address the protection and regeneration requirements to care for water, care for nature, and care for the Don community. Integrating groundwater resources into this plan remains a challenge for the future

1994 Survey of Groundwater and Stream Water Chemistry, Oak Ridges Moraine

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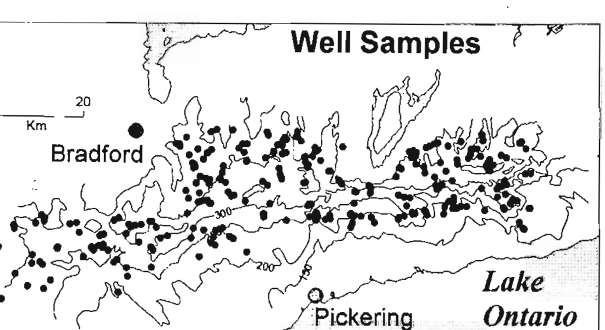
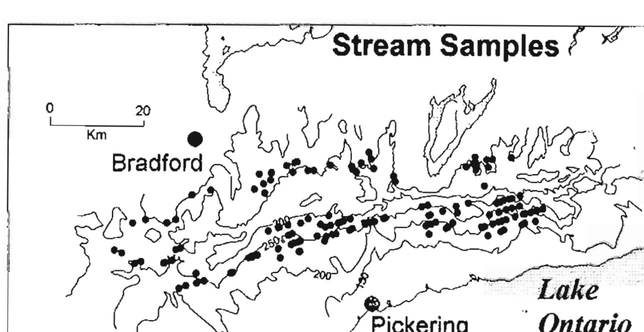
Water from approximately 400 private wells (in surficial sediments) and 150 stream sites in the Oak Ridges Moraine area was sampled over three months during summer, 1994. The objective was to gain a general indication of groundwater quality over a short time interval and determine if chemical changes are taking place on a scale that would indicate regional groundwater flow. Chloride in water well samples shows a wide range in concentration. A few samples have chloride concentrations of between 500 and 1000 mg/L (same as parts per million) but most are under 50 mg/L and one quarter contain less than 2 mg/L. Chloride shows a general tendency to decrease in concentration with intake depth over the 10 to 100 m depth range exhibited by the sampled wells. However, there is no other systematic distribution of values either with depth or location in the sampled area.

The highest chloride concentrations in streams tend to concentrate in the western, more urbanized part of the area sampled. This is consistent with the more extensive use of road de-icing salt in this area. The frequency of concentrations in stream waters is similar to that for wells with the notable exception that there are very few stream samples with chloride concentrations of less than 2 mg/L. Streams potentially gain a considerable part of their groundwater contribution from local, shallow groundwater flow along the entire course above any given sampling point, so the chances are great that a given sample will contain more than a background chloride level.

The eastern, more rural part of the sampling area shows the highest nitrate values in streams, suggesting an influence of agricultural nitrate sources on stream water quality. About 5 % of the well samples exceed the water quality objective of 45 mg NO_3/L established by the Ontario Ministry of Environment and Energy. However, no values exceed 70 mg NO_3/L. Most well samples are below 40 mg NO_3/L and slightly over one-third are below 2 mg NO_3/L. A considerable number of stream samples show nitrate values below 2 mg/L but this may simply be a function of nitrate sources being less abundant than chloride sources.

Sulphate concentrations in wells have a bimodal distribution. Concentrations below 2 mg SO_4/L make up 15 percent of the wells sampled whereas sulphate concentrations between 2 and 10 mg/L are rare. The distinct portion of very low sulphate concentrations suggests that sulphate is being removed from groundwater rather than simply not encountered. Almost all the wells with very low readings are below a surface elevation of 300 m, at the base of or below the lowest elevation of Oak Ridges Moraine exposure. This apparent evolution of sulphate content suggests that groundwaters become chemically reduced on a scale defined by the distance between the regional recharge area along the moraine crest and the location of very low sulphate wells.





Seismic Facies and Regional Architecture of the Oak Ridges Moraine Area

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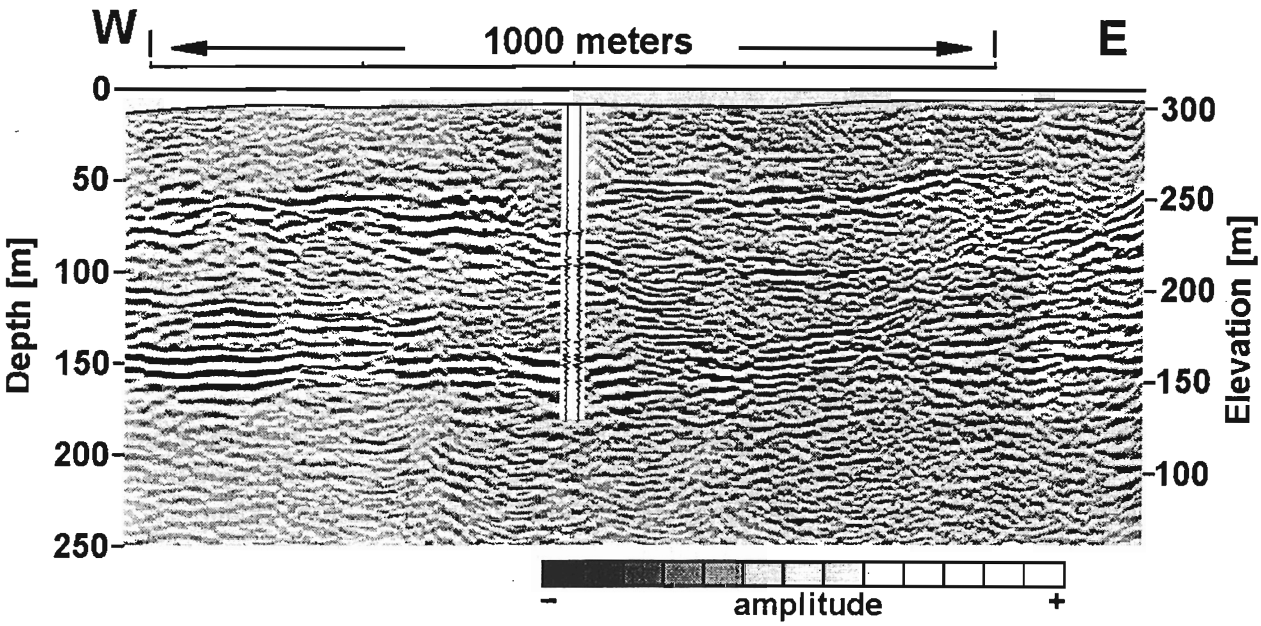
Approximately 50 line-km of shallow seismic reflection surveying was conducted in the Oak Ridges Moraine (ORM) area since 1993. This data provides subsurface structural information and contributes to an understanding of the structural and stratigraphic controls of groundwater flow beneath the Oak Ridges Moraine. While it is a relatively expensive and time-consuming survey method, seismic sections have yielded subsurface information in the depth range of 20 m to several hundred metres below surface, with lateral and vertical resolutions on the order of metres. The seismic data have provided information on bedrock depth and nature, presence or absence of lower drift, Newmarket Till and ORM sediments, and on spatial variations of lithologies and thicknesses of these units. This information has contributed to the development and refinement of a conceptual geological model for the region. Such a model is a critical tool in hydrogeological assessments and exploration, as it provides a regional framework and a stratigraphical context in which additional geological and hydrogeological data can be evaluated.

The results provide a demonstration of the potential use of the seismic reflection technique as an exploration tool for water resources. The lateral variability in sediment packages in the region means that successful searches for water resources require some context such as provided by seismic reflection surveys. The geological-seismostratigraphical model has defined a coarse-grained, channel-fill facies of the Oak Ridges Moraine sediments (D1) that are potentially high-yield aquifers. There may also be useful aquifers within the lower drift sequence (B1, B3). The Newmarket Till (C) has been shown to be a critical unit in terms of understanding groundwater flow in the Oak Ridges Moraine area. In spite of being a sandy diamicton, it's dense, overcompacted nature and low permeability properties make it a regional aquitard. However, the potential for hydraulic windows (channels through the Newmarket Till) connecting shallow to deeper aquifers is a crucial factor in terms of regional groundwater flow. Seismic reflection sections provide examples of the subsurface structural mapping and stratigraphic interpretation that the application of this geophysical technique can provide (see Figure).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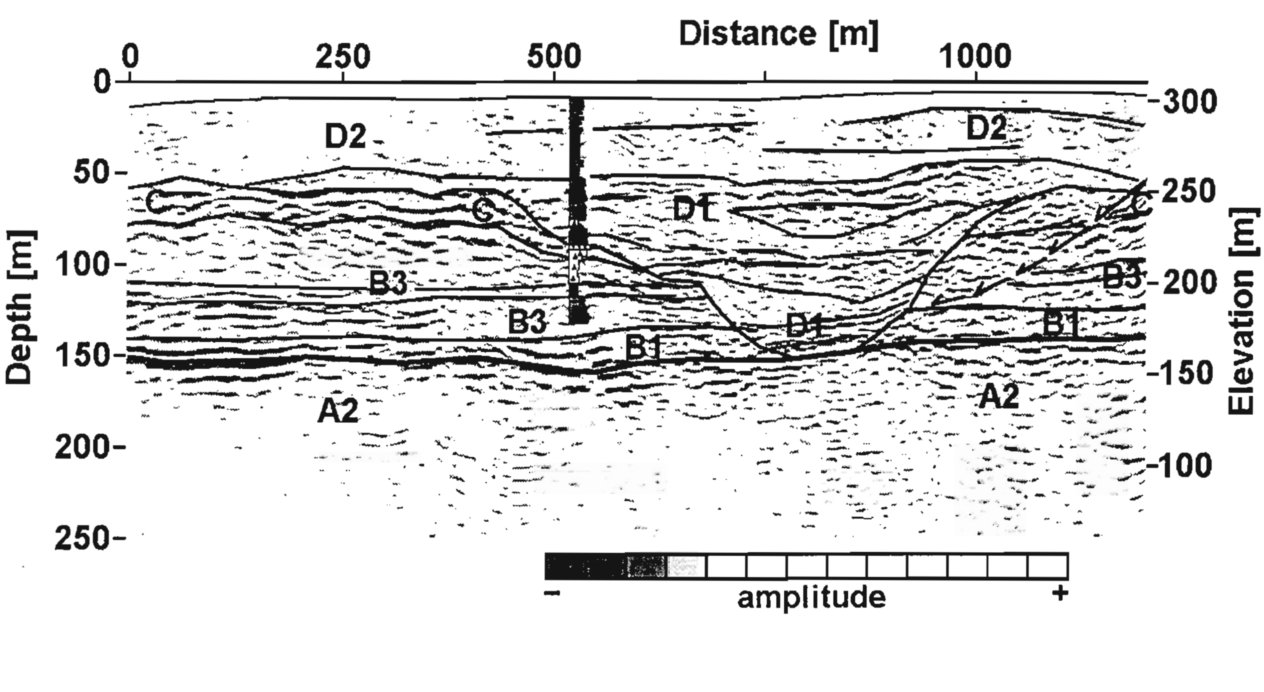
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The Development and Geoscience Applications of Digital Elevation Models: Examples from the Oak Ridges Moraine NATMAP Project

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Digital Elevation Models (DEM) have been in use for over 30 years; however, they have seen limited application in the geosciences. Advances in desktop GIS technology and in digital data protocols are providing the tools necessary for widespread application. As part of the Oak Ridges Moraine NATMAP project, a regional DEM has been generated for the Oak Ridges Moraine Area, southern Ontario and Lake Ontario. The model has been developed using 23, 1:50 000 scale digital National Topographic Series (NTS) maps and 18 Canadian Centre for Inland Waters digital bathymetric field sheets (various scales). Verification of the model integrity against available Geodetic Survey of Canada benchmark data indicates a sound model: a standard deviation of 2.87 metres with only 4 of 414 control points having a deviation of greater than 10 metres. Rigorous quality control and treatment of the topographic data not only had the effect of producing an accurate model but also produced a model rich in geomorphological detail which can be interpreted with no reservation as to model integrity.

This model is currently being used to serve a number of functions: provide a surface datum for project surface and subsurface data, ortho-rectification of satellite imagery, watershed analysis, hydrologic and hydrogeological mapping, terrain analysis and surficial geology map development. This presentation will highlight a fundamental GIS layer for environmental geoscience projects.

Statistical and Fractal Analysis of Stream Patterns in the Oak Ridges Moraine

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Conventional quantities (stream length, bifurcation ratio, density of streams, perimeter and area of drainage basins) extracted on the basis of DEM are analyzed from a statistical and fractal point of view using various GIS-based methods to characterize the surface stream networks and drainage basin systems in the Oak Ridges Moraine, southern Ontario, Canada. The results to be presented include: (1) global statistical analysis to characterize frequency and spatial distributions of streams of different orders in the study area; (2) morphometric analysis to characterize the distribution and interrelationships between the length, area and frequency of streams of various orders for individual drainage basins; (3) fractal analysis based on bifurcation ratio and stream-length distributions to reflect the property which may be associated with the randomness and geological constraints on the evolution of stream network over a particular scale in the study area; and (4) pattern recognition and classification to generate maps based on various quantities such as stream density, length ratio, fractal dimension of streams and the ratio of perimeter and area of drainage basins to demonstrate the spatial variation of surface stream patterns. Three fractal models (perimeter-area model, Hack's Law and Horton's Law) were applied to the dataset. The fractal dimensions estimated by different fractal models for the total streams and for the drainage basin in the entire area are approximately equal to 2 which implies that the stream networks in the area show statistical space filling or free of geological constraints. The variance of individual drainage basins, however, can be characterized by a combined principal component consisting of several fractal measures (related to bifurcation ratio, ratio of stream length and ratio of fractal dimensions of the total stream length in an individual drainage basin and for the drainage basin area). The distinct patterns created by the combined factor can be used to assist in geological interpretation. Spatial comparison of stream patterns with other dataset may suggest that geological structures, bedrock topography and drift thickness might be the main geological factors influencing the evolution of the streams in the area.

The Geological Coding of Sediment Descriptions and the MOEE Water Well Database: an Example From the Oak Ridges Moraine Project

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The Oak Ridges Moraine Project has developed comprehensive relational and GIS databases to address geological and hydrogeological issues in the study area. Of importance to hydrogeology are; i) to test a conceptual stratigraphic model of the area, ii) to define the geological architecture, iii) to delineate the hydrostratigraphy. To achieve these objectives a database of physiographic, geological, geophysical and hydrogeological data has been compiled. Geological data within the database has been ranked according to; sediment description quality, detail, reliability, and location confidence. Data are assigned to one of four categories, from lowest to highest; i) MOEE water wells, ii) geotechnical, iii) hydrogeology, and iv) ORM hydrogeology project.

For subsurface geological and hydrogeological investigations and interpolation in a GIS, the spatial distribution and density of the MOEE waterwells make it a key dataset, yet, it has the lowest assigned confidence on all ranking criteria. Site verification has been completed using embedded cadastral and elevation data and the OBM base maps and a 30 m grid digital elevation model. Site errors have been identified in 27% of the records. To permit seamless integration of the MOEE database with more detailed geological information a two-tier, sediment texture and stratigraphic coding system was developed. The sediment texture system is coded on recognized sediment texture and glacial process relationships to assign the best possible textural identifier to the original descriptions. This was important as the dataset contains virtually no descriptions of till or diamicton, units that are key to the regional stratigraphic framework of the area. Original descriptions are a three word adjective/noun string permitting ~250,000 combinations. From some 2300 unique descriptions in the Oak Ridges Moraine area dataset, 11 principal geologically significant textural units were assigned. Using the conceptual model as a geological hypothesis the MOEE database has been recoded to one of the five regionally identified stratigraphic layers. This has been achieved by assignment of the surface stratigraphic unit to the first unit in each borehole.

Following code assignment, verification of the word strings was completed by comparison of the first unit in each hole with the surficial geology - as mapped by the ORM project. Additional verifications have been made by comparison of coded descriptions with screen intervals and flow rates of wells from the MOEE database.

A three step methodology is recommended for the use of water well data in geological and hydrogeological investigations. First, a sound geological coding be applied to water well descriptions. This coding system should integrate local geological knowledge with recognized glacial processes. Second, the coding should be verified against the best geological data available. Third, the data should be used within a conceptual geological understanding.

Oak Ridges Moraine Hydrogeology Study: Overview

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The Oak Ridges Moraine is a regionally significant hydrogeologic feature, and source of drinking water for more than 200,000 people north of the Greater Toronto Area. Approximately 70% of this population is serviced by municipal communal well fields and 30% by private wells. The Oak Ridges Moraine is a significant groundwater resource area for storage and recharge for supply of high quality drinking water and stream baseflow. This abstract provides an overview of the regional, hydrogeological resource management issues in the Oak Ridges Moraine and suggested planning considerations, presented to the Ontario Oak Ridges Moraine Technical Working Committee in 1996.[a]

Presently, some major well fields in the moraine are approaching sustainable yield and some are being mined. There is evidence that old softer residual waters are being replaced with new hard water recharge at some locations. Well field pumping decreases static levels (hydraulic head) and causes the movement towards and the mixing of upper moraine aquifer waters with deep channel aquifer residual waters. However, measurable impact of pumping of the major deep aquifers has not been observed in stream flow records. Static level drawdowns in the central upper moraine aquifers may induce increased snowmelt and stormwater flood recharge. Therefore local headwater stream baseflow emerging on the moraine margins is not measurably affected, i.e. flood flows and evapotranspiration losses are reduced.

Although the groundwater quality in the Oak Ridges Moraine Aquifer system is generally good to excellent, the upper aquifers are unconfined and at risk to contamination from existing and future intensive land uses in the moraine. Recharge increases with elevation from about 300 mm/yr on the lowlands flanks to about 400 mm/year at the higher elevations of the moraine. The upper aquifers provide "reservoir" storage and recharge to the deeper aquifers along the moraine axis and discharge to the headwater streams at the moraine margin. Protection and maintenance of groundwater quality in the upper aquifers in turn will protect the deeper aquifer and discharge to the headwater streams.

[a] Oak Ridges Moraine Technical Working Committee: Ministry of Natural Resources; Geological Survey of Canada; Ministry of the Environment and Energy; Ministry of Municipal Affairs; Regional Municipality of Peel, York and Durham; Town of Caledon; Metropolitan Toronto and Region Conservation Authority; Ganaraska Region Conservation Authority; Urban Development Institute of Ontario; Aggregate Producers Association of Ontario; Federation of Ontario Naturalists; Conservation Council of Ontario and the STORM Coalition.

The 275 m asl contour has been accepted as the 'toe of slope' definition for the Oak Ridges Moraine, and corresponds, for the most part, to a natural boundary between the high density urban forms encroaching from the south and the sparse rural developments historically characteristic of the moraine.

A pervasive and widespread threat to the regional quality of the shallow Oak Ridges Moraine aquifers is road salt employed for highway de-icing. Stormwater and road salt seepage into the upper aquifers results in increases to chloride, sodium and hardness levels that exceed drinking water objectives and may render the water aesthetically unacceptable for a variety of domestic uses. Road salts are also a problem in combination with septic tank effluents in village plumes and impair a number of domestic and communal supplied on the moraine. Road salts have also impacted surface waters and there is a trend of increasing chloride concentrations in most streams emerging from the moraine.

Urban development, even when serviced with sanitary sewers is a source of a wide variety of contaminants in urban storm runoff. In general, large communal sewage disposal systems are considered environmentally inappropriate for new residential development in the Oak Ridges Moraine upland area and headwater catchments above 275 m asl. There is little evidence to suggest that dispersed private individual soil effluent absorption systems in low density residential developments are adversely impacting the Oak Ridges Moraine aquifers.

As a general planning principle, lake based water supply expansion to Oak Ridges Moraine areas should be limited to below the 275 m asl elevation contour. The moraine environment, i.e., at elevations above 275 m asl, should be protected from major new high density urban and transportation development.

The surface watershed divides in the Oak Ridges Moraine often differ substantially from the groundwater divides. Indeed, there are localized areas within the moraine where lateral groundwater flow direction may be opposite to surface flow directions and opposite to groundwater flow direction at alternate depths. Most existing water budget and stream base flow estimates close to surface watershed boundaries should be regarded as 'suspect'.

Environmental databases related to the moraine are often not adequately maintained, integrated and cross-referenced by source agencies. At present, historical long-term environmental monitoring data at best is virtually inaccessible and at worst has been lost by the administrative processes of the multi-jurisdictional agencies which operate within the moraine. Many old monitoring records appear to have been lost, destroyed, redistributed with administrative mergers, lost on key employee retirement, or buried in archives. Often the only source of continuous long- term monitoring information are the production wells and existing large landfill sites. Comprehensive integrated environmental information management systems should continue to be implemented.

ORM Groundwater: Our Legacy for the Next Generation

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Water in Abundance

Development of Toronto and the GTA communities began as a result of an abundance of water. Lake Ontario provided transportation and water supply and rivers flowing from the Oak Ridges Moraine (ORM) provided a source of power. As development spread radially out of Toronto and beyond the reach of the lake water supply, the search for a lower cost supply began. Several granular-filled bedrock valleys were soon discovered which yielded large groundwater supplies. These buried valleys were traced northward to the ORM. They supported 500-1000 gpm (40 -80 L/s) wells for communities like Milton, Brampton, Weston, Mimico, Downsview, North York, Unionville, etc.

Most of the rural growth pattern in the GTA during the post-war years centred around the most productive aquifers. When Metro Toronto was created in the 1950's, lake-shore treatment plants and pumping stations were expanded to serve the growing population. As the lake-based supply system spread out, the original supply wells were shut down and abandoned.

Today, water supplies in the rural GTA communities continue to be provided by groundwater from deep aquifers beneath the ORM. These aquifers supply high yields to wells in every major community on the ORM, from Halton Hills in the west to Scugog in the east.

With such an abundance of water, it is no surprise that the GTA community is one of the highest water consumers in the world. Water supply systems in the GTA area are designed to deliver over 100 gal (450 L) per capita per day. This is about 10 times the World Bank supply requirement for developing nations.

The ORM's Hidden Treasure

The search for groundwater supplies over the past 50 years has demonstrated that the ORM aquifer complex is among the most extensive and productive in Ontario. Until recently, however, there has been no attempt to map or understand the aquifer systems. This is attributed to the ease of locating more than sufficient water supplies to meet the growing demand.

There is generally no strong incentive to conduct detailed mapping of aquifers or modelling of regional flow patterns when groundwater is so abundant. In the last decade or so, there has been evidence of over- pumping in some aquifers. For example, heads in parts of the deep Yonge Street aquifer have been lowered over 20 m as a result of over-pumping. Similarly, pumping from some Halton Hills municipal wells has caused interference with nearby streamflow. In some cases, these kinds of impacts have triggered a more detailed assessment of local aquifer conditions.

Recently, there has been a renewed interest in groundwater conditions in the ORM. Major groundwater research programs have been initiated by the Geological Survey of Canada (GSC), the Ontario Geological Survey of Ontario (OGS) and the University of Toronto. This research effort has been timely, because most GTA communities are embarking on major expansions over the next few decades. Much of this growth will occur in the ORM and availability of groundwater supplies will become critical.

One of the most interesting research findings has been improved mapping and understanding of the deep aquifer systems beneath the ORM. The GSC has developed a conceptual model of the geologic architecture. Much of the research has focussed on the occurrence of deep "channels" of sand and gravel. The GSC researchers believe that the deep channel deposits "*may be more productive than previously suggested*" ("Groundwater Prospects in the ORM Area", Sharpe et al., 1996).

It is becoming apparent that major groundwater reserves exist below the ORM and in the buried bedrock valleys that extend southward. The existing municipal wells tap only a few of the numerous channel aquifers that have been mapped. Most of the high yielding aquifers south of the ORM are currently undeveloped as a result of the shutting down of dozens of old municipal wells in Metro Toronto, Brampton, Vaughan, Richmond Hill and Markham.

The vast untapped groundwater resource in the ORM constitutes a valuable hidden treasure for future generations. The major challenge over the next decade will be to delineate the aquifers and measure their sustainable yields.

<u>Water for the Next Generation</u>

The population of the GTA communities is expected to nearly double over the next few decades. The groundwater reserve in the ORM aquifer complex has a significant economic value. This resource is now recognized as a significant water supply source for the next generation.

The GTA communities now have an opportunity to demonstrate how sustainable development can be achieved. But first, mapping of the aquifer system should be completed. The ORM could be a focal point of fundamental research on aquifer mapping and management.

Sustainable development for future generations will require a paradigm shift with respect to the water supply industry. The "new economics" requires a shift from the "abundance" complex to thc "scarcity" complex. A new framework must be developed for political decision-makers to re-assess service delivery options.

The great water delivery schemes of the past are not appropriate for the next generation. Society will no longer support costly water-supply schemes that were conceived in the 1950's, such as the James Bay water diversion to New York. Global trends in the water supply industry are moving away from costly engineering solutions to more affordable water management solutions. This new approach will require much more efficient use of our groundwater resources.

The paradigm shift to more sustainable development will require an extensive public education program on water conservation. Secondly, a much better understanding of the ORM aquifer complex will be needed. Finally, a central government agency must take a leadership role in developing the framework for achieving sustainable development for the next generation.

Poster session / Abstracts

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2. **Barnett, P.J.**
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12. **Russell, H.A.J. and Lemieux, D.**
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13. **Sharpe, D.R., Russell, H.A.J, Brennand, T.A., Barnett, P.J., Gorrell,G., Kenny, F.M., & Finley, D.**
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14. **Sharpe, D.,R., Barnett, P.J., Brennand, T.A., Russell, H.A.J, Finley, D., & Gorrell,G.**
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15. **Sharpe, D.,R., Barnett, P.J., Brennand, T.A., Gorrell, G., and Russell, H.A.J.**
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16. **Sharpe[1], D.R., Dyke[1], L.D., Hinton[1], M.J., Pullan[1], S.E., Russell[2], H.A.J., Brennand[3], T.A. Barnett[4], P.J., and Pugin[5], A.**
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17. **Skinner, H. and Moore, A.**
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    Ontario Encourages Voluntary Ecosystem-based Watershed Management

Early to Late Holocene and Historical Hydrological Changes in the Oak Ridges Moraine, Southern Ontario

Anderson, T.W.

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Texture pollen and seed stratigraphies in cores from 15 lakes and bogs in the Oak Ridges Moraine document Holocene and historical changes in water level. Lake cores were recovered in offshore-nearshore transects to determine upslope/downslope displacements of the littoral zone, displacements that represent lake-level rises and declines.

Swan Lake shows an early Holocene period of deep-water gyttja deposition. By 9-8 ka shallowing was evident in the nearshore area based on a change from gyttja to shallow-water deposition and increased frequencies of seeds and pollen of pond plants such as *Najas flexilis, Potamogeton* and *Nuphar*. By 6 ka, a nearshore moss mat extended offshore; by 4 ka it changed to a sedge mat which was flooded shortly thereafter by rising lake levels. Musselman Lake shows evidence of a nearshore sediment hiatus and low-water levels prior to 5 ka. *Najas flexilis*-dominated, shallow ponding existed at 5 ka, but by 3 to 3.5 ka the nearshore pond habitat was flooded by rising lake levels. Water levels in Swan and Musselman lakes were approximately 4 m lower than present at 4 to 5 ka.

Several bogs originated as lakes as indicated by basal gyttja/marl deposition. One bog at the head of Bruce Creek shows marly clay succeeded by wood-rich peat dated 8.3 ka. Abrupt pollen changes across this sediment boundary suggest there was a sediment hiatus followed by low but fluctuating water levels to 5.9 ka, followed by lake infilling.

In general, water tables were low between about 9 and 4 ka. The low water tables and lake-infilling processes coincide with periods of maximum warmth (8 to 4 ka) and dryness (9-10 to 5.5 ka) in the area. The dryness was possibly a reflection of early-middle Holocene low-lake levels in Lakes Huron and Ontario. The synchroneity of these events represents a regional hydrological (groundwater) change which has implications for future climate warming since the middle-Holocene climate was 1-2^{0}C warmer than present.

Deforestation and land clearing at time of settlement (1850 A.D.) promoted basin-wide clay deposition in many swamp depressions. The clay acted as a sealant by plugging recharge to shallow groundwater flow systems or aquifers causing water levels to rise by as much as 12 m. This recent water-level rise led to the creation of Mud, North Thompson and Kelly lakes.

Quaternary Geology Mapping of the Oak Ridges Moraine at 1:20,000 scale

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A trial series of 1:20,000 digital Quaternary geology maps has been prepared for the central part of the Oak Ridges Moraine. Aside from the obvious benefits of their digital nature, maps at this scale permit the geologist to depict more detailed information on the surface distribution of materials and stratigraphic relationships, particularly along river valleys and lake bluffs.

This greater level of detail can be very useful for watershed management and modelling studies, enabling important watershed parameters such as permeability, erodibility, slope stability and source areas of base flow to be determined from these maps more accurately.

The maps have a standard geological legend with sediment types separated by age and origin. There is also a sediment matrix which is an alternate legend designed to show the variation in grainsize distribution for each map unit in relation to typical ranges for hydraulic conductivity. It is colour coded to map units and the origin of the sediments is described along the top of the matrix. It is hoped that this material matrix will help facilitate practical applications of the mapped data, particularly for watershed planners.

These maps are in digital form which will aid in the incorporation of geological information into Geographic Information Systems for groundwater modelling studies and natural resource, land use, and watershed planning.

Bedrock Topography of the Greater Toronto & Oak Ridges Moraine Areas, Southern Ontario; Geological Survey of Canada Open File 3419

Brennand, T.A.[1], Moore, A.,[4] Logan, C., [2]Kenny, F., [3]Russell, H.A.J., Sh[4]arpe, D.R., and [2] Barnett, P.J.[5]

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The configuration of the bedrock surface in the GTA has been of interest since the early reports of Spencer (e.g. 1881) who drew attention to the location of a former channel network connecting Georgian Bay and Lake Ontario. More recently the location of bedrock valleys has been of interest related to their hydrogeological significance and possible control on regional groundwater flow (e.g. Gadd, 1950, Haelifi, 1970). A series of bedrock topography maps have been produced as part of geological mapping in the area (e.g. Karrow, 1967) and these data were used to re-assess the location of the Laurentian channel (Karrow and White, 1971; Eyles, 1987). The regional Ministry of Environment and Energy (MOEE) water well records were used to show the surface of bedrock (Eyles et al., 1993).

The present map is a synthesis of a range of subsurface records including sources such as government agencies (e.g. MOEE), geotechnical consulting firms, utilities, local government, most geological mapping records and new and archival geophysical data. The map incorporates a series of data assembly, checking, and verification stages consisting of rigorous location checks (e.g Kenny, 1996; Kenny et al., 1997), standardized coding of subsurface lithologies (e.g. Brennand, et al., 1997; Russell, et al., 1997), and error-trapping procedures. The final corrected data was run through a series of GIS analysis routines using MAPINFO (Vertical Mapper) and ARCINFO to process the data and derive the most reasonable interpolation of the bedrock surface (e.g. Moore et al, 1997). Preliminary versions of this bedrock surface are shown as "page" figures on the new series of surficial geology maps (see Sharpe et al., this vol.).

The bedrock surface map of the GTA and surrounding area is shown with no data interpretation other than noting than there is very sparse data coverage in the thick sediment-covered areas such as the Oak Ridges Moraine and the general location of the Laurentian channel between Georgian Bay and Lake Ontario. Data interpretation in these areas may be tenuous but the bedrock surface-low running from Georgian Bay to the Toronto area coincides with a broad area underlain by erodible shale bedrock. There is an apparent break-in-slope (north to south) beneath the Oak Ridges Moraine east of the broad Laurentian channel. There is a general correspondence between bedrock valleys and some modern rivers (e.g. lower Humber, Holland rivers) but the pattern of modern stream courses needs more rigorous assessment (Cheng et al., this vol.). More detailed interpretations of this bedrock surface of the GTA and surrounding areas will be published in a separate paper.

Digital 3-D Geoscience Modeling of Aquifer Potential, Oak Ridges Moraine, Ontario

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Geological investigations have traditionally relied extensively on conceptual 3-dimensional models of the subsurface. Advances in computing hardware and software along with increasing availability of digital databases making data-driven 3-dimensional modeling increasingly attractive. The Oak Ridges Moraine Project has developed an extensive relational database of subsurface data collated from archival and field sources. Borehole data within this database are highly variable in terms of geologic attributes ranging from minimum sediment texture descriptions to detailed lithofacies descriptions and accompanying physical property measurements. In an attempt to identify the suitability of these datasets and operational limitation of 3-dimensional geoscience software a 200 km^2 area of the west Duffins-Rouge River systems was selected. Data from 475 boreholes were brought into a workstation-based geoscience modeling and visualization system (Lynx). Using sediment texture the dataset was reclassified according to aquifer potential and ranked from 0 (aquitard) to 3 (high potential for aquifer). Two approaches were tried in modeling the geology; i) manual construction of correlated sections, ii) triangulation and contouring.

In the first modeling approach, borehole interval data were visualized in 3-D from various perspectives and geologists correlated units on vertical sections using on-screen digitizing. Given the scarcity of data (<3 borehole per square kilometre) and the complex stratigraphy, difficulties were encountered during attempts to model aquifer potential volumes. Fence diagrams viewed in 3-D perspective are presented.

In a subsequent approach, triangulation and contouring were applied to model the upper and lower surfaces of aquifer potential units (4 units from class 0 to class 3). As was anticipated due to the complex intercalated stratigraphy, numerous "holes" occur in the triangulated surfaces where, for example, high-aquifer potential intervals are absent from boreholes. These surface modeling results could be used to guide the on-screen digitizing process to correlate stratigraphic units.

Lessons learned from this exercise are numerous and involve both operational, program and data constraints. The exercise proved to be time intensive and required a dedicated operator to run the 3-D modeling and visualization system. The package used imposed a number of data handling constraints which resulted in significant time delays and difficulties in completing the job. It became clear that even with a data density of ~3 sites per km^2 the irregular distribution and variable data quality severely restricted the ability to fully exploit the system capabilities. Additionally, glacial environments, while lacking the structural complexities of bedrock geology, offer their own challenges; particularly, rapid and unpredictable lateral facies changes, lack of base level controls common to marine-fluvial systems and the potential for incised stratigraphic relationships.

Remotely Sensed Thermal Imagery of Springs Along the Southern Flank of the Oak Ridges Moraine

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Groundwater discharge into streams is an important component of the water cycle. Discharge may be concentrated in small areas (springs or seeps) or may be spread out over longer reaches of streams. In the Oak Ridges Moraine, groundwater discharge accounts for most of the flow in streams. In areas without groundwater discharge, streams can dry up between rainstorms or during cold periods of snow accumulation.

Groundwater discharge also plays an important ecological role for aquatic habitats of these streams. In addition to maintaining flow in streams, groundwater discharge regulates stream temperatures near groundwater springs or seepage areas. The temperature of groundwater springs in this area remains nearly constant around 4 to 9°C throughout the year. Therefore, groundwater springs prevent streams from freezing in the winter and keep streams relatively cool in the summer. This constancy in temperature is essential for the habitat requirements of many aquatic species (e.g. trout).

This map demonstrates the use of thermal imagery collected from an aircraft for identifying potential areas of groundwater discharge to streams. This map presents data extracted from thermal infrared images that show contrasts in surface temperatures on a cold winter night. Warm areas on the thermal images coincide with portions of streams and may indicate areas where significant groundwater discharge occurs.

Methodology

The survey was flown between midnight and 3 am on the morning of March 1st 1994. The flight had an airspeed of 200 km/hr and an elevation of 1520 m above ground level. The data were collected by Ontario Ministry of Natural Resources using a Daedalus DS-1230 Infrared Line scanner. The effective ground resolution at survey airspeed was 1.7 m. Analysis was completed manually by transcribing thermal 'hotspots' to 1:50 000 NTS mapsheets. The data were digitized from the 1:50 000 NTS sheets and transferred to a vector GIS system. No systematic ground verification of the data has been completed. Stream baseflow gauging conducted by the Geological Survey of Canada provides an initial verification of the thermal imagery results. Temperature loggers provided continuous records of water temperature in selected groundwater springs.

Discussion

The thermal imagery provides a qualitative measure of ground surface temperatures that depend on the prevailing weather conditions during the flight. Air temperatures were cold for the three days prior to the flight (mean daily temperature <-10°C) with air temperatures below -6°C to -15°C during the flight. In contrast, groundwater discharge at springs in the headwater reaches of several streams is warmer (4 to 9°C) and is not influenced by the daily air temperature fluctuations . At the time of the imagery, fresh snow covered the area and the warmest natural surface was open water. Portions of the stream that appeared cold on the imagery were probably frozen at the surface or obscured from the sensor. The large thermal contrast between the open and frozen portions of the streams is the essential value of the imagery. It is inferred that areas of open water did not freeze because of their proximity to areas of groundwater discharge.

The comparison of these results with measurements of summer baseflow in several watersheds suggests that the warm winter temperatures correspond with areas of high groundwater discharge. However, many segments of small streams in groundwater discharge zones appear cold on the imagery. It is possible that these streams may have had too little discharge to prevent the water surface from freezing or other factors such as obscuring vegetation could have affected the imagery. Although several ponds appear as warm winter surfaces on the imagery, this does not necessarily imply that these are areas of groundwater discharge.

Implications

Under appropriate weather conditions, thermal imagery can be a useful tool for the preliminary assessment of groundwater discharge at a regional scale. Field verification of water temperatures and distribution of groundwater discharge and stream ice during cold temperatures in conjunction with thermal imagery are needed to validate this method. The identification of significant discharge zones at a regional scale could help in the delineation of the discharge boundaries of prominent aquifers in the Oak Ridges Moraine. Although data are collected in the winter, these results may be useful year round since groundwater discharge occurs throughout the year and can be important for maintaining summer baseflow and providing summer habitat for some aquatic species.

Regional Distribution of Groundwater Discharge Inferred fromStream Baseflow Surveys, Oak Ridges Moraine, Southern Ontario

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Groundwater discharge to surface waters is spatially variable, yet few data on the spatial distribution of groundwater discharge are collected at the regional scale. A simple and useful method to estimate the regional distribution of groundwater discharge is to measure changes in streamflow along streams during baseflow conditions. A detailed survey of stream baseflow and water chemistry was conducted in 1995 and 1996 in four watersheds (from 80 to 900 km2) that drain the Quaternary deposits of the Oak Ridges Moraine Area, Ontario. The survey permitted the delineation of high and low groundwater discharge areas in all four watersheds. However, the precision of groundwater flux estimates decreases downstream as streamflow and the magnitude of the error in streamflow measurements increase. Groundwater discharge from small upland areas (<10% of the area) are responsible for a large proportion (up to 40%) of the total watershed discharge in this geological setting. The locations of discharge zones suggest some stratigraphic and permeability controls on groundwater discharge. High groundwater fluxes occur predominantly where surficial deposits are of glaciofluvial or glaciolacustrine origin whereas low groundwater fluxes are located in areas where diamicton is present at the surface.

Surficial 3-D Image/Map Exploration Using a DEM; Examples from the Oak Ridges Moraine NATMAP

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The newly constructed digital databases resulting from the Oak Ridges Moraine NATMAP project allow for the surficial 3-Dimensional nature of these data to be explored using image/map visualization techniques. For this area of southern Ontario, digital Quaternary geology maps, a seamless geo-referenced Landsat mosaic, geo-referenced RADARSAT images and a high quality Digital Elevation Model (DEM) have been compiled/constructed and integrated onto a common raster base. Using the DEM as the map base, these image and thematic data, including enhancements of the DEM, can be draped onto the DEM, viewed obliquely or viewed as continuous updated oblique views (or "fly-throughs") . In this way 3-Dimensional perspective views of these data have been generated and are providing an additional tool for geological analysis in this project. As well, presentation of data in this fashion is proving valuable as a project communication tool.

This presentation will demonstrate on-screen the image/map viewing possibilities using these integrated data sets. This presentation will be conducted using PCI s "Image Works" and "FLY" software packages.

Physiographic Analysis of the Oak Ridges Moraine Area, Southern Ontario; an Application of a Digital Elevation Model

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A Digital Elevation Model (DEM) has been generated for the Oak Ridges Moraine area, southern Ontario. Several enhancements of this DEM, including shaded relief, perspective shaded-relief and chromo-stereo, have been produced and a visual terrain analysis conducted. On the basis of surface roughness, slope, linearity, and elevation at a 1:250 000 scale, seven regional physiographic elements can be identified and delineated; Oak Ridges Moraine, Niagara Escarpment, streamlined uplands, lowlands north of the moraine, low-relief plains south of the moraine, erosional scarps, and incised alluvial valleys. Each of the seven physiographic elements contain unique terrain information as well as regional terrain characteristics that can be traced across several physiographic elements. Within each of the physiographic elements the enhanced DEM products are providing supporting evidence for existing theories, and new insights into the origins of this complex landform. For example, the trend of tunnel valleys mapped north of the ORM continues south to Lake Ontario; east-west trending channels occur within the ORM, and possible esker-fan arrays also occur. The model is also providing a means for recognizing slightly different terrain elements or variations in the orientation and distribution of elements within streamlined physiographic elements north of the moraine.

Mapping of glacial terrains has traditionally relied on ground surveys in combination with airphoto interpretation. Visual analysis of enhanced DEM, derived using 1:50 000 scale digitally structured topographic maps, is found to be complementary to these traditional mapping methods. DEM, while lacking the resolution and surface tonal contrasts of airphotos, have several distinct mapping advantages. These advantages pertain to the ability to integrate or overlay other data sets, the ease of analysis in Geographic Information Systems, and the presentation of seamless, uniformly enhanced composites at synoptic scales.

A Seamless, Geo-referenced Landsat TM Mosaic for the Oak Ridges Moraine and Greater Toronto Areas of Southern Ontario

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As part of the Oak Ridges Moraine NATMAP program, a 32,000 square kilometre, geo-referenced Landsat Thematic Mapper (TM) mosaic has been created covering the Oak Ridges Moraine (ORM) and Greater Toronto Area (GTA) of southern Ontario. Portions of three Landsat TM images, from two dates (May 7, 1988 and May 11 1992) have been geometrically corrected to UTM co-ordinates using 23 digital, 1:50,000 scale NTS maps as the map base.

For each image, 18 or more Ground Control Points (GCPs), were collected and from which full second order polynomial transformations were calculated and applied to each image. The image mosaic was created by digitizing cut-lines along man-made discontinuities (i.e. roads) in the areas of overlapping imagery. Radiometric differences between overlapping images were compensated for by employing histogram matching techniques calculated in the areas of overlap. To further mask the evidence of image seams, the images were interleaved or "feathered" together over a distance of 6 pixels (180 metres). The result of these carefully selected and applied geometric and radiometric corrections produced a nearly seamless mosaic. Independent quality control, using over 80 additional GCPs, indicates an accurate registration with an overall RMS error of less than 16 metres (i.e. sub-pixel accuracy).

This digital mosaic is being used for several functions within the Oak Ridges Moraine NATMAP project, including for traditional "photo-interpretation", merged with other image products to derive more geologically informative enhancements and as an image backdrop within GIS analysis. This poster will present this mosaic and highlight its applications. Additionally this poster will show how, with some additional effort, these same data can be used for the derivation of digital land cover maps.

Intranet / Internet Presentation of Oak Ridges Moraine Hydrogeological Datasets

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This poster presentation will demonstrate efficient Intranet/Internet technology for distribution of Ontario's water well and environmental databases. However, this potential cannot be fully realized until datasets are current, integrated, clean, coincident and extended to jurisdictional boundaries. The hydrogeological datasets prepared within the Oak Ridges Moraine study boundaries (although now dated at 1992) substantially meet these requirements. Water well records, Ontario Basic Mapping (OBM) layers, and a digital terrain model (DTM) are viewed and queried via Autodesk's MapGuide^{TM} browser plug-in and Java applets. Analytical results of the Oak Ridges Moraine Hydrogeological Study are presented in Web publishing format. Source agency approvals must also be negotiated for access to key data.

Development of a Regional Geoscience Database: Application to Hydrogeologic Investigations, Oak Ridges Moraine Area, Southern Ontario

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Quaternary geologic investigations including mapping, sedimentologic analysis, drilling, and shallow geophysics provide local insights into the regional geology and hydrostratigraphy of Quaternary sediments from which hypothetical models are constructed. The Oak Ridges Moraine (ORM) NATMAP and hydrogeology projects have assembled a regional digital database to: (i) evaluate the validity of other available data against traditionally developed models; (ii) test and improve our geologic model; and (iii) devise and refine a hydrostratigraphic model.

The ORM database synthesizes relational point data, GIS data layers, and flat files. Originally in a myriad of digital and hardcopy formats, borehole and field data have been transformed into a relational database with a common format and coded using standard rules to facilitate comparison. In total, the relational database contains more than 70,000 records from boreholes and field sites. The validity of the relational database is compared to geological maps and sedimentary exposures.

The regional point database provides a useful subsurface geologic and hydrogeologic mapping and analysis tool. Queries of the database can be used to construct geologic and hydrostratigraphic cross-sections, surfaces and isopachs. In such formats, these data provide an opportunity to refine the regional geologic and hydrostratigraphic architecture. The database may then be investigated for the properties of regional hydrostratigraphic units. From these results, a more realistic representation of the hydrostratigraphic boundaries to hydrogeologic models are attained.

Terrain Sciences Division
Division de la Science des terrains

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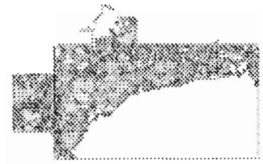

Oak Ridges Moraine NATMAP and Hydrogeology Project

Objectives

- Define the three dimensional geometry of surficial sediments.
- Develop a geological model for the moraine - area.
- Define the elements of the hydrogeological system on a regional scale.

The Oak Ridges Moraine (ORM) Project is an environmental mapping initiative of the Geological Survey of Canada, carried out in collaboration with the Ontario Geological Survey. The study area extends from the Niagara Escarpment to Trenton and from Lake Ontario to Lake Simcoe. The principal goals are: to map the surface and subsurface geology; to identify regional aquifers; and to apply this geological understanding to more detailed hydrogeological investigations on an aquifer or watershed scale.

- NATMAP: Canada's National Geoscience Mapping Program

- Study Area
- Data Releases

- Geology
- Hydrogeology
- GIS Analysis
- Database
- Investigative Techniques
- Groundwater Prospects in the Oak Ridges Moraine (Download PDF files) NEW
- 3-D Images & Animations NEW

- Collaborative Organizations: Government Agencies, Universities, Industry
- Research Team
- Related Sites

For further information, please contact:
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Oak Ridges Moraine Web site Development: Russell, H.A.J. and Lemieux, D.

Hydrogeology

Terrain Sciences
Division Home Page

Oak Ridges Moraine URL:
http://sts.gsc.emr.ca/page1/envir/orm/orm.htm

Desktop GIS in Geological Mapping, Oak Ridges Moraine, Southern Ontario - A National Mapping Program Study

Sharpe, D.R.[1], Russell, H.A.J.[2], Brennand, T.A.[3], Barnett, P.J.[4], Gorrell, G.[5], Kenny, F.M.[6] & Finley, D.[7]

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The Oak Ridges Moraine NATMAP project has updated the surficial geology map coverage of the Greater Toronto Area. This has involved new mapping at 1:20 000 and 1:50 000 scales for eight core map sheets and a digital conversion and reinterpretation of seven existing maps. Combined, these 15 maps are also being released as a regional compilation for the Greater Toronto Area at 1: 200 000 scale. Each of the 15 1:50 000 scale maps consists of three digitally produced map components: regional setting, thematic series, and 1:50 000 scale surficial geology. The digital cartographic assembly has been completed using MapInfo GIS.

The regional setting component of each map consists of a Digital Elevation Model and 1:1 000 000 geology of the Greater Toronto Area. These two maps provide a regional context for the detailed 1:50 000 geology and thematic maps .

The thematic map series consists of five maps at a common scale, field locations with a voronoi polygon sediment attribute map, geology map, DEM , bedrock topography, and sediment thickness map. Field site information is commonly absent on Quaternary maps, yet these sites provide the critical control for the airphoto interpretation process. The voronoi polygons attributed with simple sediment descriptions create a rapid point to polygon map. The DEM provides users with an improved understanding of the principal landscape elements of the 1:50 000 map. To provide an insight into variations of the sediment thickness in the area, bedrock and sediment thickness maps are presented.

The 1:50 000 scale geology maps have been compiled using traditional techniques of airphoto interpretation and field checking. The mapping process has been aided by the availability of the DEM for each map sheet and the development of a relational database which contains point datasets of archival OGS data, hydrogeological investigations, geotechnical studies, and new field data.

Surficial Geology of the Greater Toronto Area: a 1: 200, 000 Scale GIS Synthesis Map

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A regional, 1:200 000 scale, surficial geology map of the Oak Ridges Moraine (ORM) and Greater Toronto Area (GTA) summarizes a new series of 15 digital 1:50, 000 maps for the area. Mapping was initiated in response to a number of earth and environmental management issues identified during resource planning by the Ontario government, particularly the Ministry of Natural Resources. The regional mapping was sponsored by the National Mapping Program (NATMAP) of the Geological Survey of Canada in collaboration with the Ontario Geological Survey (OGS) and a number of other provincial and municipal agencies and local groups. This regional map also incorporates data from a series of 9 new OGS, 1:20,000 geology maps covering the central area of the ORM.

Objective and Content

The objective of the regional map is to synthesize the geology of the ORM-GTA study area as a basis for terrain evaluation, regional planning, resource management and environmental analysis, particularly hydrogeology and water resource assessment. The mapping provides a uniform geological synthesis across the region as required for standardized resource evaluation. The map provides a basis for understanding the surficial geology of the area in three dimensions and for proposing a regional conceptual geologic model. Regional cross-sections show how the map view can be extended to provide a view of the subsurface. Map notes briefly describe the geological context, topography, drift thickness, landforms, sedimentary units and their distribution.

Related maps products

The regional map is georeferenced, at 1:200,000 scale, to a number of other maps that complement this geological synthesis: 1) a hill-shaded digital elevation model (Skinner and Moore, 1997), 2) a chromo-depth digital elevation model (DEM; Kenny, 1997), 3) bedrock topography (Brennand et al., 1997), 4) drift sediment thickness (Russell et al., 1997), and 5) regional map of potential springs (Dyke et al., 1997). Other related map data e.g. LANDSAT, land use, vegetation, etc., will be available to compare with this geological summary (e.g. Kenny 1997). The map is also linked by a sediment coding scheme to ~100,000 coded water well, geotechnical and geologic field records across the area. Digital map files will be released as part of a CD-ROM data release in late 1998.

Surficial Geology of the Oak Ridges Moraine-NATMAP Area, Ontario, Geological Survey of Canada Open file 3456

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A 1: 200,000 map of the surficial geology of the Oak Ridges Moraine accompanies a fieldtrip guide describing eleven sites covering the eastern half of the ORM. The guide was compiled by Sharpe, D.R., and Barnett, P.J. 1977 and is entitled: *Where is the water? Regional geological/hydrological framework, Oak Ridges Moraine area, southern Ontario.* Geological Association of Canada – Mineralogical Association of Canada, Joint Annual Meeting, Ottawa '97, Field Trip A1, Guidebook, 49 p. The map and guide complement an earlier guidebook covering the western portion of the ORM (Sharpe *et al.,* 1994).

The field trip provides an overview of a developing regional geologic and hydrogeologic model for the ORM/GTA area (*e.g.* Sharpe *et al.* 1996) and a regional context for hydrogeologic modeling (*e.g.* Gerber *et al.* 1996). At Stop 1 a borehole record (~190 m), which goes from the Halton sediments to the deepest and most complete part of the regional Quaternary sedimentary sequence, is presented. Downhole geophysical methods and lithofacies of the youngest sediments, covering or interbedded with the ORM, are emphasized. Stop 2 is located south of the ORM but reveals the platform upon which the ORM is built, an eroded regional till sheet and aquitard complex. The hydrologic function of this aquitard and of lower beds can be observed. Stop 3, located at a groundwater discharge area on the exposed southern margin of the sandy ORM sediments, provides an opportunity to assess the recharge - discharge roles of the ORM. The guide also discusses a reconnaissance regional groundwater chemistry program. Stop 4 provides a scenic view of some of the landform elements and discussion of their controlling factors. Stop 5 illustrates the value of shallow reflection seismic methods to regional geology and hydrogeology by examining buried channels cut into the Newmarket Till. Stop 6 in the Pontypool wedge, one of the four sediment wedges of the ORM, is at one of the largest sand and gravel pits in the Oak Ridges Moraine. The stop illustrates sandy and gravely subaqueous fan complexes that are common elements of the ORM sedimentary architecture. Another scenic lookout, Stop 7, provides an overview of the southern slope of the ORM and an inlier of drumlinized Newmarket Till with local discharge zones. Stop 8 reveals channeled Newmarket upland terrain south of the ORM and the character of partial sediment fills. Stop 9 reveals sedimentary sequences along the Lake Ontario bluffs and it provides an opportunity to examine the geologic and hydrogeologic elements of the regional model in a well exposed area beyond the ORM. Stop 10, at the east end of the ORM, illustrates the moraine composition in the better-exposed eastern wedge. Stop 11, east of the ORM complex, reveals landform-sediment relationships that are linked to ORM sediments.

A Regional Geologic Model for The Oak Ridges Moraine Area, Southern Ontario: Groundwater Prospects

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A geological model is presented for the glacial deposits of the Oak Ridges Moraine area of southern Ontario. The model contains four units as well as incised channels dissecting the strata. Channels eroded through the Newmarket Till, a regional aquitard, provide hydraulic connection between the aquifers of the overlying Oak Ridges Moraine and those of the underlying lower drift. Buried channels filled with silt, sand and gravel, and preferentially oriented NNE-SSW, are indicated by drill core and seismic reflection profiles. The model, with two successful case studies, has significant implications for groundwater resource development in the Greater Toronto Area. Groundwater flow to the lower drift may occur through channels so that groundwater resources in the lower drift may be more productive than previously suggested. Gravel sequences within channels may be targets for high yield wells. Further investigations are required to examine buried channel locations, distribution and sediment fill.

Hill-shade Enhanced Digital Elevation Model of Oak Ridges Moraine

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This Digital Elevation Model (DEM) is the result of collaborative work with the Ontario Ministry of Natural Resources (Information Management Branch). This DEM is a preliminary version of a larger hydrologically sound DEM model presently under development (Kenny et al., 1996, Kenny 1997). The DEM is being used for landform and hydrologic analysis, and as an elevation datum for the ORM subsurface dataset (Russell et al., 1996). The DEM is also serving as a base for a number of image integration studies related to digital geological mapping.

A preliminary DEM was compiled from National Topographic Survey (NTS) digital data (1:50000 scale) for use in regional and geological analysis. Contour and spot elevation data combined with hydrologic features were the primary sources of terrain surface information. Interpolation was performed using a Triangular Irregular Network (TIN) method and then converted to a raster data structure (ESRI, 1987).

The TIN data structure is defined by a set of triangular facets where adjacent input samples are the nodes of each of the triangles. These facets vary is size, shape, slope and aspect to better reflect the actual terrain surface. For this DEM, the vertices from the NTS digital contour vectors along with the NTS digital spot elevations were used as input data for the TIN structure. The hydrologic features, also found in the digital NTS data, carried no elevation component and could not be directly used as surface elevation input. The shoreline vectors of seven large lakes were coded with elevation values read from the paper versions of the NTS maps. These were also used in the surface generation. From these input data, a first version of the elevation model was generated.

The remaining hydrologic features were draped on this initial model. The vertices of this hydrology were given an interpolated surface value. Though not hydro- logically sound, these remaining lakes, rivers and streams were then used as breakline features (linear features which enforce a surface representation) in a second version of the elevation model to better define valleys and lake (flat) surfaces (Bonham-Carter, 1994).

Finally, the TIN data structure was further interpolated into a raster (cell-based) format using a quintic interpolation model (ESRI, 1987). This model assumes a smooth continuous surface and considers adjacent facets when interpolating values within the triangular plane. This model does not alter the values of the original input locations thus resulting in a very good regional representation. The raster format was sampled at a 30m resolution for optimal analysis with other digital layers (e.g. satellite imagery).

While this DEM is a preliminary dataset, it is suitable for regional geomorphic analyses. Though it is difficult to quantify the accuracy of any DEM, the 30m cell resolution used here was chosen more for ease of analysis than for detailed resolution. It was understood that the hydrologically sound DEM in production will provide the necessary accuracy for more detailed analysis.

Ontario Encourages Voluntary Ecosystem-based Watershed Management

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In 1993, the Ontario ministries of Environment and Energy (MOEE) and Natural Resources (MNR) released three guidance documents to provide advice on how to voluntarily carry out watershed management studies and how the results could be implemented by municipalities through the planning process. The three documents: *Water Management on a Watershed Basis: Implementing an Ecosystem Approach*; *Subwatershed Planning*; and, *Integrating Water Management Objectives into Municipal Planning Documents* provide a basis for ensuring both the sustainability of water and related resources and the long-term economic and social health of the urban and rural communities they serve.

The release of the documents signaled the commencement of the Watershed Management Initiative evaluation carried out by the Province, key stakeholders, Conservation Ontario (formerly the Association of Conservation Authorities of Ontario), the Association of Municipalities of Ontario and provincial ministries. The evaluation was completed with the release of a final report in February 1997 entitled *An Evaluation of Watershed Management in Ontario.*

The Province supports and encourages locally initiated, community driven ecosystem-based watershed management by providing advice and policy, legislative, scientific and technical information on watershed management. A joint Watershed Management Coordinating Committee has been established with representatives from MMAH, MNR and MOEE to develop a Watershed Management "How to Kit' which will include: a layperson's guide to watershed management, community outreach documents (newsletters, factsheets), technical documents, including Internet access to information.

A fundamental component of the Kit is a *Watershed Action Guide* which is in the final stages of completion and is expected to be available by early 1998. The purpose of this guide is to provide practical information for building partnerships, projects, and processes for a sustainable watershed. The guide will assist individuals or groups which initiate, lead and participate in ecosystem-based watershed management across the Province.

A recently released joint MOEE and MNR report entitled *Inventory of Watershed Management Projects in Ontario, 1990-1995* provides details on the 87 watershed management projects initiated in Ontario between 1990 and 1995. This report can be used to help groups to: become more aware of the number and location of watershed management activities in Ontario; acquire information on lead agency contacts; become more aware of local land and resource use issues; and, obtain important scientific data.

Products of the GSC Oak Ridges Moraine hydrogeology and NATMAP projects

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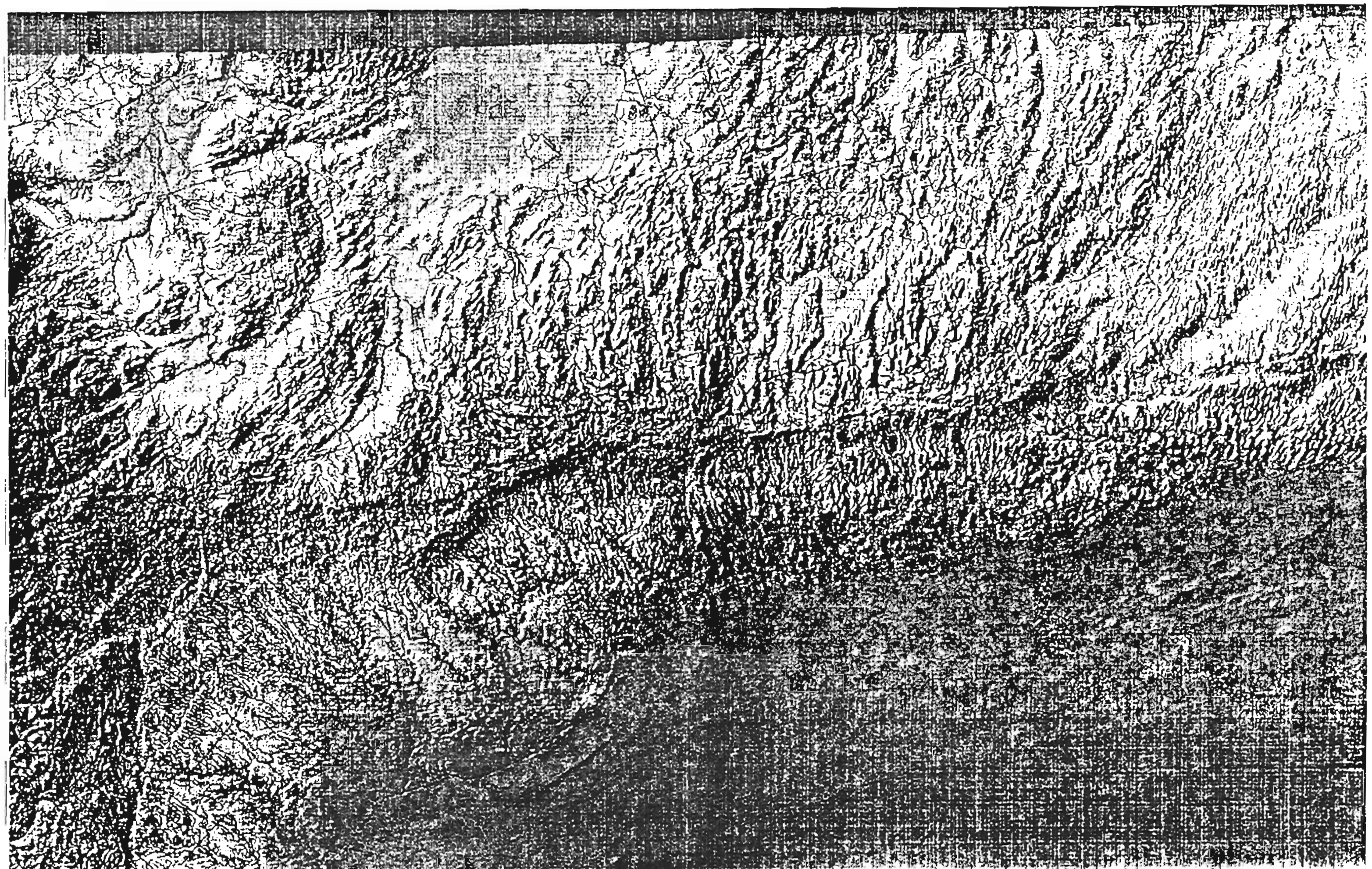
Oak Ridges Moraine NATMAP Project: a Digital Elevation Model of the Oak Ridges Moraine, southern Ontario



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Oak Ridges Moraine NATMAP Regional Surficial Geology Map

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SURFICIAL GEOLOGY OF THE GREATER TORONTO / NATMAP AREA

QUATERNARY PERIOD (~last 2 million years)

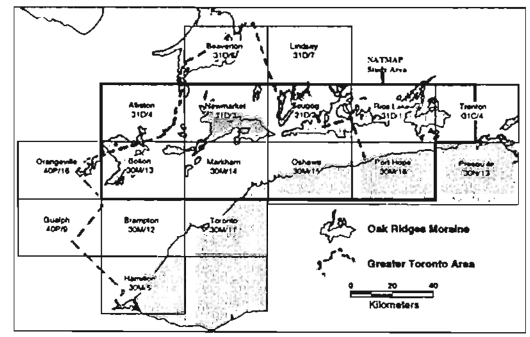
11	Recent Deposits:	sand, gravel and diamicton:
10	River Deposits:	sand and gravel
9	Organic Deposits:	peat, muck and marl,
8	Glacial Lake Deposits:	sand and gravel
7	Glacial Lake Deposits:	silt and clay,
6	Glacial River Deposits:	sand and gravel
5	Moraine Deposits:	fine sand to gravel
4	Glacial Deposits (till):	clayey silt to silt,
3	Glacial Deposits (till):	sandy silt to sand,
2	Lower (drift) Deposits	till, sand, silt and clay

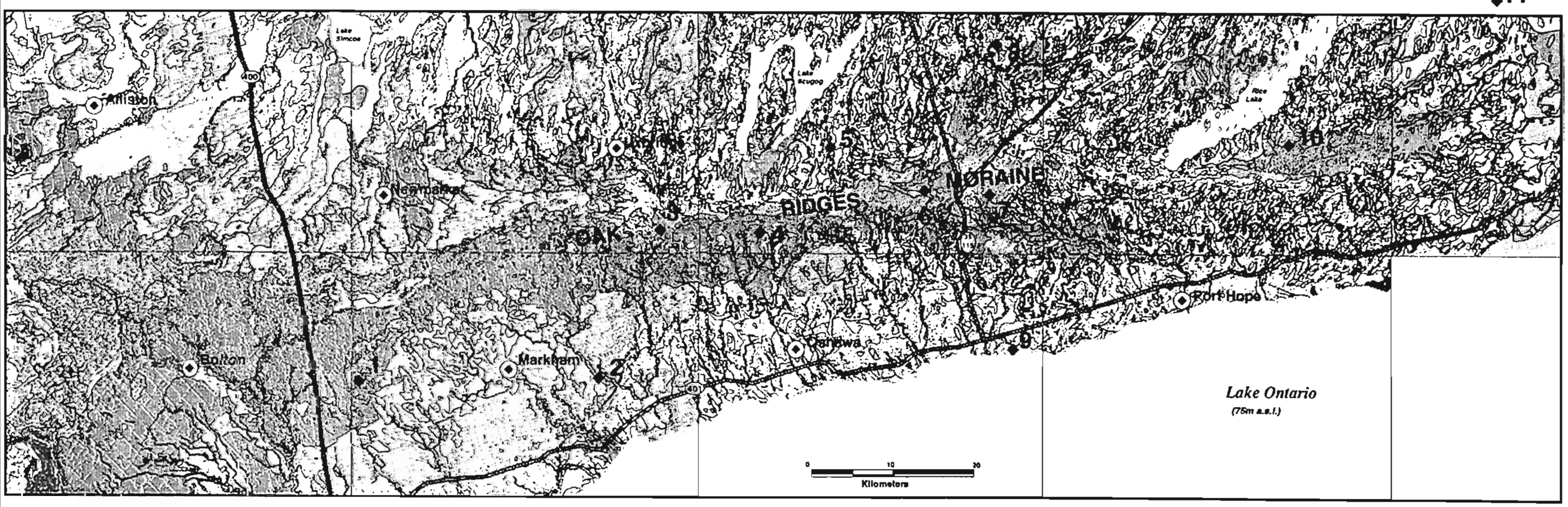
Unconformity ______________ (interval with no deposits and/or major erosion)

PALEOZOIC

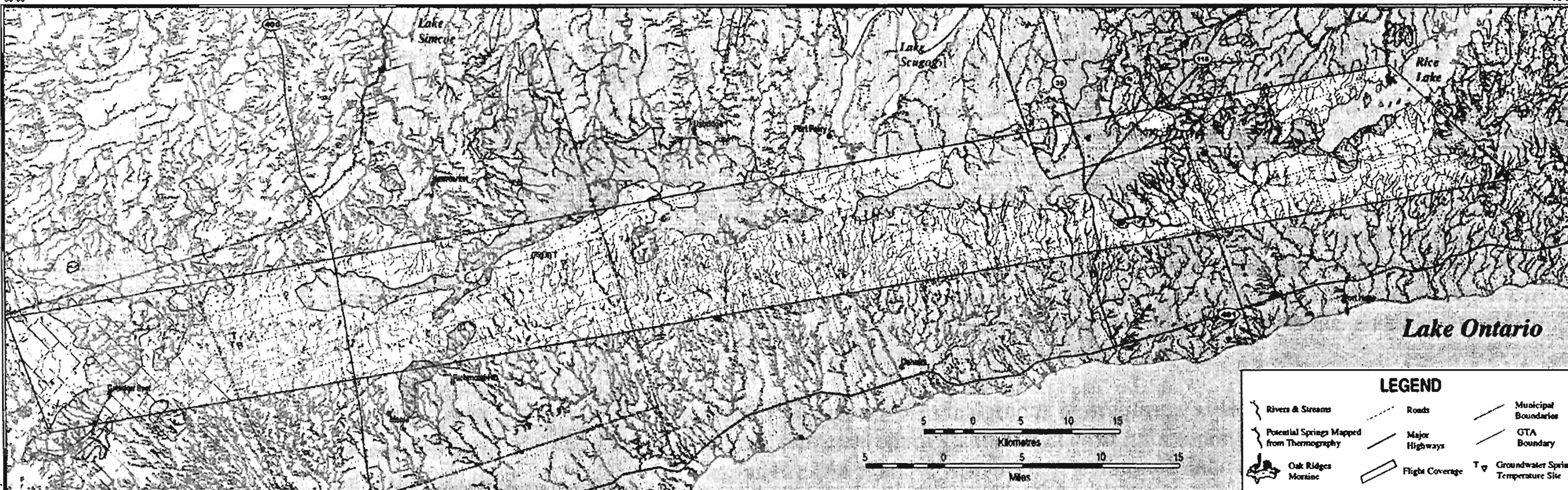
1	Bedrock: limy mudrock and clastic sedimentary rock	

A 1:200,000 scale compilation of nine 1:50,000 scale surficial geology maps for the Oak Ridges Moraine study area has been completed by the Geological Survey of Canada (GSC) in collaboration with the Ontario Geological Survey. This modified version of GSC Open File 3456 shows the eleven field trip stops (numbered below) for field trip A1, Geological Association of Canada, meeting Ottawa, Ontario, May 1997.





Potential Springs in the Oak Ridges Moraine, Southern Ontario: Mapping from Aerial Thermography



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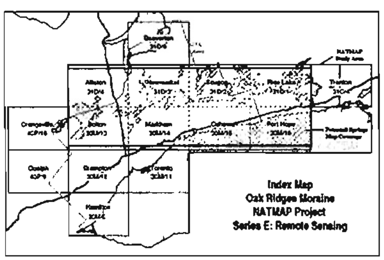
Scale 1:200 000



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Introduction

Groundwater discharge into streams is an important component of the water cycle. Discharge may be concentrated in small areas (springs or seeps) or may be spread out over longer reaches of streams. In the Oak Ridges Moraine Area, groundwater discharge accounts for most of the flow in streams. In areas without groundwater discharge, streams can dry up between rainstorms or during cold periods of snow accumulation.

Groundwater discharge also plays an important ecological role for aquatic habitats of these streams. In addition to maintaining flow in streams, groundwater discharge regulates stream temperatures near groundwater springs or seepage areas. The temperature of groundwater springs in this area remains nearly constant around 4 to 9°C throughout the year. Therefore, groundwater springs prevent streams from freezing in the winter and keep streams relatively cool in the summer. This constancy in temperature is essential for the habitat requirements of many aquatic species (e.g. trout).

This map demonstrates the use of thermal imagery collected from an aircraft for identifying potential areas of groundwater discharge to streams. This map presents data extracted from thermal infrared images that show contrasts in surface temperatures on a cold winter night. Warm areas on the thermal images coincide with portions of streams and may indicate areas where significant groundwater discharge occurs.

Methodology

The survey was flown between midnight and 3am on the morning of March 1st 1994. The flight path was from west to east, at an airspeed of 200 km/hr and an elevation of 1520m above ground level. The data were collected by the Ministry of Natural Resources, Ontario using a Daedalus DS-1230 Infrared Linescanner having a spectral range of 8.5-14 μm, an instantaneous field of view of 1.7 mill radians, at 80 scans per second. The effective ground resolution at survey airspeed was 1.7 m.

The images were printed on photographic paper to permit analysis. Analysis was completed manually by transcribing thermal 'hotspots' to 1:50 000 NTS mapsheets. This also provided a first level of data verification, permitting identification of major heat sources registered in the data. The data were digitized from the 1:50 000 NTS sheets and transferred to a vector GIS system (MapInfo). No systematic ground verification of the data has been completed. Stream baseflow gauging conducted as part of the Geological Survey of Canada Oak Ridges Moraine Hydrogeology Project provides an initial verification of the thermal imagery results. Temperature loggers provided continuous records of water temperature in selected groundwater springs.

Discussion

The thermal imagery provides a qualitative measure of ground surface temperatures that depend on the prevailing weather conditions during the flight (Figures 1-3). Air temperatures were cold for the three days prior to the flight (mean daily temperature <-10°C, Figure 1) with air temperatures below -6°C to -15°C during the flight (Figure 2). In contrast, groundwater discharge at springs in the headwater reaches of several streams is warmer (4 to 9°C; Figure 4) and is not influenced by the daily air temperature fluctuations (Figure 1). At the time of the imagery, fresh snow covered the area (Figure 3) and the warmest natural surface was open water. Portions of the stream that appeared cold on the imagery were probably frozen at the surface or obscured from the sensor. The large thermal contrast between the open and frozen portions of the streams is the essential value of the imagery. It is inferred that areas of open water did not freeze because of their proximity to areas of groundwater discharge.

The comparison of these results with measurements of summer baseflow in several watersheds suggests that the warm winter temperatures correspond with areas of high groundwater discharge. However, many segments of small streams in groundwater discharge zones appear cold on the imagery. It is possible that these streams may have had too little discharge to prevent the water surface from freezing or other factors such as obscuring vegetation could have affected the imagery. Although several ponds appear as warm winter surfaces on the imagery, this does not necessarily imply that these are areas of groundwater discharge. Open water in ponds could result from heat storage within the ponds. Similarly, other factors such as water depth, turbulence and flow rate could also influence the formation of surface ice in streams.

Implications

Under appropriate weather conditions, thermal imagery can be a useful tool for the preliminary assessment of groundwater discharge at a regional scale. Field verification of water temperatures and distribution of groundwater discharge and stream ice during cold temperatures in conjunction with thermal imagery are needed to validate this method. The identification of significant discharge zones at a regional scale could help in the delineation of the discharge boundaries of prominent aquifers in the Oak Ridges Moraine. Although data are collected in the winter, these results may be useful year round since groundwater discharge occurs throughout the year and can be important for maintaining summer baseflow and providing summer habitat for some aquatic species.

Acknowledgements

This collaborative effort between the Geological Survey of Canada and the Ontario Ministry of Natural Resources would not have been possible without the efforts of Fred Johnson. The digital files of the field data were produced by Wendy Lewis and data handling managed by Charles Logan. Hazen Russell assisted with the map production and layout.

Climatic Conditions Relevant to Thermography

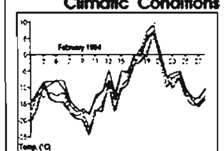

Figure 1: Daily mean temperatures

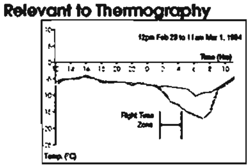

Figure 2: Hourly temperature record

Meteorological Stations

- Richmond Hill
- Peterborough
- Orangeville
- Pearson Airport, Toronto

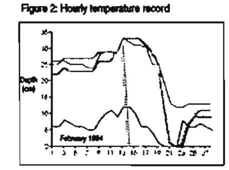

Figure 3: Daily snow depths

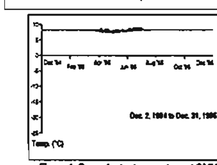

Figure 4: Groundwater temperature at OMNR Ringwood Fish Hatchery

Index Map

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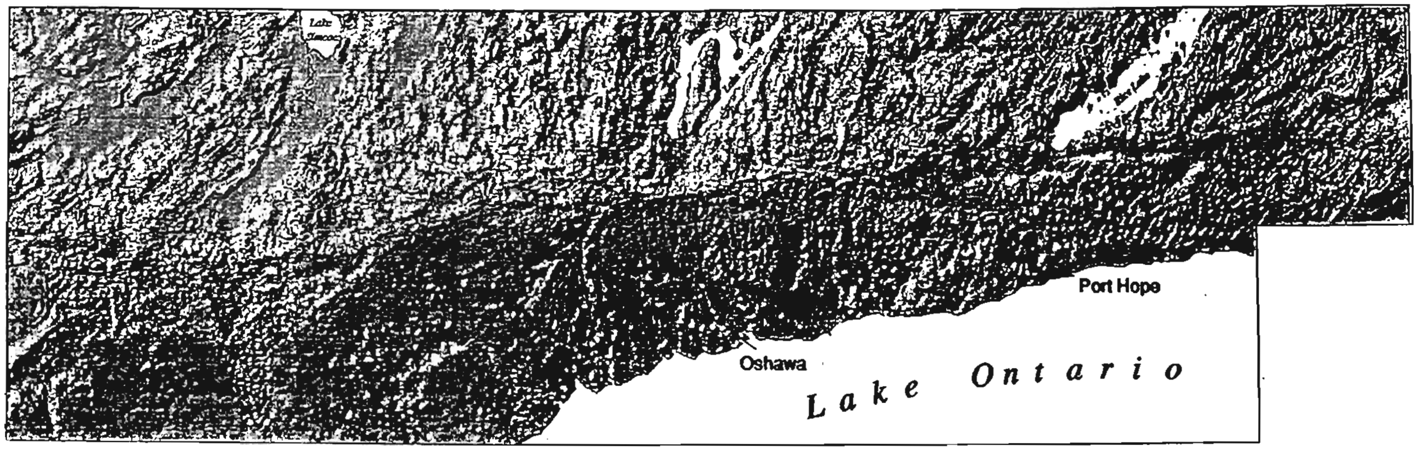
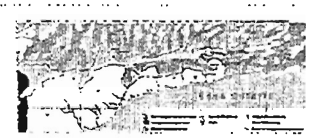
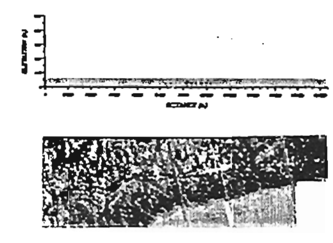
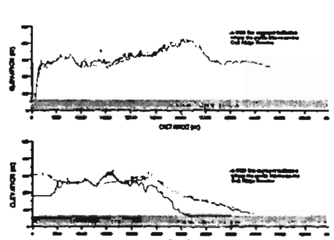
Oak Ridges Moraine NATMAP Project: a Digital Elevation Model of the Oak Ridges Moraine, southern Ontario









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Oak Ridges Moraine NATMAP Project: a Digital Elevation Model of the Oak Ridges Moraine, southern Ontario

Abstract:

A Digital Elevation Model is presented for the Oak Ridges Moraine area, southern Ontario. Three enhanced images are presented: hillshaded, perspective shaded-relief, and hillshaded chrono-depth. Using surface roughness, linearity, elevation, and spatial context, seven regional terrain elements can be identified.

Surficial mapping has traditionally relied on 1:50 000 scale airphoto interpretation. Digital Elevation Models, derived from 1:50 000 structured digital files, with 25 to 50 m grid resolution, are equally well suited for this purpose. While lacking the resolution and surface tonal contrasts of airphotos, distinct advantages are provided by the ability to integrate or overlay other data sets, and by the ease of analysis in Geographic Information Systems. Digital Elevation Models provide flexibility for geomorphic analysis whether completed in a digital or visual manner.

Introduction

The Oak Ridges Moraine (ORM) NATMAP Project was initiated in the spring of 1993 as a collaborative multiagency environmental mapping project with the Ontario Geological Survey (OGS). This program is part of the GSC National Mapping Program (NATMAP), a digitallyorientated geoscience program that encourages broad partnerships. This Digital Elevation Model (DEM) is the result of collaborative work with the the Ontario Ministry of Natural Resources Information Management Branch.

The study focuses on the Oak Ridges Moraine, a 150 km long east west tending landform which forms the drainage divide between Lake Ontario and Georgian Bay. The moraine is the most easterly of a number of glaciofluvial glaciolacustrine moraines in southern Ontario (cf. Barnett et al. 1991; Fulton 1995). The study area is predominantly composed of glacial sediments which reach thickness of up to 200 m. The stratigraphy is complex with sediments having been deposited during a succession of glacial events and with major erosional events incising older deposits (Sharpe et al. 1994, 1996). In some areas surface landforms may be controlled or influenced by subsurface features.

This DEM is a preliminary version of a larger hydrologically sound DEM model presently under development (Kenny et al. 1996; Russell et al., 1996). The DEM is being used for landform and hydrologic analysis, and as an elevation datum for the ORM subsurface dataset. The DEM is also serving as a base for a number of image integration studies related to digital geological mapping.

Recommended Citation:

Skinner, H., and Moore, A. 1997: A Hillshaded Enhancement of a Preliminary Digital Elevation Model of the Oak Ridges Moraine, Southern Ontario; Geologicval Survey of Canada and Ontario Ministry of Natural Resources; Geological Survey of Canada, Open File 3297

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