HYDROGEOLOGICAL RESEARCH NEEDS IN ONTARIO

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1) CANADIAN GROUNDWATER RESOURCES - A NEGLECTED RESOURCE

It is estimated that 90% of Canada's fresh water is stored as groundwater - primarily contained in clastic sedimentary rocks, limestones/dolomites (including karst), fractured crystalline rocks of the Canadian Shield, and glacial sediments. This fraction compares with approximately 4% stored in the nation's 100,000 glaciers and about 3 % stored, at any one time, in its numerous rivers and lakes. To help put these figures in perspective, it has been suggested that the lakes and rivers, which cover nearly 8% of the country, contain enough water to flood the entire nation to a depth of 2m (Science Council of Canada, 1988). If groundwater were described to similar effect, the water depth would approach 50m or more.

The most recent figures suggest that groundwater obtained from aquifers provides a domestic supply for between 25 and 30 % of all Canadians. The value varies regionally from 100% in Prince Edward Island to as little as 1% in the Northwest Territories and Nunavut. Almost 70% of those reliant on groundwater are rural users; in fact, over 80% of the rural population depend on groundwater for domestic use. Industrial use of groundwater is about 1% and partly reflects the large volumes of surface water used by thermal plants (electrical power generation).

In general, and as observed by Vonhof (1985), the attention paid by individual Provinces to the protection of groundwater resources is a function of its relevance as a source of potable water and the availability of alternate surface-water resources. Largely, it is the rural communities (including rural towns such as Walkerton) that have greatest dependence on groundwater; yet, in many Provinces with abundant surface water supply, it is precisely these stakeholders that have least influence on the decision-making process. Groundwater continues to be a neglected resource in Canada. Few Provinces maintain adequate groundwater monitoring networks (either for quality or quality); few attempts have been made to document groundwater resources and the extent to which the potability of these resources is being compromised by pollutant sources. Moreover, while some Provinces argue that they "manage" groundwater resources, the truth is that most do little more than issue permits for water taking. It should come as no surprise that groundwater contamination is becoming a serious issue for concern.

2) EXISTING LEGISLATION

Until recently, groundwater resources and the threat of contamination would have barely raised an eyebrow for the vast majority of Canadians. In Toronto, for example, Canada's largest urban region, virtually all drinking water is drawn from Lake Ontario, and the risk of land use change to groundwater resources is regarded by many as of little consequence. In the past eighteen months, this attitude has changed rapidly, first with proposals by land developers to "sprout" housing along tracts of the Oak Ridges Moraine (Howard et al., 1995), and later by the events of Walkerton.

The case of the Oak Ridges Moraine, one of the Province's larger aquifers is a good example. "Concerned citizens", fired by activist groups and supported by the local press, have been waging an intense campaign to "Save the Moraine" from urbanization, an increasingly politically motivated movement that has brought the issue of groundwater protection to the public eye. In many regards, the groundwater science has been lost in the ensuing and highly contentious debate. Few protestors seem to care, for example, that the unusually detailed hydrogeological studies conducted as a prerequisite to development suggest potential problems are readily manageable and that impacts will be negligible. What has been highlighted, however, and brought to centre stage *is the archaic state of existing groundwater legislation for much of the Province.* In fact, somewhat ironically, the Oak Ridges Moraine *is one of very few areas in the Province where existing legislation provides groundwater with a significant degree of protection.*

For the most part, the legislation for groundwater protection in the Province of Ontario is woefully inadequate. Comprising little more than a patchwork of statutes, policies, programs, regulations and guidelines, it clearly lacks the breadth, versatility and conviction to deal with the wide range of potential land-sourced contaminants (Howard, 1997a) and the dynamics of groundwater flow within frequently complex aquifer systems. For example, in the context of land development, prospective developers find they are faced with a maze of legislation at virtually all levels of government (Howard, 1997b) while the outcome is that groundwater receives only piecemeal protection. One key underlying problem is that there is no single body, either at the Provincial or Federal level, which is willing to take jurisdictional responsibility for the management and protection of groundwater resources.

3) ONTARIO'S LEGISLATIVE PROCESS

The urban planning process in Ontario, Canada's most populated Province provides a good illustration of the complex and archaic state of the legislation that is supposed to protect groundwater. The 1995 Ontario Planning Act gives the Ministry of Municipal Affairs (MMA) responsibility for the approval of official plans, official plan amendments (OPAs), subdivisions, consents and zoning order amendments. In practice, approval authority for sub-divisions and, in some cases, OPAs is delegated to regional municipalities at the local level (Counties and Townships). By similar token, the Ontario Water Resources Act, the Environmental Protection Act, and the Environmental Assessment Act, all passed into law by the Provincial government in 1990, vests legislative responsibility for the management and protection of ground and surface water to the Ontario Ministry of Environment (MOE). Increasingly, the Ministry of Environment passes this responsibility on to the regional municipalities, despite the fact that few have either the expertise or the resource base to make informed decisions. Groundwater protection issues become further complicated and sometimes obscured when other agencies enter the picture. Regional municipalities are responsible for providing services such as water, sewage treatment, waste disposal and roads. Conservation Authorities become involved where land development is likely to affect valley lands and flood plains. The Ministry of Natural Resources (MNR) has no direct interest in water resources, but is responsible for protecting, aquatic habitats, and areas designated as environmentally sensitive (ESAs) or determined to be of natural and scientific interest (ANSIs). MNR has also assumed primary responsibility for the protection of "special areas of local or Provincial interest". These areas include large moraine areas and selected watersheds/sub-watersheds, even though such areas receive this designation based largely on water resource issues - issues that should logically fall under the jurisdiction of MOE.

Fortunately, some help is available to the prospective land developer in the guise of an unwieldy document published by the Ontario Ministry of Environment (previously the Ontario Ministry of Environment and Energy) (MOEE, 1995). This document was commissioned by the Office of the Provincial Facilitator of the Ministry of Municipal Affairs, and was prepared by external consultants to guide land development applicants (and likely, no doubt, confused government personnel) through those aspects of the planning process that are relevant to groundwater. While the document is clearly useful for steering prospective developers through a veritable minefield of statutes, policies, programs, regulations and guidelines, it also allows the many shortcomings and inconsistencies of the process to be identified. For example, *groundwater protection is not explicitly recognised in the urban planning process*, and hydrogeological investigations are required only where one or more of the following conditions are met:

> i) Groundwater is required for domestic supply (in which case *the adequacy of the resource and potential interference problems must be examined i.e*. no explicit consideration of water quality issues – wellhead protection etc.);
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> ii) Sewage systems are proposed that require subsurface disposal of waste via leaching beds or surface disposal using spray irrigation (in which case, impacts must fall within Provincial guidelines);
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> iii) Soil and/or ground water at the site is known or suspected to be contaminated; or
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> iv) The site is located on areas that have been designated as hydrogeologically sensitive and therefore of "special" interest to the Province (designation given to the Oak Ridges Moraine)

In effect, for a major urban expansion comprising fully serviced subdivisions, arterial roads and highways, parks, shopping malls and gas stations, groundwater protection becomes a consideration (and often little more than that) only in areas that have been designated as "hydrogeologically sensitive". Equally serious is the fact that the designation "hydrogeologically sensitive" is normally assigned to "recharge areas of major aquifers", in the misguided belief that

a) Recharge to aquifers occurs exclusively in upland areas where aquifer material is exposed i.e. "outcrops" at the surface; and

b) Areas where recharge to underlying aquifers is highest are the most sensitive and thus most in need of groundwater protection.

Quite to the contrary, many studies including Gerber and Howard (1996,1997) and Howard and Gerber (1997) have shown that with respect to a), significant quantities of recharge can occur through finer-grained aquitard material in lowlands, including dense till deposits once regarded as "impervious" to water. Furthermore, while it may be appropriate to protect high recharge areas in some circumstances, there can be many situations where poorly recharged areas deserve greatest protection. For example, high rates of infiltration and/or high aquifer storage volumes provide for greater attenuation of contaminants, and thus result in less serious impacts on water quality. In effect, *it is the weaker aquifer with low recharge and low groundwater storage that is likely to be the most seriously affected* (i.e. is most "sensitive") *to any sort of land use change.* This runs contrary to popular perception.

3) TOWARDS A SOLUTION

There is now no questionthat Ontario, in fact, Canada as a whole, is in serious need of a broad, and scientifically based legislation that will provide for the protection and management of all ground and surface water. Key questions to be asked include:

"What type of legislative policy is appropriate?"

"What level of government should enact the legislation?"

"Is there anything to be learnt and possibly salvaged from the piecemeal legislation presently in place?"

An important starting point is to understand what "groundwater protection" really means and what needs to be achieved. For some, protection means maintaining the long-term viability of the groundwater resource from both quality and quantity perspectives i.e. it includes a "management" component. For others, particularly those using popular groundwater protection practices such as wellhead protection (USEPA, 1987, 1993), and vulnerability mapping (methods that consider <u>only</u> water quality), aquifer management is seen as a separate, albeit very important, issue. Experience suggests that the best compromise is to *define aquifer protection purely in terms of maintaining groundwater quality, but recognise that this protection <u>must</u> be carried out as an <u>integral part of an</u>*

overall resource management plan (i.e. a plan that includes both quality and quantity issues).

In terms of approach, there are two basic types of methodology: application of “standards of practice” and application of “standards of performance”. The standards of practice approach requires that the land above an aquifer be zoned and classified in such a way that strict controls can be imposed on land use practices of concern. Examples include the commonly used wellhead protection and aquifer vulnerability mapping techniques. These methods have become popular primarily because they are easily applied e.g. well head protection zones are readily generated by even the simplest of groundwater models; vulnerability maps are conveniently prepared using routine GIS techniques (Geographical Information Systems). These methods are not the panacea that some have come to believe. A survey of such methods will show that the classification schemes invoked are many and varied and that choice of land use control is often arbitrary. Sometimes the classification is based on estimated travel time of contaminants to the aquifer or well, an approach that has some virtue for contaminants such as bacteria where time of travel is more critical than actual concentrations. In other cases, the classification uses an “index” which is usually derived by combining a large range of geological, hydrological and hydrogeological factors. The index provides a relative indication of contamination potential but is not a measurable property. None of the methods involving “standards of practice” provide a measure of the potential impact in terms of the actual water quality degradation (i.e. the concentration of a particular contaminant). This is a major criticism of the approach. Clearly, choice of the appropriate methodology is critical. It must also be recognized that the ultimate reliability and effectiveness of any selected approach will depend heavily on good quality subsurface data. Choice of methodology aside, these essential input data are seriously lacking for much of Ontario.

An alternative or supplementary approach to groundwater protection uses quantitative “standards of performance“. Enforced at the Provincial level of government, performance standards could provide protection for both quality and quantity by designating limits to which land use practice is allowed to impact an aquifer. The onus would be put on the proponent of the land use change (e.g. sub-division, golf course, highway, intensive farming operation) to perform the necessary sub-surface investigations and provide designs, monitoring programs and contingency plans that would ensure that the designated standards are met for all time. In the case of water quality, the method is especially appropriate for contaminants derived from common distributed pollutant sources such as road salts and fertilizers – contaminants that can frequently be diluted to safe levels under appropriate aquifer conditions. The “standards of performance“ approach is not on common use but it clearly has a number of significant advantages over more routine “standards of practice” methods. In Ontario, the approach could be introduced quite readily through modifications to the existing “Reasonable Use Guidelines” (MOE, 1994), presently used by the Province to regulate the design of domestic landfills and communal septic systems.

4) RESEARCH NEEDS

The Province sorely needs a broad-based policy to protect and manage all of its groundwater (e.g. including Walkerton's), not just the groundwater it perceives to be sensitive (notably, the Oak Ridges Moraine). The policy must be developed on sound scientific basis and founded on solid hydrogeological principles and good data; it needs to recognize that significant recharge can take place via tills (e.g. at Walkerton) and that aquifers which are the most vulnerable to impact are not necessarily the most sensitive to those impacts. Prior to the 1990s, the Province was highly proactive in its attitude to groundwater. It maintained a readily accessible water well database, published regular water resources reports and aquifer maps, and monitored a network of purpose-drilled observation wells. It also funded external research, notably in Universities, and hosted an annual technology transfer conference. In less than ten years, the scene has changed dramatically. Funding for research has dried up, mapping and resource assessment programs have been wound down and monitoring programs have virtually ceased. The Province which was once acclaimed for its progressive approach to landfill design and its forward looking Reasonable Use guidelines for point source groundwater protection, today lacks any real quantitative understanding of its groundwater resources, has no resource management strategy and no viable methodology in place for groundwater protection. While the rest of the world moved on, Ontario largely ignored its most critical resource and fell seriously behind in its responsibilities.

If there is anything positive to come out of the "decade of demise", it is that the Province is at least in a position to learn from the considerable amount of groundwater protection research undertaken by others. This work has shown or confirmed that

- Groundwater is a major component of any hydrologic system and under natural conditions eventually discharges to surface water bodies such as springs, rivers and lakes. Consequently, groundwater <u>must</u> be adequately managed and protected *even where it is not used as a resource*.

- Groundwater protection is a complex task. Many approaches are available but none is ideal and many have questionable merit. In all cases, the effectiveness and reliability of the method is highly dependent on the quality of the subsurface data. Even methods based on sophisticated computer model codes have little practical value if the geological and hydrogeological database is lacking.

- The protection of groundwater quality is an impossible task if the behaviour of the aquifer system is not understood. Groundwater protection strategies are best developed as an integral part of a management program that addresses both quality and quantity issues. In Europe, groundwater protection is founded on a good knowledge of groundwater flow system behaviour including extensive monitoring networks for water level and water quality.

With these considerations in mind, future research needs are itemized below. Much of this research could be conducted efficiently and cost effectively by resurrecting the

Province's external research grant program directing funds into the Province's Universities.

- *Aquifer mapping.* With a few rare exceptions, the distribution, thickness and resource potential of the Province's aquifers is not well known. Analysis of the province's immense water well database (hundreds of thousands of records) can provide a starting point for this exercise. However, borehole and surface geophysics, drilling, monitoring and test pumping are required if the resource is to be adequately quantified and groundwater flow directions are to be determined. The objective should be a complete system of aquifer maps for the Province.

- *Aquifer water balances.* At present, the Province issues "permits to take water" with scant understanding of the extent to which aquifers are being naturally replenished or are discharging to surface water bodies. Knowledge of aquifer water balances (distribution and quantities of aquifer recharge and discharge) are essential pre-requisites to any management program that purports to protect the quality and quantity of the resource. Given the nature of Ontario's climate and the fact that fine grained till sediments drape much of the land surface, it is particularly important that the research extends to mechanisms of aquifer recharge e.g. recharge through till fractures, indirect recharge due of surface water runoff, and recharge resulting from snow melt events.

- *Aquifer behaviour.* Effective resource management and protection also requires that aquifer behaviour be fully understood, both naturally and in response to pumping. Key information here would include aquifer flow rates (fluxes and velocities), hydraulic interactions with neighbouring aquifers and anticipated water level responses to well field production, droughts and other external influences. Knowledge of aquifer parameters (permeability and storage) is also important here, but a full appreciation of aquifer behaviour can only be achieved with well-calibrated groundwater flow models. In turn, calibration demands reliable water balance estimates and long-term data on groundwater levels. Advanced modelling technology is available, much of it developed by the University of Waterloo. Ironically, while this technology is in use all over the world, its application to aquifer management and protection in the Province of Ontario is minimal.

- *Groundwater quality information.* Compared to water quality data for <u>surface water</u>, water quality data for <u>groundwater</u> is virtually non-existent. Some data exist for major pumping wells, notably municipal wells, but these data do not give a reliable indication of general groundwater quality trends. Salted highways, farms and golf courses are often criticized for introducing contaminants to Ontario aquifers, but the reality is that there is very hard, reliable data to demonstrate whether or not these potential contaminant sources represent a significant long-term threat to groundwater quality or not.

There is an essential need for groundwater quality to be collected on a broad basis, at regular intervals, and in a structured organized fashion. The information needs to be organized in a provincial data bank and used as a basis for developing groundwater quality management objectives and designating limits to which land use practice is allowed to impact an aquifer.

- *Fracture and fissure flow.* Throughout much of Ontario, subsurface flow takes place preferentially through fractures and fissures. Examples include fracture flow in glacial tills and Canadian Shield rocks and "karst" fissure flow in carbonate rocks such as limestones and dolomites (as exemplified at Walkerton). Typically, these aquifers are strongly heterogeneous and anisotropic and make the task of aquifer management and protection considerably more difficult. In many countries, research into the origin distribution, frequency, aperture, orientation and hydrogeologic role of fractures and fissures has been a high priority. Thus, the behaviour of the aquifers is well known. In Ontario, very little comparable work has been conducted and the systems are consequently poorly understood. A comprehensive program of research is required for such systems. This work would involve drilling, borehole logging, packer testing, tracer experiments, and hydrochemistry including isotopes.

- *Loading and impact of non-point source contaminants.* A frequent problem with groundwater quality monitoring is that by the time contamination is detected, water quality deterioration is so pervasive that expensive remediation is the only possible solution. Long-term impacts on groundwater quality can be predicted provided aquifer recharge rates are well known, contaminant releases (e.g. road salt loadings, fertilizer leaching rates and storage tank leakages) can be estimated and chemical fate processes (e.g. biodegradation) is well known. This important area of research was initiated with MOE funding to the University of Toronto in the early 1990s (Howard *et al.*, 1996; Howard and Livingstone, 1997), but funding sources dried up before the methodology could be fully developed. Essential further research would involve chemical audits, field experimentation, and shallow unsaturated zone modelling.

- *Transport and fate of bacteria and viruses.* Remarkably little is known about the transport and fate of bacteria and viruses in groundwater. Research in UK and Australia has suggested that microorganisms can be more mobile and persistent than previously believed and considerably more research is warranted. Field and laboratory experimentation is required supported by tracer tests and DNA amplification technology.

- *Conjunctive use of ground and surface water.* Most developed countries draw maximum benefit from their available fresh water by integrating ground and surface water resources into a single management plan. This can only be achieved with prior knowledge of ground and surface water interactions both naturally and under pumping stress. Much research needs to be carried out on the hydraulic relationship between ground and surface water in Ontario, notably on the hydrogeologic function of kettle lakes, baseflow contributions to streams, and groundwater – lake water exchange.

- *Methodologies for Aquifer Protection.* The development and implementation of appropriate resource protection technologies is clearly a high priority in the Province, but has been deliberately inserted towards the bottom of the list to underline its strong dependency on basic hydrogeological research needs listed above. A wide range of methodologies is available and suitable techniques need to be carefully selected and appropriately refined. However, ultimately, it must be recognised, that aquifer protection cannot be effectively implemented without serious attention to significant data gaps and fundamental research needs.

  Wellhead protection methodologies provide a viable approach for protection Ontario's major municipal wells. However, wellhead protection requires the development of well-calibrated three-dimensional models and this in turn demands an extensive and reliable hydrogeological database. Considerable work is also required to develop appropriate and realistic land use controls for the protected areas. Ideally the wellhead protection methodology should be developed further to consider water quality impacts (i.e. contaminant concentrations) and not simply travel times to the well. Developed in this way the methodology could be integrated with "standards of performance" techniques to provide reliable protection against non-point source contaminants such as road salt and fertilizers.

  A serious limitation of the wellhead protection zone approach is that it will not protect groundwater in the aquifer beyond the well's zone of contribution. In this regard, aquifer vulnerability / sensitivity / susceptibility mapping can provide a useful supplementary approach, but the definitions of these terms needs careful re-examination in the light of the Province's needs, and the general approach needs to made more quantitative through incorporation of anticipated contaminant loadings and attenuating processes such as dilution and degradation, in addition to advective transport.

In conclusion, Ontario is in urgent need of effective and reliable strategies for the protection and management of its ground and surface water resources. The task is considerable but the goal is achievable. There are no easy solutions and no short cuts. Methodologies are available but their success implementation will ultimately demand a serious commitment of funds and resources to significantly advance our basic understanding of the Province's groundwater resources and provide key input data.

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