REPORT

The Case for Groundwater Protection in Ontario:

Results of the Workshop held at the University of Waterloo, May 1, 2001

A Contribution to the Walkerton Inquiry, Phase II

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Executive Summary

A Workshop authorized by the Walkerton Inquiry was held at the University of Waterloo on May 1, 2001, to address the issue of groundwater protection in Ontario. The Workshop attendees included renowned experts from groundwater science, agriculture, municipal water management and planning, watershed management, the legal profession, and the environmental movement.

The primary objective of the Workshop was to consider the case for standards and policy for groundwater protection in Ontario by examining the state of technical knowledge and information that is needed as a basis for a legislative initiative: *Do we have enough knowledge and information to give our groundwater resource an effective legal protection?* This focal question was recast into a number of key questions that were addressed and answered. The Workshop did not consider the exact form of the legislation that would be needed for effective groundwater protection, that aspect being beyond the scope of the Workshop. A secondary objective was to develop a Draft Table of Contents for a document on Standards and Policy for Groundwater Protection in the Province of Ontario.

Several invited experts gave presentations on the significance of groundwater protection, the state of groundwater protection in other countries, the groundwater protection and management program of Waterloo Region, the mapping of regional groundwater resources in the Grand River watershed, the Elmira case, groundwater protection in agriculture, integrated ecosystem and watershed management in British Columbia, and legal issues in groundwater protection.
With this background information, the Workshop considered and answered the following key questions:

Question 1: ***Is the groundwater resource in Ontario understood well enough to support groundwater protection?*** It is well known what types of data are required. These data are generally adequate for areas that have traditionally relied on groundwater. Numerous research initiatives to characterize and map groundwater resources throughout the Province have been completed recently or are underway. To encourage the filling of the remaining data gaps, the proposed Provincial groundwater protection

program should include incentives for data acquisition and the mapping of aquifers and aquitards. There is a need for Province-wide technical standards for hydrogeologic data acquisition and management. The databases developed by the Province or other public bodies should be publicly available without fee.

Question 2: ***Are the processes and theories that are relevant to groundwater protection understood well enough?*** The key processes and theories required for effective groundwater protection and for the formulation of suitable policies are adequately understood and documented. The fundamental physical processes include groundwater flow, transport by advection and dispersion, and sorption. Aquifer recharge mechanisms are well understood, and theories linking surface and subsurface flow are now available. The fundamental chemical and biochemical processes that can be important as natural attenuation mechanisms have also been well documented. Likewise, the processes that control the migration and dissolution of non-aqueous liquids have been thoroughly studied. Flow and transport in fractured and karstic systems is more complex, but advances have been and are being made. The fundamental processes of flow and transport across aquitards are well understood, with key elements being the understanding of windows, manmade openings such as abandoned boreholes, and fractures. Matrix diffusion in aquitards is an important protective mechanism for underlying aquifers. More advanced theories for complex situations continue to evolve, and future standards and policies should be flexible to accommodate such advances.

Question 3: ***Are appropriate technical tools and expertise for the implementation of effective and efficient groundwater protection available?*** Technical tools include hydrogeological, geophysical, and geochemical field methods, mathematical simulation methods, and visualization tools. Appropriate and proven tools of this type are available, and more advances in methodologies for complex situations are being made. Hydrogeologists and engineers trained in the use of these tools are available in Ontario and throughout Canada. Professionals working in the implementation of groundwater protection programs will increasingly require experience in watershed-scale and regional-scale flow processes. Universities and colleges should recognize this need in designing their hydrogeology curricula.

Question 4: ***What geographic scale is appropriate for groundwater protection?*** Groundwater protection should be considered as an integral part of groundwater management, including both quantity and quality aspects. The appropriate geographic scale for groundwater management is the major watershed. Within a major watershed, different approaches may be needed for municipal and rural groundwater protection, but the standards and guidelines for municipal and rural groundwater protection should be compatible. They should also recognize the overall objective of groundwater protection in maintaining the water cycle, providing the baseflow needed for streams and other aquatic habitats, and in promoting a healthy ecosystem, in addition to providing safe drinking water.

Question 5: What groundwater protection standards exist for municipal supplies, and what are needed? Ontario has diverse policies and objectives on water quality, but no standards for protecting water sources such that these quality objectives can be achieved. This lack of standards was one of the contributing factors of the Walkerton tragedy. Existing groundwater protection standards in other jurisdictions (e.g. the United States, European countries, New Brunswick) are generally based on the designation of wellhead protection zones based on aquifer vulnerability. These zones are usually defined to correspond to travel times for different types of contaminants according to their persistence in the groundwater. Substances as well as activities that could pose a risk are listed and land-use restrictions are applied accordingly. Various Ontario municipalities have taken steps toward defining their own standards. With increasing demands on the water supply, Provincial standards for groundwater protection are urgently needed in order to effectively protect our municipal groundwater supplies and to guarantee safe drinking water for Ontario's residents. These standards should be workable, practical, proven, and enforceable, and they could be modelled on the existing standards of other jurisdictions. There must be standards for the delineation of wellhead protection zones, standards for the definition of aquifer vulnerability, and standards for the use of potentially hazardous materials and products within the wellhead protection areas, as well as appropriate and enforceable guidelines for land use within groundwater protection zones. Appropriate land-use guidelines for the land contained within a wellhead protection zone should be developed with the objective of preventing any harmful substances from reaching a well at unacceptable concentrations. These standards and guidelines should be carefully designed such that established drinking water directives are met. They should also be flexible so that new approaches can be incorporated.

Question 6: What groundwater protection standards exist for rural supplies, and what are needed? At present, rural groundwater protection is approached mainly through application of Best Management Practices (BMPs) designed to minimize the environmental impact of farming operations. Nutrient management procedures have been established, and steps toward groundwater protection for rural areas are being implemented through programs under the Environmental Farm Plan established by the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA). These programs provide incentives, education, and advice to farmers to encourage the use of Best Management Practices. A model agricultural operations bylaw for use by rural jurisdictions is being developed. A regulation controlling farm wells already exists. However, there is little monitoring of the real impact of BMPs, and their benefits with respect to groundwater protection are difficult to quantify. There are gaps also in the nutrient management procedure. A cause for concern is the tendency toward intensive farming in Ontario, which is expected to lead to increased pressure on groundwater resources. Particularly troubling is the removal by OMAFRA of some environmental commitments from its Statement of Environmental Values (SEV) in 1998, as well as recent changes to the Farming and Food Production Act. Non-agricultural activities such as large water takings must also be considered in the context of rural groundwater protection. The relevant procedures should be reviewed with respect to their impact on groundwater quality, taking into account recent scientific advances. The review should include BMPs, farm wells, large water takings, and other activities that potentially impact the groundwater resource. Existing programs should be made compatible with future municipal groundwater protection standards and integrated into an overall Provincial framework for groundwater protection. Watershed-scale mapping of groundwater resources and aquifer vulnerability is needed as a basis for effective protection. Public education is important.

Question 7: ***What is the present state of the groundwater resources we wish to protect, and what existing or potential problems can be identified?*** The state of our groundwater resources varies throughout the Province. Deeper aquifers generally carry water of high quality, while some shallower aquifers tend to be affected by human activities. Legacy sources of contamination, such as old waste disposal or sanitary landfill sites, coal tar deposits, and chemical industry byproducts, are of concern. These sources of contamination should be identified, characterized, and their contamination potential with respect to water resources should be assessed. The impact of road salting on groundwater is a serious concern, as is the contamination of shallow aquifers in rural areas by nitrates and bacteria. Increasing urbanization is also becoming a threat to our groundwater resources, and the establishment of land-use standards for areas that are potential water sources should be a matter of high priority.

Question 8: ***What specific legal powers would be necessary to restrict or control the discharge of potentially harmful substances into the ground within a groundwater protection zone?*** The Canadian Environmental Law Association (CELA) is presently preparing a comprehensive document to that effect for submission to the Walkerton Inquiry. The establishment of policies within a legal framework is necessary for groundwater protection to be effective.

Question 9: ***Which jurisdiction(s) should be responsible for groundwater protection in Ontario?*** The Province of Ontario should be responsible and accountable for groundwater protection in Ontario. Within the Government, the ministries that already have certain jurisdictions over water resources issues, including Environment (MOE), Agriculture (OMAFRA), Natural Resources (NMR), and Northern Development and Mines (MNDM) could form a cluster, probably under the leadership of MOE, to take responsibility for the overall program of groundwater protection, for setting standards, policies and regulations, for developing protocol for implementation, for establishing rules for compliance, and for ensuring the compatibility of municipal and rural groundwater protection programs. At the local level, water providers such as municipalities, conservation authorities, and First Nations should be responsible for implementation, administration, compliance monitoring and enforcement of the standards, wherever possible. Training and funding to bring staff up to the required standards of competence should be provided through the groundwater protection program. A clear line of responsibility and accountability should be established.

Question 10: ***What is the cost of groundwater protection compared to the cost of treatment?*** Costs are site-specific and would be difficult to estimate in a general way. However, the high cost of *not* having groundwater protection is well known (e.g. Elmira, Walkerton). In addition to the cost of remediation of contaminated sites, there are costs for alternative water supplies, replacement infrastructure, and the inquiries that inevitably follow the more spectacular cases. Sometimes remediation is extremely difficult or impossible, and a legacy of a contaminated groundwater system remains. There are also intangibles such as the loss of public confidence in the water supply system, and the wider impact on the economy in the form of lost business. Usually, the cost of effective remediation is far in excess of the cost of any pro-active protection. In many cases, once the resource is polluted, remediation may not be possible. On this basis, protection is clearly the more efficient way to provide safe drinking water.

Question 11: ***What additional data and research needs can be identified?*** To meet future data needs, an increased effort is called for in the mapping of aquifers and aquitards, the systematic acquisition of groundwater quality data, and the acquisition of karst aquifer data. Future research should include the migration and fate of bacteria and viruses in the groundwater, improved quantitative methods for defining aquifer vulnerability, and the development of risk assessment methods for groundwater contamination.

The Workshop further developed a draft Table of Contents for a framework document defining Provincial Standards and Policy on Groundwater Protection in Ontario. The overall policy should combine existing legislation, policy and guidelines into a single integrated whole. A Task Force of experts from the scientific, planning, managerial, legal, and consulting professions should be formed and charged with working out the details of the required standards and policy. Once the policy is established, a standing Review Committee for standards and policy should be formed to ensure that the policy is continually updated as required in order to incorporate the results of relevant new research, data, and practical experience. The Table of Contents is given in Appendix A.

The Workshop concluded that sufficient data are available to initiate a systematic and comprehensive program of groundwater protection for Ontario in a step-by-step fashion. For areas where data are scarce, the groundwater protection program should provide the impetus needed to expand and complete the database. Various initiatives are already underway at the national, provincial, and local levels to upgrade the database and to map groundwater resources. Scientific and technical tools including mathematical models are at a reasonably mature stage, and expertise capable of using these tools is available in Ontario and throughout Canada. Thus the question *"Do we have enough knowledge and information to give our groundwater resource an effective legal protection?"* can be answered in the affirmative.

We propose that the Walkerton momentum be used for a major initiative to put groundwater protection in Ontario on a sound footing by creating consistent standards and an effective policy for the protection of groundwater resources. It is time to move ahead to ensure safe drinking water for present and future generations of Ontario's residents. Further delays, in the present environment of rapid growth and increasing demands on our water resources, will likely risk more tragedies such as Walkerton.

The formation of a Task Force that will develop a detailed document for groundwater protection standards and policy in Ontario will be the first step. The policy should merge the requirements of municipal and rural groundwater protection within an overall framework of groundwater management, covering both quantity and quality of the water resource. The overriding objective of environmental protection should be recognized.

This initiative will require a sustained effort by the Province, the municipalities, water providers, agricultural and conservation organizations, and the scientific community. Most importantly, it will require adequate funding to hire sufficiently skilled hydrogeologists into key positions in the leading organizations that will be responsible for setting standards, and to provide training for staff in organizations placed in charge of implementation and enforcement. This unavoidable cost represents an ongoing investment that will pay for itself in the form of a safe and reliable source of drinking water for present and future generations.

Recommendations

The Workshop recommends:

Recommendation 1: That a detailed framework of standards and policy for groundwater protection for the Province of Ontario be developed.

The issue of groundwater protection should be considered within a comprehensive framework of groundwater management including both quantity and quality. The Table of Contents laid out in the Workshop Report (Appendix A) will be a suitable starting point for this framework. The overall objective should be the protection of groundwater as a safe source of drinking water, as a reliable resource for municipal and rural/agricultural uses, and as a vital component of a healthy ecosystem. Existing standards should be incorporated as far as possible. The framework should cover, but not be limited to, the following topics:

Standards:

- technical standards for defining groundwater protection zones, vulnerability, risk
- drinking water quality standards (existing)

- experimental standards
- reporting standards
- review standards
- competence standards for implementing agencies

Guidelines/Policies:

- land-use guidelines for high-risk areas
- implementation policy
- compliance policy

Training, public awareness:

- training of municipal staff charged with implementation
- involvement of community groups

Funding objectives:

- research
- data collection
- local incentives
- implementation
- compliance monitoring

Recommendation 2: That a Task Force be appointed by the Province of Ontario and charged with developing this detailed framework.

The Task Force should have representatives from:

- Municipalities
- Agricultural organizations
- Industrial organizations
- Conservation authorities

- Universities
- Environmental organizations
- Groundwater professionals

Recommendation 3: That these groundwater protection standards and policy be subject to periodic review, and that a Standing Review Committee be created for this purpose.

Periodic reviews are necessary to keep abreast of new developments and insights, and an expanding database.

Recommendation 4: That the groundwater protection standards and policy described by the above framework be passed into legislation.

The establishment of a legal basis is necessary for groundwater protection to be effective.

Recommendation 5: That implementation of these standards and policy within the Province be carried out in a step-by-step manner established in consultation with communities.

A clear line of responsibility for implementation should be defined. Wherever possible, local water providers, including municipalities, conservation authorities, and First Nations should be responsible for implementation, compliance monitoring and enforcement, in accordance with Provincial standards. Appropriate incentives and funding for the training of staff should be provided. Existing local groundwater protection programs should be taken into account.

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1. Introduction

> *"There shall be no man or woman dare to wash any unclean linen, wash clothes, … nor rinse or make clean any kettle, pot or pan, or any suchlike vessel within 20 feet of the old well or pump. Nor shall anyone aforesaid within less than a quarter of a mile of the fort, dare to do the necessities of nature, since by these unmanly, slothful, and loathsome immodesties, the whole fort may be choked and poisoned."* (Lord Delaware's proclamation to the people of Jamestown, 1610, as quoted in EPA, 1997.)

Thus 400 years ago, groundwater protection was already recognized as being vital to the life of a community. In today's Ontario, as suggested by recent events, it seems that groundwater protection has still not been receiving the attention it deserves.

Ontario is endowed with abundant resources of groundwater of excellent quality, found in an extensive network of aquifers. Approximately 23% of Ontario's residents and almost all rural communities depend on these resources for their potable water supply. In the past, more groundwater could always be found to meet demand simply by drilling another well, and the capacity of the groundwater to assimilate waste was taken for granted. This historic abundance gave rise to the perception of an unlimited resource, where management, conservation and protection of groundwater were not high priorities.

Now, with increasing agricultural and industrial activities of many kinds, with increasing water demands and more types of waste being produced, this historical perception of a completely secure, unlimited resource must come to a close. This does not mean that we are running out of groundwater or that our groundwater as a whole is polluted. It means, however, that an effective groundwater protection strategy must be put in place to safeguard the integrity of our resource so that it will always be available for present and future generations. It also means that ways need to be found to reconcile conflicting land-uses that might put the resource at risk.

Groundwater, as a natural resource, has many unique characteristics that have made it invaluable to Ontario residents. It is a renewable resource that is available year-round even in times of drought, it is to some extent protected from surface sources of pollution through natural barriers, and it can be obtained in substantial quantities nearly everywhere. In fact, one of the foundations of the economic development of Ontario has been the availability of groundwater resources in the Province.

The need for groundwater protection was highlighted in 1993 by the Canadian Geoscience Council (CGC, 1993). The Council noted that millions of dollars were being expended for the cleanup of contaminated aquifers and the provision of alternative water supplies, and that the cost of groundwater protection would be a fraction of these cleanup costs. Little was done on a province-wide basis since then, and in 2000, the Environmental Commissioner of Ontario (Annual Report, 1999-2000, p. 40) reminds us again that "*Ontario urgently needs a groundwater protection and management strategy, as evidenced by the demands being placed on Ontario's groundwater resources and fragmented management of groundwater*". Clearly, the historic piecemeal management of water demands in Ontario, with each new use being evaluated in isolation of other past, present, and future uses, is no longer appropriate.

Encouragingly, a few Ontario communities have made progress on their own in protecting their groundwater resources. For example, the Regional Municipalities of Waterloo, Halton, and Peel have taken the initiative to find ways toward an effective groundwater protection strategy. Beyond Ontario, British Columbia and New Brunswick have recently implemented or are implementing state-of-the-art groundwater protection strategies. In both provinces, legislation protecting the water resource has already been passed.

The status quo with respect to groundwater protection standards in Ontario shows a patchwork of legislation involving various different jurisdictions, which are difficult to implement and enforce (CELA, 2001). There is a lack of legal powers for water providers who have made efforts to develop and implement groundwater protection programs. There is no clear line of responsibility and accountability. Continuation of this situation will likely risk more problems such as seen at Walkerton.

Other industrialized countries with a similar standard of living and geology/climate (e.g. most European countries) recognized the need for groundwater protection years ago and now have well-proven groundwater protection strategies in place as part of their comprehensive water resource management programs. These strategies generally include the designation of wellhead protection areas, monitoring, and sensible land-use rules that are accepted and respected by residents and businesses. These countries have found that groundwater protection is not an economic burden, but that it works to the benefit of all.

Twelve years ago, at the time of the Elmira groundwater contamination crisis, a unique opportunity for establishing a groundwater protection strategy was missed. With the Walkerton crisis, this need for a coherent strategy has been demonstrated once again. If effective guidelines or regulations had existed, such as those implemented in Germany or Switzerland for example, the Walkerton tragedy would likely not have happened. The issue will not go away. Now, with the Walkerton momentum and better methodologies available than ever before, the time is right for finding ways to develop a viable groundwater protection strategy for Ontario.

2. Groundwater Protection

Groundwater serves municipalities, it serves the rural/agricultural community, and it is essential to the preservation of a healthy ecosystem. Accordingly, a comprehensive groundwater protection strategy should have municipal, agricultural, rural domestic, and ecological components. The groundwater resource is at present subject to a multitude of mounting stresses including contamination from a variety of sources, land-use changes, urbanization, climate changes, and other factors.

To develop an effective strategy, we need, first, a good understanding of the resource: where is it, how much is there, how vulnerable is it, how is it replenished, what are its limits, and what are the threats to its integrity? Second, do we have the scientific tools needed to acquire and interpret hydrogeologic information, do we understand the processes that control the flow and storage of water and the transport and transformation of contaminants in the ground, and are we able to translate the technical information into a basis for managerial decisions? Third, do we have the legal, planning, and policy tools available for effective implementation?

Because there will inevitably be conflicting demands on the resource, there must be standards and guidelines for its orderly development and utilization. Most importantly, there must be good legislation, with well-defined compliance and accountability requirements, to frame these standards and guidelines. There must also be public education to provide a broad base of support for these measures. Only in this way will we be able to ensure that safe, clean water will continue to be available for present and future generations.

From these fundamentals, it is evident that both the quantity of the groundwater in our aquifers and the quality of this water must be considered in the context of an effective groundwater protection program. Both components are essential not only in keeping a supply of safe water flowing to our wells, but also in maintaining the baseflow that sustains a healthy aquatic environment in streams, wetlands, and lakes. Therefore, although in the wake of Walkerton the emphasis has been on groundwater quality, quantity must not be neglected. It follows that in any standards that will eventually be adopted, the overreaching role of groundwater in maintaining the ecosystem must be recognized. Groundwater quality protection, to be fully effective, should be carried out as part of an overall groundwater management plan including both quantity and quality. (Nevertheless, in order to keep our scope within manageable proportions, we will focus here on the water quality aspect of groundwater protection, with only some digressions into quantity aspects.)

In the protection of the municipal water supply, key components are the delineation of wellhead protection zones and the mapping of vulnerability (for definitions see Appendix B). A wellhead protection zone delineates a land surface area within which sources of pollution would have the most significant potential impact on the quality of the groundwater resource being utilized. A wellhead protection zone is generally based on the well capture zone, which is the recharge area from which the well draws its water. The risk of aquifer contamination from various land-uses within the capture zone depends on the vulnerability of the aquifer within the capture zone. The extent and the integrity of aquitards providing natural protection, as well as dilution and natural attenuation, play important roles in determining the vulnerability of an aquifer. The capture zone delineation itself should be based on a detailed hydrogeologic assessment for each individual site. In cases where the available hydrogeologic data are limited, a conservative preliminary assessment can be made while a more thorough assessment is phased in. This will allow the timely application of appropriate land-use constraints to minimize the threat to long-term water quality. In this context, progress is more important than perfection.

The case of Walkerton Well #5 is a classic example of where application of the basic principles of wellhead protection would almost certainly have avoided the tragic consequences of groundwater contamination. This well is located in a low-lying area where thin surficial sediment covers a highly permeable fractured limestone aquifer. The surficial sediment may be discontinuous or heterogeneous and thus may offer little protection to the shallow limestone aquifer from which the well draws its water. The area in the immediate vicinity of the well (and within its capture zone) is used for livestock farming where manure is generated, stored, and routinely spread on adjacent fields. The combination of these conditions has led to an extremely high potential for contamination of the municipal water well, a situation that, in hindsight, would have been immediately recognized if the concept of wellhead protection had been understood and applied by those in charge of the water supply.

The Regional Municipality of Waterloo (RMOW) has developed a comprehensive source water protection and management program (RMOW, 1994). The Region is committed to the sustainable use of the resource recognizing its limitations, it has initiated proactive measures to minimize impacts, and it has invested in public awareness and partnership programs. Both water quality and quantity issues are addressed. Wellhead protection areas have been defined and vulnerability maps developed for the well fields of the Region, and land-use guidelines (so far applying only to undesignated areas) were developed. The program covers municipal, rural, and industrial water use within the boundaries of the Regional Municipality. The most serious hurdle was found to be the lack of legislation, making the implementation of protection measures difficult. The Waterloo program, which has won national and international recognition, could be an example of effective groundwater protection for Ontario.

Other Ontario municipalities have also taken the initiative. For example, Halton Region has developed its own groundwater protection program (Regional Municipality of Halton, 1995, 1997, 1999). Likewise, Peel Region has implemented groundwater protection for its municipal wells (AMEC, 2000).

For the rural water supply, groundwater protection within an overall framework of groundwater management must again start with a good understanding of the resource. Where are the aquifers, how are they recharged, what is their condition, and what are the potential threats? This understanding is necessary in safely separating the water supply from potentially contaminating activities. Shallow aquifers are most vulnerable to contamination from agricultural activities; the consistent use of Best Management Practices (BMPs) in farming and other activities is therefore important. Often, a deeper aquifer will have better-quality water than a shallow aquifer. Abandoned wells can become a serious problem by providing shortcuts for contaminants reaching deeper aquifers; therefore there should be a clear and enforceable protocol for the safe abandonment of wells. Problems can also be caused by the improper construction of wells and septic fields. As the Regional Municipality of Waterloo has demonstrated, rural and municipal groundwater protection can go hand-in-hand for maximum benefit.

Groundwater protection can be seen as a primary line of defense in a conceptual multiple-barrier approach to safe drinking water, along with such sound concepts as the safe storage and handling of toxic or hazardous materials, BMPs, and treatment of the well water. Reliance on just one of these barriers would not be wise because, as Walkerton has shown, to err is human. Water treatment by itself is not a substitute for protection, because first, it can never be totally foolproof, second, treatment is contaminant-specific and usually expensive, and third, treatment itself can cause other health-related problems (e.g. creation of potentially cancer-causing trihalomethanes through chlorination).

An example of how the groundwater resource in a major watershed can be characterized in a broad and comprehensive way is given by the Grand River Conservation Authority (GRCA) in its pioneering Groundwater Mapping Study of the Grand River Watershed (Holysh et al., 2000). The study considers municipal, rural and environmental aspects of groundwater protection, covers quality as well as quantity aspects, and explores the roles of governments, water agencies, and the public.

3. Existing Groundwater Protection Standards and Related Research

Many industrialized countries with similar climatic and geologic conditions and a similar standard of living, for example Germany (DVGW, 1995) and Switzerland (Der Schweizerische Bundesrat, 2001), have already confronted this issue long before us and now have effective groundwater protection strategies in place. These European countries have a history of effective groundwater protection and aquifer management, and have established regulations or guidelines that are universally accepted and respected by the population and by businesses.

Most European groundwater protection standards are based on a zoned system, which generally includes three primary zones and often several sub-zones. The innermost zones may be based on either distance or time of travel with respect to the well to account for short-lived microbial contaminants, while the outer zones may include the entire well capture zone to account for persistent chemical contaminants. The European Union has now formed an International Consortium to set uniform standards for the delineation of groundwater protection zones within the member countries (European Commission, 2000).

In the United States, the U.S. Environmental Protection Agency has developed highly detailed guidelines covering all aspects of groundwater protection (Federal Register, 2000; EPA, 1997). The states of the U.S. are charged with implementing groundwater protection on the basis of these guidelines (EPA, 1997). Other useful documents can be found on the EPA website (see for example EPA 1987; EPA 1990; EPA 1991a; EPA 1991b; EPA 1993; EPA 1995). The program is explained to the public through easily understandable literature (EPA, 1990).

In Canada, the Provinces of British Columbia and New Brunswick have recently established groundwater protection programs (Province of British Columbia, 2001; Province of New Brunswick, 2000). The New Brunswick regulations focus specifically on the concept of wellhead protection, imposing detailed restrictions on what chemicals can be stored or used in each of three protection zones, which are defined individually for each well field. New Brunswick has also produced an easily understandable guide for use by the public (New Brunswick, 2000).

Present groundwater protection standards in Canadian provinces, as well as in the U.S., Great Britain, and other countries are reviewed by CELA (2001). This comprehensive document analyses the state of the groundwater resource in Ontario and the lack of groundwater protection standards in the Province, and it proposes a clear approach for creating the necessary legislative framework for guaranteeing safe drinking water for Ontario's residents. In the same vein, the Environmental Commissioner of Ontario urges the Provincial Government *"to develop a groundwater management and protection strategy in consultation with key stakeholders and the public"*, and lays out the components of an effective groundwater management and protection strategy (Environmental Commissioner of Ontario, July 27, 2000).

It should also be noted that the Government of Canada has recently initiated the development of a National Centre of Excellence (NCE) in the area of Clean Water. It is referred to as the Canadian Water Network (CWN) and is located at the University of Waterloo, Ontario. This Centre involves over 32 universities and 150 scientists from across Canada and abroad. It also includes participation from all levels of government and industry. The main focus of the Centre is to ensure the sustainability of fresh water including groundwater for all stakeholders in Canada through the development of new technologies, technical understanding, and management strategies by means of collaborative research. Research advances made by the CWN will be immediately available to the Provincial ministries responsible for groundwater protection in Ontario. Close liaison between the Province and the Centre will ensure continuous access to the most current information on the management and protection of groundwater resources.

4. Objectives of the Workshop

This Workshop on Groundwater Protection in Ontario was constituted at the request of the Honourable Dennis O'Connor, Chief Commissioner of the Walkerton Inquiry, with a mandate to provide input to Phase II of the Walkerton Hearings, specifically to the Expert Meeting on Source Protection May 3-4, 2001. The Workshop was held on May 1, 2001 at the University of Waterloo. The participants of the Workshop are listed in Appendix C.

The primary objective of the Workshop was to consider the case for standards and policy for groundwater protection in Ontario by examining the state of technical knowledge and information that is needed as a basis for a legislative initiative: *Do we have enough knowledge and information to give our groundwater resource an effective legal protection?* This focal question was recast into a number of key questions that were addressed and answered. The Workshop did not consider the exact from of legislation that would be needed for effective groundwater protection, that aspect being beyond the scope of the Workshop. A secondary objective was to develop a Draft Table of Contents for a document on Standards and Policy for Groundwater Protection in the Province of Ontario.

Although groundwater protection in general should consider both quantity and quality of groundwater within an overall framework of groundwater management, the one-day Workshop was primarily focused on quality aspects to keep the scope within manageable bounds. Some aspects of quantity management were also considered and are incorporated in the Draft Table of Contents (Appendix A). To cover groundwater quantity in a comprehensive way would require another workshop.

5. Key Questions affecting Groundwater Protection

A series of seven invited talks were given in order to provide background information and to familiarize participants with the state of research in specialties other than their own. These talks were:

- Groundwater protection: Definitions, standards in other countries (Emil Frind)
- Source water protection and management in Waterloo Region (Eric Hodgins)
- Groundwater protection and the Oak Ridges Moraine (Ken Howard)
- Mapping of groundwater resources for the Grand River Watershed (Dwight Boyd)
- The Elmira Case: A history of groundwater contamination (Susan Bryant)
- Agriculture and groundwater protection (John Fitzgibbon)
- Integrated watershed management in British Columbia (Asit Mazumder)
- Legal issues in groundwater protection (Theresa McClenaghan)

With this background information, participants addressed the key questions relating to the state of knowledge and information on the groundwater resource, and the existing standards and guidelines pertaining to the protection of this resource in Ontario. Answers were drafted by participants during the workshop, refined and expanded in the course of post-workshop discussions, and extensively reviewed. These questions and answers are as follows:

Question 1: Is the groundwater resource in Ontario understood well enough to support groundwater protection?

In order to protect the resource, we must know the location, the condition and the capacity of the resource. This means that we must be able to characterize, with reasonable accuracy, the aquifers that store and carry the groundwater and the aquitards that may provide protection against contamination. It is well known what types of data are required to develop this fundamental knowledge. These data include geologic information, measurements of piezometric head, groundwater quality data, surface hydrologic and climatic data, as well as inventories of primary groundwater users and current/historical land-use practices.

The quantity and quality of the available data vary for different areas of the Province. In areas that have traditionally relied on groundwater, such as Waterloo Region, data are generally adequate. For example, the aquifers of the Waterloo Moraine that are important municipal water sources have been studied, mapped and modelled in considerable detail (see for example Martin and Frind, 1998). The aquifers and aquitards of the Oak Ridges Moraine north of Toronto have also been well studied (see for example Howard, 1997; Howard & Gerber, 1997; Howard et al., 1995). Most groundwater studies utilize the extensive borehole database maintained by the Ontario Ministry of the Environment (MOE), which contains the data logs of the majority of the wells that have been drilled in the Province.

In some areas of the Province, the upper fractured zone of the bedrock is also an important groundwater source. Examples are the Cambridge area within Waterloo Region, and Walkerton. Fractured and karstic rock aquifers are more difficult to characterize and model than granular aquifers (EPA, 1991b), but progress is being made in this area as well (see for example Bauer et al., 1999; Worthington et al., 1999).

Climate recording stations and streamflow gauging stations are essential data sources for defining groundwater resources. The existing network of stations should be expanded by adding new stations (rather than closing existing stations as is current practice) to develop a better record of precipitation and streamflow trends. These data are necessary to characterize aquifer recharge.

There is also an urgent need for data that would allow the evaluation of the impact of urbanization on our aquifer systems. At present, urbanization is progressing at a rapid pace near our major population centres, while the resulting impacts are poorly understood. Detailed hydrogeologic data collected before, during, and after construction of new subdivisions and other urban growth are needed to evaluate this impact.

Aquitards can play an important role in protecting aquifers from contamination. However, this protective capacity depends critically on the integrity of the aquitard, which can be compromised by the presence of windows (openings), manmade penetrations such as abandoned boreholes, and fractures in the aquitard (Howard and Gerber, 1997; Martin and Frind, 1998). In the case of large openings, the protective capacity can be completely lost, while in the case of fractures, matrix diffusion may still act as a protective process. Although the controlling processes are understood, the associated parameters are often not well known. The distribution of natural tracers can sometimes yield an indication of migration rates through an aquitard (Rudolph et al., 1991). The mapping of aquitards including their characteristics is therefore as important as the mapping of aquifers.

A number of important initiatives have recently been completed or are underway to map groundwater resources regionally or locally in Ontario. Notably, the Grand River Conservation Authority has completed a comprehensive mapping project of the water resources of the Grand River watershed (Holysh et al., 2000) as a basis for future decision-making. This project has produced a number of detailed maps characterizing the physical attributes of the resource. Efficient mapping tools that will be useful also in other projects were developed, and some data gaps were identified. This definitive study will be a good basis for similar studies in other watersheds. Likewise, Halton Region (Regional Municipality of Halton, 1995, 1997, 1999) and Peel Region (AMEC, 2000) have mapped their groundwater resources as part of their individual groundwater protection programs. These activities show that there is great interest in groundwater protection at the local level.

The Ontario Ministry of the Environment (MOE) has completed an inventory of 34 municipal groundwater management studies funded under the Provincial Water Protection Program, which provides water and sewage infrastructure funding to municipalities with immediate health and environmental problems (MOE, 2000). In addition, the MOE has initiated a program to establish a provincial network of monitoring wells (approximately 350) to provide regional groundwater quality and piezometric data throughout most of Ontario (pers. comm., G. Soochan, MOE). This monitoring network can be considered a key component of the future Provincial groundwater protection program. Further at the National scale, the

Geological Survey of Canada (GSC) is in the initial stages of a project with the long-term goal of mapping Canada's groundwater resources (Natural Resources Canada, 2000).

Thus a substantial database is already in existence or is being developed in Ontario. For areas that are not yet covered by any of the ongoing initiatives, the data gaps should be filled, with emphasis on the types of data required for the inventory and mapping of the aquifer resources. The expansion of monitoring networks, which provide critical physical and chemical information required to continuously evaluate the state of the resource and give early warning of pending problems, should be encouraged. Aquifer and aquitard mapping should be accelerated wherever possible. To facilitate appropriate initiatives, incentives and funding should be provided through the groundwater protection program. There is a need for consistent Province-wide technical standards for data acquisition, mapping, and database management.

The databases developed by the Province or other public bodies should be publicly available without fee.

Question 2: Are the processes and theories that are relevant to groundwater protection understood well enough?

Of relevance are the physical processes that conduct the water from the recharge area to a well or discharge area and that transport contaminants in the water, and the chemical/biochemical processes that transform those contaminants. The main processes include:

- groundwater flow and transport in saturated porous media,
- flow and transport in the unsaturated zone,
- sorption,
- aquifer recharge,
- flow of surface water and interaction with the groundwater system,

- chemical reactions,
- biodegradation and decay,
- migration and dissolution of non-aqueous liquids,
- flow and transport in fractured and karstic systems,
- flow and transport through aquitards,
- matrix diffusion,
- transport of bacteria and viruses.

The key physical processes of flow and transport, which provide the essential scientific basis for groundwater protection methodologies, are well understood and detailed developments of the governing theories can be found in textbooks such as Freeze and Cherry (1979) and many others. Physical transport includes transport by advection and dispersion, as well as sorption, and theories relating to saturated and unsaturated groundwater environments are readily available. Likewise, the mechanism of aquifer recharge is well understood. More recently, advances have been made in understanding and developing theories for linking surface water flow/transport with groundwater flow/transport (VanderKwaak, 1999).

Fundamental chemical/biochemical processes in the groundwater are likewise well understood (see for example Chapelle, 1993). Some of these processes are important natural attenuation mechanisms for certain contaminants and should therefore be considered in groundwater protection. Natural attenuation mechanisms are important in many situations; for example, wetlands can be instrumental in cleaning up certain types of contamination by biofiltering and biodegradation.

A large body of literature also exists on groundwater contamination due to non-aqueous-phase liquids, such as chlorinated hydrocarbons and petroleum products (see for example Pankow and Cherry, 1996). The key processes in this context are the percolation of the non-aqueous phase into the groundwater system, the formation of pools and residual zones as persistent sources of contamination, and the dissolution process that forms the aqueous phase that migrates with the flowing groundwater. These processes are fairly well understood, and advanced research is continuing.

Flow and transport in fractured and karstic systems is more complex than in porous systems, and intensive research is continuing in this area. Fundamental theories have been developed (see for example Dreybrodt, 1992; Worthington, 1999). Data for characterizing karst systems can be difficult to obtain, and uncertainties are in general greater than for porous systems. Factors of safety should therefore be applied in the delineation of groundwater protection zones for karstic systems. Surface water can be a major contributor to the recharge of a karstic groundwater system.

The theories controlling flow and transport across aquitards are generally well understood. Apart from windows and abandoned boreholes, fractures can provide effective pathways for contaminants reaching an aquifer (see for example Harrison et al., 1992). An important control on transport through fractures is matrix diffusion (Sudicky and Frind, 1982). In combination with sorption and degradation, this process can remove much of the contaminant mass from the active flow system, thereby helping to restore the protective capacity of a fractured aquitard. In some cases where significant fracturing exists, matrix diffusion has been shown to be one of the most important protective mechanisms for aquifers (Rudolph et al., 1991). However, migration characteristics through fractured aquitards also depend on the nature of the contaminant. For example, dense non-aqueous liquids such as chlorinated solvents can infiltrate through fracture networks faster than dissolved contaminants due to their density (Hinsby et al., 1996). For bacterial species, matrix diffusion may be less effective than for solutes, also resulting in a relatively rapid migration rate (Hinsby et al., 1996; Rudolph et al., 1998).

The transport of bacteria has conventionally been assumed to be an advective non-reactive transport process in the context of groundwater protection – a safe assumption. For the purpose of setting time-of-travel zones to protect against bacterial contamination, reliable estimates of the life expectancy of bacteria and viruses are needed. There may be some uncertainty regarding the life expectancy of certain bacteria and viruses in the groundwater; therefore this aspect should be reviewed in more detail and further research may be needed.

In general, the fundamental processes needed for the formulation of groundwater protection standards are well known. More advanced theories for complex situations will continue to evolve, and future standards and policies should be flexible to accommodate such advances.

Question 3: Are appropriate technical tools and expertise for the implementation of effective and efficient groundwater protection available?

The technical tools required are hydrogeological, geophysical, and geochemical field methods for acquiring the necessary data, mathematical simulation methods for integrating the data with the relevant processes, and visualization tools for interpreting the results into a form useful to water managers and decision-makers. These tools can be used to study both quantitative and qualitative aspects of groundwater.

Hydrogeological field methods include modern drilling techniques that provide undisturbed samples for the mapping of hydrogeologic units (aquifers and aquitards). Geophysical methods provide the means to visualize the subsurface, to spatially interpolate point data from hydrogeological methods, and to determine the continuity of the various units. Advanced hydraulic testing methods permit the determination of the physical parameters that control groundwater flow within the different units, and to allow the interconnections between the different components of an aquifer system to be assessed. Geochemical field methods can be used to interpret groundwater ages, flowpaths, travel times, and velocities through the analysis of natural isotopic and geochemical tracer distributions. This type of information is extremely useful for inferring or verifying flow system characteristics.

Modern mathematical simulation methods are based on the discrete application of the governing theories for flow and contaminant transport under complex conditions. They are used to analyze the response of a groundwater system and the mechanism of aquifer recharge under a variety of stresses and scenarios, and they provide detailed water and material balances. They can also be used to determine groundwater capture zones for wells or well fields. Various powerful and well-proven methods have been developed over the last 25 years.

These include two-dimensional (2D) and three-dimensional (3D) models. The most popular model at this time is *MODFLOW*, developed by the U.S. Geological Survey (MacDonald and Harbaugh, 1988). For more complex situations, advanced models such as *FEFLOW* (Diersch, 1994) or *WATFLOW* (Beckers et al., 2000) are available. Most models have been developed for porous media, but fractured rock models are also available, for example *FRAC3DVS* (Therrien and Sudicky, 1996). The particular challenges of karst modelling are discussed in the proceedings of a recent symposium on karst waters (Palmer et al., 1999).

Conventional methodologies for groundwater protection are often based on simple graphical methods or two-dimensional modelling under the assumption of a single aquifer (see for example EPA, 1993). In more general situations involving complex multiple aquifer-aquitard systems, this assumption will be invalid. Advanced state-of-the-art methodologies are therefore based on three-dimensional modelling, which allows the hydrogeologic complexity of aquifer systems to be represented more realistically, and which leads directly to 3D capture zones (see for example Martin and Frind, 1998; Frind et al., 2000; Muhammad, 2000).

Models for flow or contaminant transport in the unsaturated zone are also available (see for example Therrien and Sudicky, 1996). The unsaturated zone can, in certain situations, provide an important attenuation mechanism for contaminants. For example, in the case of a distributed source of fertilizer or pesticide, the potential contaminant may degrade sufficiently to become harmless while being transported through the unsaturated zone. Therefore, the unsaturated zone can act as a protective layer to the groundwater. Suitable models can be applied to analyze this mechanism in individual cases.

More powerful models are continually being developed. For example, the recently developed Integrated Hydrologic Model *InHM* (VanderKwaak, 1999) integrates saturated flow/transport, unsaturated flow/transport, and surface flow/transport. This is the first model of this type that integrates groundwater and surface water processes in a rigorous way. In the area of chemical transport, the highly advanced model *MIN3P* (Mayer, 1999) simulates the transport of reacting substances in the groundwater under saturated and unsaturated conditions.
Basin models have been developed for the evaluation of large-scale impact of land use on

water quality (see for example Holysh et al., 2000).

As a tool to minimize the effect on groundwater due to farming operations, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) has developed the model *NMAN2000* (OMAFRA, 2001) which provides guidance on the application of the correct amounts of nutrients such that leaching does not occur. This model is basically a nitrogen balance model that includes a crop-growth component as well as export components for both surface runoff and leaching to groundwater. It is not known whether this model can be coupled to a groundwater model to simulate groundwater impact.

Various methodologies, including sensitivity analyses and stochastic methods, have been developed to account for the effect of hydrogeologic data on capture zone predictions (see for example Kunstmann and Kinzelbach, 2000; van Leeuwen, 2000). In order to standardize groundwater protection methodologies in the presence of uncertainties, the European Union has formed a scientific consortium to deal with this aspect (European Commission, 2000).

Risk assessment methodology has also been applied in groundwater. For example, Goodwin et al. (1994) developed a procedure for predicting the risk of contamination from radionuclide waste stored in fractured rock, integrating groundwater flow and transport modelling tools with risk assessment methods. A similar methodology could be developed for assessing the risk of contaminants reaching a well at unacceptable concentrations.

For effective visualization, various sophisticated tools are presently available to the groundwater scientist. Among these, the Geographic Information System (GIS) is becoming increasingly popular due to its power and flexibility in allowing the integration of many types of different information. These features are important in the mapping of groundwater resources and aquifer vulnerability.

The application of this comprehensive array of tools requires trained hydrogeologists or engineers. An adequate pool of these professionals with basic or advanced training is available in Ontario and throughout Canada. Professionals working in the implementation of groundwater protection programs will increasingly require experience in watershed-scale and regional-scale flow processes. Universities and colleges should recognize this need in designing their hydrogeology curricula.

Question 4: What geographic scale is appropriate for groundwater protection?

Although in the present context we focus on water quality aspects, it should be understood that groundwater protection in general has both quantity and quality aspects. Groundwater protection should therefore be considered as an integral part of groundwater management. Accordingly, the appropriate geographic scale for groundwater management is the major watershed. As an example, recent work by the Grand River Conservation Authority (Holysh et al., 2000) has demonstrated how resource mapping at the watershed scale can provide a sound basis for water management and decision-making.

Within a major watershed, different approaches may be needed for municipal and rural groundwater protection. For municipal water systems, the priority is to provide safe drinking water to the urban community, and the focus of groundwater protection should therefore be on the area that contributes the recharge to the municipal wells, namely the corresponding capture zones. These zones must be the areas most stringently controlled. This places the focus of protection on the areas that are most sensitive to contamination.

For rural areas, private wells, agricultural water uses, and industrial/extractive operations in rural areas, appropriate standards and guidelines are also needed. These standards and guidelines should be compatible with those for municipal groundwater protection. They should also recognize the overall objective of groundwater protection in maintaining the water cycle, providing the baseflow needed for streams and other aquatic habitats, and in promoting a healthy ecosystem, in addition to providing safe drinking water.

Question 5: What groundwater protection standards exist for municipal supplies, and what are needed?

Ontario has a number of policies and guidelines relating to water quality (for a complete review see CELA, 2001). Drinking water quality guidelines with respect to a number of substances are laid down in detail by the Ministry of the Environment (MOE, 1994). However, there are no standards in Ontario for assuring that these quality objectives can be achieved for individual water sources.

Groundwater protection standards for assuring water quality objectives are well established in many countries and in some Canadian provinces. Usually, capture zones and wellhead protection areas are defined and appropriate land-use guidelines are applied within these zones. Various conventional methods for delineating well capture zones exist (see for example EPA, 1993; EPA, 1991b). The most systematic method, however, is by means of three-dimensional mathematical modelling, where the aquifer system hosting the well is characterized in as much detail as possible, the flow system is simulated, and the capture zone and time-of-travel zones are defined on the basis of the 3D flow system. Because the hydrogeologic parameters vary from site to site, capture zones will generally be site-specific. The model should be fully calibrated and uncertainties in the hydrogeologic parameters should be addressed either by means of stochastic methods, or by conducting a sensitivity analysis reflecting the unknown parameters, where the final capture zone is delineated by drawing an envelope curve around the sensitivity-based capture zones. An excellent graphical representation of capture zones in complex 3D systems under various conditions is given by the U.S. Geological Survey (1998).

The extent of a wellhead protection zone also depends on the nature of the target contaminant. In the case of microbial contaminants, the protection zone is generally defined in terms of time of travel, on the basis that microbes can survive in the groundwater for only a limited length of time. In the case of persistent contaminants such as chlorinated hydrocarbons, nitrate from fertilizer, or road salt, the entire well capture zone may be designated as a groundwater protection zone.

The actual risk of contamination within a capture zone depends on the vulnerability of the aquifer. Vulnerability is a measure of the degree of protection provided by overlying aquitards (thickness, continuity, fracturing, etc.), the capacity of the aquifer (thickness, dilution), and the degradation processes available. These factors must be evaluated individually for each site. In the United States, various organizations have studied groundwater vulnerability and produced vulnerability maps (Federal Register, Vol. 65, No. 91, p. 30222). According to an earlier approach proposed by the U.S. Environmental Protection Agency, vulnerability (or "intrinsic" vulnerability, i.e. vulnerability due to hydrogeologic factors only) can be expressed in terms of numeric factors assigned to various system characteristics (EPA, 1987). More recently, the U.S. EPA has defined standards for the assessment of site-specific vulnerability based on the performance of existing hydrogeologic barriers such as unsaturated zone and saturated zone thickness, as well as other factors (Federal Register, Vol. 65, No. 91, p. 30227). Lists of risk substances are given in the same publication.

In addition to vulnerability, the term "sensitivity" can be used to characterize an aquifer in the context of a groundwater protection strategy. The U.S. EPA defines aquifer sensitivity in terms of the ability of the aquifer to transport pathogens rapidly for long distances in the absence of a hydrogeologic barrier (Federal Register, Vol. 65, No. 91, p. 30223). Karst, fractured rock, and gravel aquifers are considered to be sensitive. To meet the requirements of a hydrogeologic sensitivity assessment according to EPA standards, it is sufficient to identify the type of aquifer as one of the three types considered sensitive. This assessment does not consider the actual hydraulic gradients prevailing in the aquifer.

The Regional Municipality of Waterloo uses "sensitivity" as a measure to express aquifer vulnerability plus the importance of the wells within a well field in terms of the percentage of the total water supply coming from this well field and the dollars spent on the corresponding infrastructure (vulnerability + importance = sensitivity) (RMOW, 2000). Defined in this way, sensitivity becomes a planning tool. Other factors may be added to the definition to reflect local situations.

While the above definitions are adequate for the present, there seems to be a need for a more systematic and quantitative definition of aquifer vulnerability for future use. Such a future definition should include both aquifer and aquitard characteristics, and should provide some quantitative measure of the probability of a contaminant reaching a well.

European countries (see for example the German groundwater standards in DVGW, 1995) generally have regulations based on three protection zones that surround a well, where the innermost zone (some tens of metres) protects the well installation itself, the intermediate zone protects the well against bacterial contamination (approximately 50 days of travel time, depending on the longevity of the target bacteria in the groundwater), and the outer zone protects against persistent contaminants such as chlorinated hydrocarbons (usually the entire well capture zone).

New Brunswick (Province of New Brunswick, 2000; New Brunswick Department of the Environment and Local Government, 2000) has implemented a similar approach, but which better reflects today's understanding of the behaviour of contaminants in groundwater. Three protection zones are defined on the basis of travel time in the aquifer: the innermost zone (100 to 250 days) protects against bacteria and viruses, the intermediate zone (up to 5 years) protects against petroleum products, and the outer zone (up to 25 years) protects against chlorinated solvents. Activities explicitly permitted in each of the three zones are defined, potential contaminants are listed, and the amounts of each potential contaminant that may be used or stored in the respective zones are specified. Activities that are not explicitly permitted are prohibited. Provincial and municipal inspectors are designated to monitor compliance, and offenders may be fined. The new regulation is being implemented gradually on a case-by-case basis (see for example Aqua Terra Investigations Inc., 2000).

In Ontario, a number of communities, among them the Regional Municipalities of Waterloo, Halton and Peel, have established their own groundwater protection standards. As an example, the Region of Waterloo has established wellhead protection zones for all of its well fields (RMOW, 2000). These protection zones were obtained by means of groundwater modelling using detailed conceptual models of the aquifer system (the conceptual model of the Waterloo Moraine is described by Martin and Frind, 1998). Uncertainty in the hydrogeologic parameters was accounted for by conducting scenario analyses involving various feasible hydrogeologic configurations. Within the designated protection areas, vulnerability and sensitivity zones were mapped in a qualitative way on the basis of surficial characteristics of the geology, as well as other factors relevant to the planning process. Land-use guidelines were established on the basis of these maps. However, because of the lack of provincial standards, implementation of these local land-use guidelines has been limited to lands not yet zoned for development. The Region of Peel has developed a set of land-use prohibitions in consultation with the Town of Caledon; these prohibitions are implemented via the Town's bylaws.

As an alternative to the established approach using land-use restrictions, Howard (1997) proposes to define certain "standards of performance" that would be incorporated into the urban planning process. This approach could apply to either a watershed or a capture zone scale. These standards would designate limits to the degree of contamination that would be acceptable, and may also require that the recharge be maintained at pre-development levels. The proponent of a development would be encumbered with the responsibility to perform the necessary subsurface investigation to assure that environmental guidelines will always be met. With this approach, an early-warning monitoring system should be installed to minimize risk, auditing should be mandatory to ensure compliance, and consequences of non-compliance or of failure to meet the performance standards should be clearly laid out.

In the future, the "standards of performance" approach could be coupled with a risk-based approach whereby all the relevant factors controlling the concentration of a contaminant arriving at a well are integrated to estimate the probability of the concentration exceeding acceptable guideline values. The approach developed by Goodwin et al. (1994) in the context of radionuclide waste disposal could be used as a starting point for future research in this area.

For the present, however, we need standards that are workable, practical, proven, and enforceable. These standards exist in many other jurisdictions. As the lack of standards for Ontario was one of the contributing factors of the Walkerton tragedy, it is clear that provincial standards and guidelines are needed urgently. With increasing demands on the water supply, we can effectively protect our municipal groundwater supplies and guarantee safe drinking water for Ontario's citizens only if we establish these standards. There must be standards for the delineation of wellhead protection zones, standards for the definition of aquifer vulnerability, and standards for the use of potentially hazardous materials and products within the wellhead protection areas, as well as appropriate and enforceable guidelines for land use within groundwater protection zones. Existing approaches (e.g. the U.S., Europe, New Brunswick, select Ontario municipalities) could be used as starting point and refined as required. Various levels of wellhead protection zones should be defined according to target contaminant types (grouped for example as pathogens, degradable contaminants, and persistent contaminants). Substances that could pose a potential risk to the groundwater should be listed and activities (industrial, commercial, agricultural, governmental, residential) that are potential generators of these substances should be identified. Appropriate land-use guidelines for the land contained within a wellhead protection zone should be developed with the objective of preventing any harmful substances from reaching a well at unacceptable concentrations. These standards and guidelines should be carefully designed such that established drinking water directives are met. They should also be flexible so that new approaches for defining risk can be incorporated.

Wellhead protection standards should also be applied in the siting of new wells at the planning stage, in order to evaluate the practicality of land-use constraints at the particular site. Aquifer and aquitard mapping is needed as a prerequisite for this procedure. Significant aquifer systems should be identified and afforded suitable protection, even before actually being used for water supply, and future standards should cover this aspect.

Question 6: What groundwater protection standards exist for rural supplies, and what are needed?

Numerous regulations and guidelines already exist to guide all aspects of agricultural operations in Ontario and Canada, and a wealth of relevant information can be found on the websites of Agriculture Canada, the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA), the Ontario Federation of Agriculture (OFA), and Ontario Farm Environment Coalition. There are guidelines for soil conservation, nutrient and manure management, water taking, and many other aspects. A core theme among this information is Best Management Practices (BMPs), which have been developed in a partnership initiative between OMAFRA and OFA to promote environmental protection and environmental responsibility in the farming community.

In the area of nutrient management, procedures have been established by OMAFRA, and municipal bylaws requiring nutrient management planning by agricultural operations have been enacted in 57 jurisdictions in the Province (FitzGibbon and Thacker, 2001). These programs provide incentives, education, and advice to farmers to encourage the adoption of Best Management Practices (BMPs) that are designed to minimize the environmental impact of farming operations. Drawbacks are that the bylaw appears to be focused on large facilities, leaving smaller operations unregulated, and that some features of nutrient management planning, such as ownership of the land needed for manure spreading, as well as compliance monitoring and enforcement, are not covered (pers. comm., J. Harman). The state of manure management is also reviewed by Goss (1994), and the impact of manure application methods on water quality, focusing on nitrogen and bacteria transport in soil, is discussed by Wall et al. (1997).

Initial steps toward groundwater protection for rural areas are being taken through programs such as the Environmental Farm Plan. This program has currently over 20,000 farms participating with over 12,000 plans implemented with support from Agriculture Canada and OMAFRA through the Ontario Farm Environment Coalition. FitzGibbon et al., (2000) estimate that approximately one-half of the threats to groundwater due to wellhead exposure, spills of stored fuel, the use and storage of pesticides, and septic systems have already been remedied as a result of this program

Rural water protection programs are also being implemented by local communities or organizations. A successful example is the Rural Water Quality Program developed and implemented jointly by the Regional Municipality of Waterloo, the Grand River Conservation Authority, the Ontario Ministry of Agriculture, Food and Rural Affairs, and other agencies (RMOW, 1998). This program provides financial assistance to farmers to improve and protect water quality.

The Province (OMAFRA) is presently developing a model agricultural operations bylaw that rural communities can adopt. In the meantime, most rural municipalities are using the Oxford County bylaw as a model for the control of agricultural operations (FitzGibbon and Thacker, 2001). It is anticipated that the policies enshrined in the new bylaw will have a significant impact on groundwater resource protection in rural areas.

Farm wells are an important concern in rural groundwater protection. Provincial Regulation 903 (Province of Ontario, 1990) provides standards for well location, construction, and abandonment; however, this regulation is presently not enforced due to lack of staff and the absence of a clear protocol for monitoring (inspection of sites, construction and abandonment). It is absolutely critical that abandoned wells be sealed properly to avoid creating shortcuts for contaminants to reach drinking water aquifers. Therefore, there is a definite need to develop the capacity to implement and enforce this regulation. Inspection could be done by building inspectors at the local level, provided these inspectors can be trained appropriately. An alternative is to make well drillers responsible through their professional association, as is done in Alberta.

Overall, agricultural operations appear to be reasonably well regulated with respect to groundwater impact. However, the fact that the farm suspected of being the source of the bacterial contamination of Walkerton Well #5 was run in an exemplary way according to Best Management Practices raises some concerns. Do existing BMPs really protect the groundwater, and are practices that are considered “best” really best for groundwater protection? BMPs are excellent educational tools and they provide valuable information to the farmer, but they do not necessarily have a strong groundwater focus (pers. comm., J. Harman). There seems to be little monitoring of the effect of BMPs, their successes may be uncertain, and their benefits are difficult to quantify. Furthermore, as Walkerton has shown, BMPs cannot be counted on to protect the groundwater. Therefore, BMPs should be reviewed in the light of recent scientific understanding of groundwater protection issues.

The tendency toward intensive farming in Ontario is on the increase, and this trend is a cause for concern, as it will undoubtedly increase the pressure on the groundwater resource. The Environmental Commissioner of Ontario (2000) discusses several problems or potential problems related to intensive farming that could impact the groundwater. One particularly troubling concern noted is that in 1998, OMAFRA removed several environmental commitments form its Statement of Environmental Values (SEV), including the commitment to *"ensure an environmentally responsible and sustainable agriculture and food system"*. The Environmental Commissioner (2000) also showed concern about potentially environmentally negative impacts of intensive farming in the light of recent changes to the Farming and Food Production Act, which strengthen the protection of farmers, thereby possibly overriding local bylaws designed to protect the groundwater.

Non-agricultural activities in rural areas must also be considered. These include industrial activities such as pits, quarries, water bottling plants, and mines, all of which can have a substantial impact on groundwater quantity as well as quality. The application of road salt is another example of an activity that can have a potentially serious impact on the groundwater resource; this impact is now beginning to be felt by some large municipalities.

Large water takings are a particular concern. Under the Ontario Water Resources Act (OWRA), water takings above 50,000 litres/day require a permit, and Permits To Take Water (PTTW) were traditionally issued by MOE on a first-come first-served basis. In 1999, MOE introduced a new regulation setting out environmental criteria that must be satisfied, including an assessment of impact on the environment and local users, and an evaluation of the cumulative impact of the water taking. The Environmental Commissioner (2000) reviewed the PTTW procedure and expressed concern about the implementation of the new regulation, questioning whether MOE staff have adequate data available to make informed decisions about the environmental impact of water taking.

These concerns could be met if the Environmental Impact Statement (EIS) required for a major water taking would include a quantitative evaluation of the groundwater flow system (if necessary by means of modelling), delineation of the capture zone associated with the proposed water taking, and an evaluation of the cumulative impact of the proposed taking. This type of information would allow MOE staff to make a reliable assessment of the potential impact on sensitive ecosystems and future land use, as well as of the future potential for the well to be contaminated.

To avoid potential problems such as experienced at Walkerton, the placement of new wells should be based on some understanding of the state of the groundwater flow system and the quality of the groundwater resource. This understanding should include a knowledge of the extent of the well capture zone. On this basis, a new well should be located such that its capture zone does not draw in groundwater that may already be contaminated or that is at risk of contamination.

Overall, there is a need to review and coordinate the relevant procedures with respect to their impact on groundwater quality, taking into account scientific advances in the understanding of groundwater protection. The review should include BMPs, farm wells, large water takings, and other activities that potentially impact the groundwater resource. In this same context, the commitment of governmental agencies toward environmental protection should be re-examined. Existing programs should be made compatible with future municipal groundwater protection standards and integrated into an overall Provincial framework for groundwater protection.

Watershed-scale mapping of groundwater resources, including aquifer vulnerability, should be undertaken in rural areas, and water balances for watersheds should be developed. The work done by the GRCA for the Grand River Watershed (Holysh et al., 2000) can be used as an example.

Finally, the public must be educated about the importance of groundwater protection. Readable and easily understood publications are key components of this public education (see for example EPA, 1990; New Brunswick, 2000). Funding for public information programs should be provided.

Question 7: What is the present state of the groundwater resources we wish to protect, and what existing or potential problems can be identified?

The state of our groundwater resources varies throughout the province. In general, the groundwater in deeper aquifers that have good protection by overlying aquitards is of high quality, while the water in shallow aquifers exposed to the surface tends to be more affected by human activities.

The problem of legacy sources of contamination is a serious concern. These sources include, for example, old waste disposal or sanitary landfill sites, coal tar deposits remaining from early coal gasification plants (e.g. Kitchener), and chemical industry byproducts (e.g. Elmira). Hidden sources of this type can exist anywhere within the capture zone of a municipal well field and can pose a danger to the quality of the well water. It is imperative for the safety of the water supply that these sources of contamination be identified, characterized, and catalogued. The potential for contamination of such sites should be assessed and appropriate measures to mitigate the risk should be taken if possible. Remediation methodology has been the subject of intense research for the past 20 years and an extensive knowledge base exists (see for example Pankow and Cherry, 1996). For sources that cannot be remediated, a safe distance between the contaminant plume and any well capture zone must be maintained at all times. In some cases, existing wells may have to be decommissioned and moved to an appropriately protected area.

A further potentially serious problem is road salt contamination resulting from the 50-year history of road salting in Ontario. For example, some wells of the Regional Municipality of Waterloo are now showing increasing chloride concentrations, which are attributable to road salting. As salt travels slowly through aquifers, large amounts of salt may be stored in a groundwater system before the impact on a well becomes apparent. Because overall salt use has increased in recent years due to increased urbanization and an increased emphasis on road safety, the real impact on the groundwater is yet to come. Fundamental research into this problem is necessary to avoid larger problems in the future. Unfortunately, research is hampered by the lack of records of salt use during years of haphazard application.

Within the rural environment, impacts on groundwater quality in both private farm wells and in urban wells located in a rural setting have been documented in various locations throughout Ontario. Primary contaminant species include nitrates and bacteria, and to a lesser degree, common pesticides. In an Ontario-wide survey of farm drinking water wells, Goss et al. (1998) observed that approximately one third of all wells tested exceed the current Ontario Drinking Water Guidelines for at least one contaminant species. The occurrence of contamination decreased significantly with well depth. The large production wells for the Cities of Baden, Woodstock and Walkerton in southern Ontario have had water quality impacts presumed to be the result of extensive agricultural activities in the vicinity of the well fields. Research programs related to the environmental impacts of agricultural operations on water resources in rural areas are presently underway in Ontario and throughout Canada.

The impact of urbanization on aquifers is another concern. The suburbs of our cities are now rapidly spreading into rural areas, where aquifers and recharge areas are not always protected adequately. For example, paving over an important aquifer recharge area can seriously affect the quantity and quality of the recharge reaching the aquifer, thus permanently impacting its value as a resource. Fundamental research into this problem is necessary, and the establishment of land-use standards for areas that are potential water sources should be a matter of high priority.

Question 8: What specific legal powers would be necessary to restrict or control the discharge of potentially harmful substances into the ground within a groundwater protection zone?

The Canadian Environmental Law Association (CELA) is presently preparing a comprehensive document for submission to the Walkerton Inquiry (CELA, 2001). This document provides a detailed legal background information and recommendations that will assist in developing a legislative structure for the protection of groundwater resources in the Province of Ontario. A proper legal framework for groundwater protection is essential for any protection measures to be effective.

Question 9: Which jurisdiction(s) should be responsible for groundwater protection in Ontario?

The Province of Ontario should be responsible and accountable for groundwater protection in Ontario. The issue of what ministry should be responsible for groundwater protection requires careful consideration.

Recently, the Ontario government has adopted a combined approach to discuss the main issues associated with water resource management. This initiative is referred to as the clustering of Ministries and has included the Ministry of the Environment (MOE), Ministry of Agriculture, Food and Rural Affairs (OMAFRA), Ministry of Natural Resources (MNR), and Ministry of Northern Development and Mines (MNDM). Each of these ministries has had certain jurisdiction over water resources in the Province in the past and has developed expertise in different areas. It would appear logical to capitalize on this combined expertise in the development and implementation of a groundwater protection policy for the Province. The most efficient approach may be to have one of the ministries take a lead role in the administration of the policy. Considering that MOE has likely been the most actively involved in the most diverse range of groundwater issues, it may be the logical choice as lead ministry. A recent report on new approaches to managing environmental problems also recommends a cross-ministry leadership role for the Ministry of the Environment (Executive Resource Group, 2001). The lead ministry or ministry cluster should be responsible for the overall program of groundwater management and protection, for setting standards, policies and regulations, for developing protocol for implementation, and for establishing rules for compliance. It should also take overall responsibility for the compatibility of municipal and rural groundwater protection programs.

At the local level, water providers such as municipalities, conservation authorities, and First Nations should be responsible for implementation, administration, compliance monitoring and enforcement of the standards, wherever possible. Where suitably trained staff are not available locally, the Provincial groundwater protection program should provide training and adequate funding to bring staff up to the required standards of competence. Alternatively, a Provincial ministry should take responsibility for local implementation and compliance monitoring. In any case, a clear line of responsibility and accountability should be established. Existing local groundwater protection programs should be taken into account. A procedure for handling appeals should also be provided.

The ministry or ministry cluster responsible for groundwater protection should initiate close liaison with the new Canadian Water Network (CWN) to ensure continuous access to the most current information on the management and protection of groundwater resources.

Question 10: What is the cost of groundwater protection compared to the cost of treatment?

The relative cost of groundwater protection versus treatment is site- and case-specific and will be difficult to estimate in a general way. The Regional Municipality of Waterloo, which made a substantial investment in groundwater protection studies, will be a good source of information and insight on this aspect.

On the other hand, the cost of *not* having groundwater protection is well known for cases such as Elmira and Walkerton. In addition to the cost of remediation of contaminated sites, there is the cost of alternative water supplies, the cost of replacement infrastructure (e.g. pipelines), and the cost of the inquiries that inevitably follow the more spectacular cases. Sometimes remediation is extremely difficult or impossible, and a legacy of a contaminated groundwater system remains (e.g. Elmira). Usually, the cost of effective remediation is far in excess of the cost of any pro-active protection, as noted by the Canadian Geoscience Council (1993). New Brunswick (2000) also makes a compelling case about the cost effectiveness of groundwater protection. There are also intangibles such as the loss of public confidence in the water supply system, and the wider impact on the economy in the form of lost business. As suggested by recent events, these costs may be much higher than the costs associated with a protective infrastructure. On this basis, protection is clearly the more efficient way to provide safe drinking water.

Question 11: What additional data and research needs can be identified?

Groundwater science is a continually evolving discipline. While information and understanding at the level needed to launch a provincial groundwater protection program are available now, more advances will continue to be made. Some specific topics where more information-gathering and research will be useful are:

- *Aquifer mapping.* Present initiatives for the mapping and inventorying of aquifers should be strengthened and accelerated if possible. The objective should be a complete system of aquifer maps for the Province.

- *Aquitard mapping.* The inventory of groundwater resources must also include aquitards. Characteristics that enhance or diminish the protective capacity of aquitards, such as continuity, windows, fracturing, and the parameters controlling matrix diffusion, are important.

- *Groundwater quality information.* Water quality data need 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 an improved basis for decision-making.

- *Karst aquifers.* Although suitable models have been developed, data needed for characterizing karst aquifers, and for predicting flow and transport in these aquifers, are still scarce. Field experiments using tracers and other means are needed to provide a useful database.

- *Fate and transport of bacteria and viruses.* The standard assumption is that advective transport is the process controlling the migration of bacteria and viruses in the groundwater. While this approach is adequate for the establishment of initial wellhead protection zones, more refined approaches may be desirable in the future. More research is needed into the life expectancy of the various types of bacteria and viruses in typical groundwater environments.

- *Aquifer vulnerability.* As an improvement over existing qualitative approaches for defining aquifer vulnerability, quantitative methods for defining vulnerability should be developed. These methodologies should be easy to apply to specific sites, and account for protective barriers as well as transport and attenuating processes such as dilution and degradation.

- *Risk assessment tools.* Risk assessment methodologies that allow the quantification of risk (i.e. the probability of contaminant concentrations at a well exceeding drinking water standards) as a function of the uncertainties in the hydrogeologic system parameters should be developed. A risk-based approach may be seen as a possible future enhancement for existing groundwater protection methodologies.

6. Framework for Standards and Policy for Groundwater Protection in the Province of Ontario

The Workshop considered a possible framework document for Groundwater Resource

Protection which could serve as a starting point for the development of consistent standards and policy for maintaining the safety of drinking water in Ontario. The overall policy should combine existing legislation, policy and guidelines into a single integrated whole. A Task Force of experts from the scientific, planning, managerial, legal, and consulting professions should be formed and charged with working out the details of the required standards and policy. We believe that a comprehensive framework is necessary in order to avoid continued fragmentation of the responsibility for groundwater protection between different Ministries and different jurisdictions.

Once the policy is established, a standing Review Committee for standards and policy should be formed to ensure that the policy is continually updated as required in order to incorporate the results of relevant new research, data, and practical experience.

A Draft Table of Contents for this document, listing the main components that should be addressed, is given in Appendix A. Further items may be added as required.

7. Conclusions

The Walkerton crisis has made it clear that Ontario is in urgent need of a groundwater protection strategy. While other countries, as well as some Canadian Provinces, have moved ahead, Ontario is still lacking effective and consistent standards for groundwater protection, and the Province's enforcement of existing water policy is fragmented. The lack of standards and enforcement can be seen as one of the underlying causes of the Walkerton tragedy. Some Ontario municipalities have already made advances in the formulation of their own groundwater protection programs; however, the lack of consistent province-wide standards and the absence of legislative tools available to municipalities have been serious impediments to effective local implementation and enforcement.

The Workshop concluded that sufficient data are available to initiate a systematic and comprehensive program of groundwater protection for Ontario in a step-by-step fashion. For areas where data are scarce, the groundwater protection program should provide the impetus needed to expand and complete the database. Various initiatives are already underway at the national, provincial, and local levels to upgrade the database and to map groundwater resources. Scientific and technical tools including mathematical models are at a reasonably mature stage, and expertise capable of using these tools is available in Ontario and throughout Canada. Thus the question *"Do we have enough knowledge and information to give our groundwater resource an effective legal protection?"* can be answered in the affirmative.

We propose that the Walkerton momentum be used for a major initiative to put groundwater protection in Ontario on a sound footing. Although not all the pieces may be in place with complete perfection, it is time to move ahead to ensure safe drinking water for present and future generations of Ontario's residents. Further delays, in the present environment of rapid growth and increasing demands on our water resources, will likely risk more tragedies such as Walkerton.

This initiative will create consistent standards and an effective policy for the protection of groundwater resources in Ontario. These standards and policy should be:

- effective and enforceable,
- flexible to incorporate existing local initiatives, and adapt to future conditions and refined technical understanding,
- transparent and easily understood,
- generally acceptable to stakeholders,
- environmentally sustainable.

The formation of a Task Force that will develop a detailed document for groundwater protection standards and policy in Ontario will be the first step. The policy should merge the requirements of municipal and rural groundwater protection within an overall framework of groundwater management, covering both quantity and quality of the water resource. The overriding objective of environmental protection should be recognized.

This initiative will require a sustained effort by the Province, the municipalities, water providers, agricultural and conservation organizations, and the scientific community. Most importantly, it will require adequate funding to hire sufficiently skilled hydrogeologists into key positions in the leading organizations that will be responsible for setting standards, and to provide training for staff in organizations placed in charge of implementation and enforcement. This unavoidable cost represents an ongoing investment that will pay for itself in the form of a safe and reliable source of drinking water for present and future generations.

8. Recommendations

The Workshop recommends:

Recommendation 1: That a detailed framework of standards and policy for groundwater protection for the Province of Ontario be developed.

The issue of groundwater protection should be considered within a comprehensive framework of groundwater management including both quantity and quality. The Table of Contents laid out in the Workshop Report (Appendix A) will be a suitable starting point for this framework. The overall objective should be the protection of groundwater as a safe source of drinking water, as a reliable resource for municipal and rural/agricultural uses, and as a vital component of a healthy ecosystem. Existing standards should be incorporated as far as possible. The framework should cover, but not be limited to, the following topics:

Standards:

- technical standards for defining groundwater protection zones, vulnerability, risk
- drinking water quality standards (existing)
- experimental standards
- reporting standards
- review standards

- competence standards for implementing agencies

Guidelines/Policies:

- land-use guidelines for high-risk areas
- implementation policy
- compliance policy

Training, public awareness:

- training of municipal staff charged with implementation
- involvement of community groups

Funding objectives:

- research
- data collection
- local incentives
- implementation
- compliance monitoring

Recommendation 2: That a Task Force be appointed by the Province of Ontario and charged with developing this detailed framework.

The Task Force should have representatives from:

- Municipalities
- Agricultural organizations
- Industrial organizations
- Conservation authorities
- Universities
- Environmental organizations
- Groundwater professionals

Recommendation 3: That these groundwater protection standards and policy be subject to periodic review, and that a Standing Review Committee be created for this purpose.

> Periodic reviews are necessary to keep abreast of new developments and insights, and an expanding database.

Recommendation 4: That the groundwater protection standards and policy described by the above framework be passed into legislation.

> The establishment of a legal basis is necessary for groundwater protection to be effective.

Recommendation 5: That implementation of these standards and policy within the Province be carried out in a step-by-step manner established in consultation with communities.

> A clear line of responsibility for implementation should be defined. Wherever possible, local water providers, including municipalities, conservation authorities, and First Nations should be responsible for implementation, compliance monitoring and enforcement, in accordance with Provincial standards. Appropriate incentives and funding for the training of staff should be provided. Existing local groundwater protection programs should be taken into account.

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Appendix A: Standards and Policy for Groundwater Protection in the Province of Ontario; Draft Table of Contents

1. Introduction
    - definitions of terms: groundwater protection, protection zones, risk, vulnerability, etc.
    - review of existing policies and guidelines at various jurisdictions in Ontario
    - objectives
    - procedure for integrating existing policies into new framework

2. Groundwater Protection for Municipal Water Supply
    - general standards for groundwater protection:
        - groundwater protection zones (extent and vulnerability)
        - well construction guidelines
        - drinking water standards (existing)
        - list of potentially harmful contaminants
        - list of potentially contaminating activities
        - documentation of legacy sources of contamination
    - procedures for developing protection strategies for individual sites:
        - characterization of water sources
        - characterization of existing potential contamination sources
        - characterization of legacy contamination sources
        - control of de-icers on highways and roads
        - development of strategies:
            - delineate wellhead protection areas, map vulnerability
            - develop land-use guidelines
            - identify, review, and update relevant Best Management Practices

3. Groundwater Protection for the Rural Environment

- aquifer/aquitard mapping
- agricultural activities: coordinate with Environmental Farm Plan
- identify, review, and update Best Management Practices
- use and storage of fuels, pesticides
- septic systems
- farm wells: enforcement of existing regulations (location, construction, abandonment)
- review procedure for water-taking permits for large users
- quarries, mines (impact on groundwater quantity and quality)

4. Groundwater Protection for a Healthy Ecosystem
   - system water balances
   - control of cumulative water takings to stay within safe capacity
   - maintenance of baseflow and wetland habitat
   - resolution of competitive demands/requirements

5. Implementation
   - establishment of priorities (watersheds within the Province)
   - review of existing local protection programs
   - assessment of local competence (staff)
   - assignment of responsibility for implementation

6. Incentives, Support, Training
   - education and training programs for staff
   - rural compliance incentives
   - industrial compliance incentives
   - incentives review process by Auditor General

7. Monitoring and Maintenance
   - develop monitoring plan (production and monitoring wells)
   - response protocol

- monitor land-use changes
- well inspections and infrastructure updates
- reporting mechanism

8. Data Collection and Management
    - well drilling, borehole logging, sampling of groundwater and streams, climate records
    - protocol and data format
    - delivery to central database

9. Governance and enforcement
    - provincial mandate (MOE, OMAFRA, MNR, MNDM) for standards and policy
    - allocation of policy delivery power and implementation to municipalities
    - structure of audit and compliance approach
    - consequence of non-compliance

10. Standards and Policy Review
    - role of standing committee for standards and policy review
    - aspects subject to periodic review:
        - protection areas
        - risk substances, activities
        - land-use guidelines
        - legacy sources
    - mechanism for policy updates
    - implementation of standards/policy revisions

Appendix B: Definitions

Aquifer: A geologic unit capable of storing and conducting water in sufficient quantities to allow viable extraction. Aquifers can consist of porous material of relatively high hydraulic conductivity (sand, gravel), or fractured/karstic rock.

Aquitard: A geologic unit that can store water but does not conduct water in quantities that would allow viable extraction for water supply purposes. Aquitards can consist of porous material of relatively low hydraulic conductivity (clay, till), or mainly unfractured rock. Aquitards can provide natural protection to underlying aquifers against contamination. However, this natural protection can be compromised by fractures or permeable sediment features (windows) or other openings within the aquitard material.

Groundwater recharge: Recharge is defined as total precipitation minus evaporation/evapotranspiration and direct stream runoff, with the remaining amount being available to recharge aquifers. The distribution of recharge to the various aquifers is controlled by the hydrogeology. Groundwater recharge occurs over all areas of a watershed except in discharge zones very close to streams, wetlands, and springs. All topographically high areas within a watershed are potential recharge zones; however, recharge zones are not necessarily limited to topographic highs.

Well capture zone: The zone within which the water that is pumped from a well originates. A well capture zone depends on the hydrogeology, the flow system, the recharge, the pumping rate, and the depth of the well screen. Delineation generally requires use of a groundwater model. A shallow well in a watertable aquifer will usually have a relatively small capture zone, while a deep well, which draws water from a larger area, will have a larger capture zone.

Aquifer vulnerability: Vulnerability is a measure of the natural protection an aquifer has in the form of overlying layers with low permeability (aquitards), and the capacity of the aquifer to assimilate contaminants through dilution and/or degradation. The effect of the unsaturated zone can also be taken into account. Fractures or other openings in an overlying aquitard could negate the protective effect and increase vulnerability. Vulnerability is usually expressed in a qualitative way (i.e. high/low, or by means of numbers on a scale), and mapped in the form of vulnerability maps. In general, a watertable aquifer may have a higher vulnerability than a deep confined aquifer. On the other hand, a thick watertable aquifer with high assimilative capacity could have a lower vulnerability than a thin confined aquifer overlain by a thin fractured aquitard.

Aquifer sensitivity: Sensitivity can be defined as the ability of the aquifer to transport pathogens rapidly for long distances in the absence of a hydrogeologic barrier (U.S. EPA definition). Karst, fractured rock, and gravel aquifers are considered to be sensitive. To meet the requirements of a hydrogeologic sensitivity assessment according to EPA standards, it is sufficient to identify the type of aquifer as one of the three types considered sensitive. Alternatively, sensitivity has been defined as a planning term which includes the value of the infrastructure in place at a particular location (RMOW definition), in addition to the geologic and hydrogeologic factors.

Wellhead (well field) protection area: The area around a well or well field within which groundwater protection measures are to be applied. This zone is normally, but not always, part of a well capture zone. It is usually subdivided into different zones which may be defined in terms of travel time from a contaminant entry point to the well, corresponding to different types of contaminants. For example, the innermost zone (with respect to the well) may correspond to biological contaminants, the intermediate zone to degrading petroleum products, and the outermost zone to persistent chemicals. The outermost protection zone may correspond to the well capture zone. A wellhead protection zone can be delineated by approximate graphical methods, or more accurately by use of modelling.

Groundwater protection zone: A zone within which groundwater protection measures are applied. A groundwater protection zone is similar to a wellhead protection zone, but it may be associated with a sensitive aquatic environment such as a wetland, rather than a well.

Risk: In a general context, risk can be defined as the “probability of system failure”, or in a safety context as “the potential of loss or injury resulting from exposure to a hazard” (Whyte and Burton, 1980). In the context of groundwater protection, risk can be defined more specifically as “the probability of contaminant concentrations in the groundwater at a drinking water well exceeding drinking water quality standards”.

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