A Report of the Great Lakes Science Advisory Board
to the International Joint Commission

February 2010

GROUNDWATER IN THE GREAT LAKES BASIN

INTERNATIONAL JOINT COMMISSION
Canada and United States

COMMISSION MIXTE INTERNATIONALE
Canada et États-Unis

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Commissioners' Preface

The Great Lakes, which hold about 20 percent of the world's supply of fresh surface water, are one of the most recognizable sights in the world, but an important part of the region's huge water resources is hidden from view. Groundwater, the water stored underground in the cracks and spaces in soil, sand and rock throughout the Great Lakes basin, constitutes an immense unseen reservoir estimated to be equal in volume to Lake Michigan, which has some 4,920 cubic kilometres (1,180 cubic miles) of water.

Groundwater and surface water are inexorably linked in terms of both quantity and quality. For example, Annex 16, which was added to the Canada–United States Great Lakes Water Quality Agreement in 1987, acknowledges that contaminated groundwater affects the boundary waters of the Great Lakes System and specifies how the two countries should coordinate their existing programs to control this phenomenon.

Despite these connections, groundwater receives less attention in the Agreement than it should. Newer government programs for source water protection do include groundwater, but Annex 16 is the shortest annex in the Agreement. For this reason, in our 2006 advice to governments regarding their review of the Agreement, the Commissioners of the International Joint Commission (Commission) noted that groundwater is a larger input to the Great Lakes than previously recognized and recommended a number of actions for inclusion in a new or revised Agreement.[1]

The Commission's focus on groundwater is not new. We first adopted groundwater as a Great Lakes priority for the 1991-1993 biennial cycle.[2] A decade ago, in fulfilling a Reference from governments asking it to study and report on protecting the Great Lakes, the Commission devoted a section to groundwater.[3] Groundwater has also been addressed in a number of other reports to or by the Commission.

To a great extent, our 2006 recommendations to governments were influenced by the advice we received from our Great Lakes Science Advisory Board, Council of Great Lakes Research Managers and Health Professionals Task Force. Together these three advisory groups have produced a comprehensive report on groundwater in the Great Lakes basin. Their collaborative enterprise brought together different but complementary areas of expertise represented in our advisory groups, and also featured four separate consultations with other experts.

The result is this substantial document of 13 appendices covering issues that range from progress on understanding groundwater issues in the Great Lakes basin to threats to groundwater quality from a variety of sources. Actions needed on a priority basis include expanding research into the factors affecting groundwater quantity and quality; increasing monitoring and data management efforts; regulating land use, on-site wastewater treatment (septic) systems, concentrated animal feeding operations and abandoned wells; and providing financial support for remediating leaking underground storage tanks and sewers.

As recommended, the Commission will continue to monitor and report on the key issues identified in the report. We are confident that the information, analyses and recommendations in this report will be of immediate assistance to governments, environmental groups, industry and the public at large, and we expect that the findings and advice will also benefit those charged with negotiating changes to the Great Lakes Water Quality Agreement.

1 See *Advice to Governments on their Review of the Great Lakes Water Quality Agreement: A Special Report to the Governments of Canada and the United States*, International Joint Commission, 2006 at http://www.ijc.org/php/publications/pdf/ID1603.pdf.

2 See *Groundwater Contamination in the Great Lakes*, International Joint Commission 1993 at http://www.ijc.org/rel/pdf/gw-contamination-1993.pdf_

3 See *Protection of the Waters of the Great Lakes: Final Report to the Governments of Canada and the United States, 2000* at http://www.ijc.org/php/publications/pdf/ID1560.pdf

Groundwater in the Great Lakes Basin

The Commission's Investigations

The year 2007 marked the 20th anniversary of the incorporation of Annex 16 – Pollution from Contaminated Groundwater – into the Great Lakes Water Quality Agreement (GLWQA). Annex 16 focuses on the coordination of "existing programs to control contaminated groundwater affecting the boundary waters of the Great Lakes System."

The Commission adopted groundwater as a priority for its 1991-1993 biennial cycle. The resulting report, *Groundwater Contamination in the Great Lakes Basin*, published in 1993, focused heavily on the sources and extent of groundwater contamination in the basin and how such contamination might enter the Great Lakes.

For its 2005-2007 biennial cycle, the Commission again adopted groundwater as a priority, which has culminated in this stand-alone Commission report, *Groundwater in the Great Lakes Basin*, that contains findings and recommendations from the current effort. This report expands and updates the Commission's 1993 report as well as the Commission's 2000 report, *Protection of the Waters of the Great Lakes*. It also provides information about emerging groundwater issues and concerns, linkages with other Commission priorities (e.g., urbanization and pathogens) and implications regarding water quantity issues contained in the Great Lakes Charter Annex 2001.

The 2005-2007 groundwater priority, under the leadership of the Science Advisory Board (SAB), was a collaborative effort with the Council of Great Lakes Research Managers. As work plans were developed, it became clear that human health expertise also would be valuable. Therefore, the Health Professionals Task Force joined the collaboration. The Council and the Task Force respectively identified contractors to prepare scholarly reports on groundwater research needs and human health implications of groundwater-borne pathogens and contaminants. Their insight and the advice provided was considered and incorporated into this report.

The SAB, with advice and assistance from the Council and the Task Force, organized four expert consultations around the basin to learn about local and regional groundwater issues, policies, monitoring and innovative research. The consultations were held in Lansing, Michigan (March 2006), Syracuse, New York (June 2006), Milwaukee, Wisconsin (November 2006), and Chicago, Illinois (June 2007). A compact disk containing the presentations and the rapporteurs' notes was produced for each consultation and shared with participants and collaborators.

After the first consultation, it became clear that issues and concerns about groundwater in the Great Lakes Basin go far beyond the focus of Annex 16, that is, groundwater as a source of contaminants to the lakes. After the second consultation, the Commissioners specifically asked the collaborators for input, based on deliberations to that point, to assist in preparing Commission advice to the Parties regarding review of the Agreement. The co-chairs of the SAB subsequently sent a letter to the Commissioners (transmittal letter at the end of this section).

Study Findings

1. The Importance of Groundwater

Groundwater is important to both the quality and quantity of water in the Great Lakes. "The Great Lakes cannot be protected without protecting the groundwater resources in the Basin."

Groundwater is a significant source of water to the Great Lakes. It is estimated that there is as much groundwater in the Great Lakes Basin as there is surface water in Lake Michigan. The groundwater contribution to the Great Lakes tributaries ranges from 48% in the Lake Erie basin to 79% in the Lake Michigan basin.

Groundwater maintains stream flows and wetlands during dry periods, supporting significant ecosystem functions.

Groundwater is an important source of drinking water in the Great Lakes Basin. 8.2 million people, 82% of the rural population, rely on groundwater for their drinking water. Groundwater also provides 43% of agricultural water and 14% (and increasing) of industrial water in the basin.

2. Data Quality and Availability

Despite the development of new scientific tools, the funding, instrumentation and analytical capacity required to monitor basin groundwater quality and quantity has declined substantially in the last twenty years. Although modeling has improved and now offers impressive capability to inform decision makers about groundwater quality and quantity, the erosion in the collection of baseline hydrogeological data precludes meaningful model calibration or application in many parts of the basin.

The most pressing scientific issues are:

- Better characterization of subsurface conditions, especially the hydraulic conductivity of geologic materials.
- Identification of aquifer boundaries.
- Estimation of recharge rates.
- The linking of data and models collected at different spatial scales.
- Ensuring uniformity of data records across jurisdictions, for example, through the adoption of uniform well-logging procedures and implementation of quality control protocols.
- Focused attention on areas of greatest hydrogeological uncertainty.

The following are some of the research, data collection and mapping programs being undertaken in basin jurisdictions:

- In 2000, Ontario restarted a province-wide 450-well monitoring program with costs shared between the provincial government and conservation authorities. With funding from a new carbon tax, Quebec in 2008 re-established its groundwater monitoring network.

- Michigan is now digitizing approximately 400,000 well logs. When completed, the data will greatly improve capacity to delineate aquifers and model groundwater processes. However, quality assurance and quality control issues persist.

- The United States Geological Survey (USGS) has embarked on a pilot study of water availability in the U.S. portion of the Great Lakes Basin (USGS, 2008). The study focuses on understanding the dynamics of water quantity in the basin, including flows and yields of both ground and surface water.

- The Geological Survey of Canada has developed an interactive Web-based geologic mapping tool that can be used for extensive characterization on a site-by-site basis. The tool also helps communicate findings to the public, by allowing a user to "see" aquifer prospects at specific sites. It has only been used on a limited basis. For the Oak Ridges Moraine area near Toronto (10,000 km2), geological content was collected over 10 years at a cost of $1 million per year.

- The USGS undertook detailed modeling of the groundwater system in southeastern Wisconsin, adjacent to Lake Michigan. Results established the major features of the groundwater system in the region and quantified the impact of municipal pumping from the complex system of aquifers in the area. Municipal pumping in this region of Wisconsin and Illinois has created a "world-class drawdown cone" in the sandstone aquifer, with water level declines of more than 250 m. Pumping has shifted the divide in the aquifer to the west, farther away from Lake Michigan, and also has caused some deterioration in water quality, particularly with respect to radium and radon concentrations. The USGS modeling will be used to help resolve water management issues there.

3. Groundwater Quality

Groundwater quality is generally very good but is threatened in many locations in the Great Lakes Basin. Groundwater contamination is a threat to the health of residents in the basin via their drinking water. Contaminated groundwater is also a source of surface water contamination.

Threats to groundwater quality come from point sources and non-point sources. These sources are generally localized but occur in all jurisdictions and affect the basin's water resources at a regional scale. These sources include: failing septic systems, leaking underground storage tanks, landfills, hazardous waste sites, abandoned wells, leaking sanitary sewers, confined animal feeding operations, land application of septage and manure, agricultural practices, spills, urbanization (atmospheric deposition, infiltration of vehicle fluids, de-icing practices), cemeteries, petroleum refineries and injection wells.

Specific threats to groundwater in the basin include: pathogens, nutrients, toxic chemicals (including chlorinated solvents, petroleum-based products, pesticides, metals, radionuclides), household products, hormones, antibiotics, pharmaceuticals and road salt.

Due to the vast number of sources and threats, it was necessary to limit the focus of our study. The issues in Appendices B through K were selected due to their pressing and substantial nature. The most significant ones are highlighted below, with the full reports in the appendices. Other activities affecting groundwater, including landfills, cemeteries and road kill carcass burial, airborne deposition, pit and quarry operations, water bottling operations and ethanol production should not be forgotten, and as more data are gathered could be the subject of future reports.

Significant Groundwater Quality Issues:

Viruses

There have been few studies on the presence of pathogens, particularly viruses, in basin groundwater. Viruses are common in groundwater, even groundwater from deep confined aquifers, and studies show a relationship between groundwater contamination and human disease (See Appendix B). Viruses travel farther and survive longer than bacteria in groundwater because of their small size and because they have the same electrical charge as soil and rock particles.

Overall, 90% of water-borne pathogenic disease outbreaks are attributable to water systems supplied from groundwater, and more than half of these water-related illnesses may be due to viruses. The primary source of disease-causing viruses is human fecal waste from malfunctioning septic tank and seepage bed systems and leaking sanitary sewers. Studies have correlated the occurrence of waterborne viral disease to the density of septic systems. One study of the causes of diarrhea in children under age five in central Wisconsin found that more than 20% of cases were due to contamination of well water from failed septic systems. A critical observation is that the usual measures of sanitary quality based on bacteria do not correlate with viral contamination.

On-site treatment systems are discussed further below and in Appendix D.

Nutrients and Pesticides

Fertilizer use is concentrated in corn-belt states and has dramatically increased over the last 50 years, especially the application of nitrogen in both urban and agricultural settings (see Appendix C). In the 1950s and again in the early 1990s, Ontario conducted water well surveys. The surveys found that 14% of the wells consistently exceeded nitrogen standards for both time periods and that, while 15% were high for bacteria in the 1950s, 34% were high in the 1990s. Another growing concern is soluble reactive phosphate from the escalating use of manure fertilizer. Inappropriate manure land spreading practices is a contributing factor. Further, escalating demand for ethanol may lead to increased corn cropland and consequent increased fertilizer and pesticide use. Also of concern is atmospheric deposition of nitrogen in the Great Lakes Basin.

The corn belt is a prime locale for pesticide application. Any pesticide use data – urban and rural – are often difficult to obtain, and different data sources sometimes are at odds. Rarely do such data sets measure actual application; rather, the assumption is that label rates are applied.

Tile drains, common in agricultural fields, are essentially "horizontal wells" that are subsidized by most jurisdictions in the basin. Most tiling is concentrated in Ohio, Ontario, Indiana and Illinois. Tile drains intercept water in the vadose zone and transport it to surface water systems. Therefore, less water is available for groundwater recharge. Tiling also facilitates mineralization, hence mobility, of nitrogen and phosphorus. Nevertheless, not much data are available.

On-Site Treatment of Human Waste

Inappropriate septage practices are of concern (See Appendix D). Many rural communities rely on aging individual septic systems or drain tile networks that discharge sewage directly to surface waters, even though direct discharge of untreated sewage is illegal. According to the Minnesota Pollution Control Agency, there are an estimated 64,000 septic systems posing an imminent threat to public health in the state. They estimate that it will cost $1.2 billion to fix all the septic system problems in Minnesota.

On-site septic treatment of sanitary wastes is proliferating throughout the basin – serving more than 50% of new housing in some areas – even though at least 20% of existing systems fail to treat wastes adequately. Leaky sewer and waterlines are of concern – 30% conveyance loss is common, and thousands of line breaks occur in the basin every year. Few jurisdictions monitor or regulate these systems in any systematic way. In the United States, water supply regulations exempt groundwater from disinfection requirements that apply to surface water. In Ontario, lenders are increasingly requiring home buyers to certify wells and wastewater systems. Also, following a serious water-borne disease outbreak at Walkerton, Ontario adopted requirements for permitting groundwater withdrawals and mediating groundwater disputes.

Approximately 25,000 new or replacement on-site systems (OSSs) are installed annually in Ontario with similar numbers installed in each of the Great Lakes states each year. There has been little research to understand the extent of effects of OSSs on groundwater but, in addition to bacteria, viruses and nutrients, pharmaceuticals, personal care products and nanomaterials are a growing concern. Although there are 1.4 million OSSs in Michigan, there is no statewide on-site system code. Most jurisdictions do not compile information on new or existing systems.

Systems have a 30-year lifespan due to hardware issues and soil saturation; 50% of the OSSs in the United States are older than 30 years.

OSS regulatory programs are in transition due to aging systems and development of new technologies. Generally, jurisdictions are moving from design-based permitting (assumed gravity-fed system) to performance standards. About 5% of new systems in the basin use "advanced" technologies that include pre-treatment prior to release to soil, but these systems have more "moving parts" and therefore require regular maintenance. By comparison, in Texas, due to stringent OSS regulations, 50% of newly installed systems are "advanced" types.

In Ontario, since 1997, small systems (<10,000 litres per day) have been regulated by the Ministry of Municipal Affairs and Housing. Septic permits are issued alongside building permits, and minimum lot size standards have been implemented. However, emphasis is on public safety rather than public health or environmental protection, that is, to prevent surface breakouts. Local municipalities are in charge of administration but implementation is highly variable across the province, and there is little enforcement or follow-up.

Leaking Underground Storage Tanks

Leaking underground storage tanks (LUSTs) are a serious concern to groundwater quality in the basin (see Appendix E). Although an accurate measure of total USTs in the United States and Canada is currently unknown, estimates place the number, for both countries combined, in the millions. Many USTs are known to be leaking or have leaked at some point in the past. USTs frequently contain potentially dangerous and toxic substances including, but not limited to, oil, gasoline, diesel fuel, aviation fuel, other petroleum products, solvents and waste/spent fluids.

Every year hundreds of new LUST sites are discovered in both countries. Currently, the estimated United States national total of LUSTs backlogged for remediation is about 114,000; this number, however, only takes into account the known, 2.3 million USTs which are subject to federal regulations. Other sources indicate that there may be an additional 3.8 million non-federally regulated and orphan USTs in the United States.

The U.S. federal Lust Trust Fund, established in 1986, provides a subsidy to regulate the actions of tank owners and operators and to clean up contaminated soil and groundwater. The fund is financed through a 0.1 cent per gallon tax on the sale of motor fuel. Fund assets are currently in excess of $2.6 billion. Although total revenue to the fund in 2005 was $269 million, only $59 million was distributed among the 50 states and the District of Columbia.

Clean-up at one LUST site, a gasoline station in Utica, New York, cost over $2 million, which was equivalent to the total received by the state for its entire LUST program from the fund in 2006. In the Great Lake states, estimates of funding for necessary LUST remediation are over $3.3 billion. Effective 2007, New York state authorities are now able to prevent deliveries to gasoline stations with known LUSTs. Ontario municipal officials have similar authority.

There are approximately 3,800 gasoline stations operating in Ontario, each with several USTs. Accurate numbers are not presently available for the total number of commercial, residential, institutional and agricultural USTs in the province. However, recent assessments lead to a conservative estimate of at least 10,000 commercial USTs. Based on previous estimates that 5% to 35% of all tanks are leaking, it is believed that 500 to 3,500 are. Estimates to clean up LUST sites in Ontario are therefore pegged at between $73.5 and $514.5 million.

The significant frequency of spills and leaks from home and cottage heating oil tanks is another threat to groundwater quality; however, such tanks fall below regulatory volume limits. Petroleum refineries also are a significant source of groundwater contamination. At Whiting, Indiana, in the Grand Calumet Area of Concern, an estimated 60 million litres of petroleum light non-aqueous phase liquids are floating atop the water table.

Hazardous Waste Sites

There are more than 4,500 hazardous waste sites in the basin and additional sites are still being discovered. The full extent of the threat of these sites to groundwater and Great Lakes water quality is unknown, but there is significant potential for contamination. Remediation has been undertaken in many locations, but because of high cost and technical difficulties, there is a large backlog of sites awaiting remediation.

In the Niagara region, extensive remediation work has been undertaken, but contaminated groundwater continues to pollute the Niagara River and Lake Ontario. Biomonitoring for contaminants discharging to the Niagara River began in 1975 (see Appendix F). Caged mussels, placed above and below targets, effectively detect sources and discharges of organic contaminants. Due to funding constraints, surveys are only run every two to three years at 30 to 35 sites and then only for three weeks at each site.

A large number of chemical sources remain along the Niagara River. As part of the Niagara River Toxics Management Plan, upstream and downstream monitoring is conducted to calculate a mass balance for the river. Monitoring is complicated by sediment movement and volatilization of substances as they flow over Niagara Falls. However, contaminant levels appear to be declining in Lake Erie, but contributions from groundwater discharges in the Niagara region do not appear to be decreasing.
Also as part of the Plan, annual reporting on the loading of 18 priority toxic chemicals has been underway since 1998. Toxic loads were reduced by 93% from 1989 levels for 19 sites with remedial costs to date of $406 million. Estimates of future costs are $270 million. However, the quality of the original baseline study is uncertain, subsequent studies were limited or highly debated and some findings were never released. Further, calculations are based not on actual measurements but on actions taken. In addition, many significantly contaminated sites in the area are not being addressed.

The objective at these sites is not remediation but containment to prevent loadings to the river. Since there is no available remediation technology, 26 Superfund sites near Niagara Falls, New York, will undergo "pump and treat" groundwater "intervention" in perpetuity.

Abandoned Wells
Abandoned wells in the Great Lakes Basin range from small-diameter geotechnical test holes to intercontinental ballistic missile silos (see Appendix G). The Michigan Department of Environmental Quality estimates that there are two million abandoned wells in the state, and Ontario has about 500,000 abandoned oil and gas wells. Also, it is believed that there are thousands of 19th century abandoned wells in northwest and north central Ohio, within the Great Lakes Basin. In the late 1800s, exploratory oil drilling in northwest Ohio was rampant and uncontrolled. In some areas there was a drill hole every 100 metres, and few of them were plugged or abandoned properly. The potential for cross-contamination of aquifers and brine units in these areas is therefore very high, possibly affecting the water quality and conductance of surface streams. The lack of an inventory of wells and of mandatory reporting is problematic.

Through financial support of initiatives by local governments to plug abandoned wells, several jurisdictions have made significant progress to eliminate pathways for aquifer contamination as well as public safety hazards. Wisconsin's program has been especially aggressive and successful. Michigan has improved program implementation through the application of geographic information systems for well identification. The U.S. EPA has authorized states to use "set-aside" funds for this purpose.

Ontario jurisdictions offer various subsidies to decommission wells (up to 100%), improve wells and improve septic systems (up to $7,500). Ontario and Wisconsin are leaders in addressing potential environmental impacts, for example, on trout streams, from groundwater withdrawals.

Other Groundwater Quality Issues
The Appendices also address the following other groundwater quality concerns: de-icing compounds (Appendix H), confined animal feeding operations (Appendix I), conveyance losses from municipal infrastructure (Appendix J) and the Chateauguay Transboundary Aquifer (Appendix K).

4. Regulatory Issues and Groundwater Protection Initiatives

Appendix L addresses a number of regulatory issues relevant to groundwater quantity and quality. Regarding groundwater quantity, there is significant potential for conflicts between users, both locally and regionally. This is due to land use change from urbanization, climate change and increasing groundwater withdrawals in specific locations, for example, for water bottling, residential or agricultural use, or quarry dewatering. Groundwater withdrawals are regulated at the state and provincial level, but there is significant variation across the basin in how this is done. In half the jurisdictions, most withdrawals are not currently regulated. The state and provincial compact and agreement will require every jurisdiction to manage water withdrawals, including withdrawals of groundwater, in accordance with a minimum basin-wide standard, to ban diversions, to institute water conservation measures and to improve monitoring and data collection.

Groundwater quality is routinely monitored and regulated in all basin jurisdictions only when it is a public drinking water source. The U.S. EPA has promulgated the National Primary Drinking Water Regulation – The Ground Water Rule – to provide for increased protection against microbial pathogens in public water systems using groundwater sources. Full compliance is required by December 1, 2009. This rule establishes a risk-based approach to target drinking water systems that are susceptible to fecal contamination. Because of the findings discussed above about viruses, it is unclear whether the rule will fully protect human health.

Many sources of groundwater contamination are regulated, but there is significant variation among basin jurisdictions. The most urgent gaps in most jurisdictions are the failure to require septic system inspection and maintenance and the failure to ensure the proper decommissioning of abandoned wells.

"Point-of-sale" on-site wastewater system inspections are essential to any comprehensive management program, and they offer a key opportunity to inventory OSS locations. "Point-of-sale" on-site regulations are controversial. Mandatory inspection regulations provide only a snapshot of the system's condition on the date of inspection, and there is a continued shortage of qualified inspectors. Regulations have been embraced in Wisconsin but have been aggressively opposed in Michigan by Realtor associations, home and cottage owners and under-funded county health officials. The Ohio Department of Environmental Quality implemented an inspection program in 2003, but some jurisdictions in the state found that the hefty cost of replacing a failed septic system causes some residents to abandon their property, which is then repossessed by the lender and may sit vacant for long periods of time.

Door County, Wisconsin, on the peninsula separating Green Bay from Lake Michigan, has 14,000 septic tank systems and about 3,500 holding tanks. Recognizing the human health hazard posed by faulty septic systems and to protect groundwater, Door County enacted an ordinance requiring inspection of the wastewater system before sale of a property could be completed. The inspection requirement initially detected a high proportion of failing systems, and replacement was almost always required. County Realtors originally opposed the ordinance but now regard it as very effective. In 2004 the county expanded the program to include full inspection of all systems, which is expected to be completed in five years. Any system that fails must be replaced by the landowner. After inspection, whether the system has passed or been replaced, the landowner must follow the county's required maintenance schedule and keep records of the maintenance operations performed on the system.

Recommended Actions

The following recommended government actions are necessary to better characterize and understand groundwater, control known contamination sources, and restore and protect groundwater quality and quantity in the Great Lakes Basin. These recommended actions should be read in conjunction with recommendations previously made to the Commission in the Science Advisory Board's letter of July 31, 2006, regarding amendments to Annex 16 of the Great Lakes Water Quality Agreement that would recognize the importance of groundwater as a critical component of the overall aquatic ecosystem in the Great Lakes Basin, standardize mapping and monitoring and ensure regular reporting.

Research:

1. Federal, state and provincial governments should continue and expand research to provide a comprehensive basin-wide understanding of: hydrogeological conditions, groundwater discharge and recharge rates, the role of groundwater in ecosystem functioning and the effects of human-induced changes, including urbanization, climate change and tile drainage, on groundwater.

2. Provincial and state governments should support research to determine in the Great Lakes Basin: the nature and extent of pathogens, antibiotic resistant organisms and emerging chemicals in groundwater; the relative contributions of human and animal wastes to the outbreak of disease; and the extent of leaks from sanitary sewers. Governments also should ensure that research into other groundwater contaminants of concern is adequately supported. A comprehensive survey of underground storage tanks in Canada is needed.

Monitoring and Data Management:

3. Provincial and state governments should institute and expand monitoring of groundwater withdrawals, use, consumptive use and groundwater quality, including the presence of the full range of pathogens and emerging chemicals. They also should review the adequacy of groundwater monitoring around hazardous waste sites, landfills and underground storage tanks and implement additional monitoring as needed. In Canada, this effort could be based upon the existing provincial groundwater monitoring networks and also incorporate available data from municipal well monitoring and from domestic water well surveys.

4. Provincial and state governments should develop integrated, comprehensive databases of groundwater quality and quantity that incorporate data from these expanded monitoring programs as well as data from the monitoring of contaminated sites and source water protection programs. These databases should be publicly available. Among other uses, this will enable those who depend on well water for drinking water to determine appropriate monitoring for chemicals and pathogens in their individual wells.

Regulation and Enforcement:

5. State, provincial and local governments should adopt watershed-based planning and management that includes source water protection and the protection of groundwater resources even if not used as drinking water sources. Conservation measures should be incorporated into water withdrawal regulations.

6. State, provincial and local governments should develop and consistently enforce standards that ensure the adequacy of installation and maintenance of on-site wastewater treatment systems to prevent groundwater contamination by pathogens and chemicals. This could be done through requirements for periodic inspection and maintenance or for point-of-sale inspection and certification.

7. State and provincial governments should regulate confined animal feeding operations to ensure proper treatment of manure and application of methods to reduce run-off. These governments also should regulate carcass burial as well as land application of septage and manure.

8. State and provincial governments should develop and enforce abandoned well programs to avoid aquifer cross contamination and prevent the access of contaminated surface water to groundwater. Grants or incentive programs should be implemented to ensure maintenance and proper decommissioning of wells.

Financial support:

9. Federal, state and provincial governments should continue to fund the cleanup and remediation of hazardous waste sites and leaking storage tanks, the detection and replacement of leaking sewers and the adoption of best management practices for the storage and use of road salt. All governments should take efforts to minimize or prevent the generation of hazardous wastes and to develop and implement alternatives.

Role of the Commission:

10. The Commission should continue to monitor key issues identified in this report and the appendices affecting groundwater within the Basin, and report regularly on progress. The Parties should each designate a lead agency with responsibility for compiling and regularly reporting to the Commission on relevant research, monitoring and program information on these key groundwater issues.

Transmittal Letter

Groundwater/Annex16 Recommendations

July 31, 2006

To: IJC Commissioners

From: Michael Donahue, U.S. Co-Chair
Isobel Heathcote, Canadian Co-Chair
IJC Great Lakes Science Advisory Board

Subject: Groundwater/Annex 16 Recommendations

Introduction

The International Joint Commission is preparing advice to the Parties on future form and content of the Great Lakes Water Quality Agreement. Groundwater was one of the priority issues adopted by the Commission for the 2005-2007 biennial cycle, and the Great Lakes Science Advisory Board wishes to advise the Commission of its opinion concerning the attention given to groundwater in the redrafting of the Great Lakes Water Quality Agreement.

This letter presents a brief summary of information and analysis obtained to date by the SAB on groundwater issues in the Great Lakes Basin. Toward its objective of producing a *2007 Status of the Great Lakes Basin Groundwater Report*, an expansion and update to earlier IJC reports that have dealt with groundwater, the SAB has conducted two expert consultations on the topic: one in Lansing, Michigan, on March 8-9, 2006, and one in Syracuse, New York, on June 13-14, 2006. A third consultation is scheduled for November 3, 2006, in conjunction with SOLEC in Milwaukee, Wisconsin. The three consultations will form the basis of the report to be issued in 2007. The SAB has had only limited opportunity to review the results of the two consultations and anticipates that the third expert consultation will provide further findings about groundwater issues in the Great Lakes Basin. While the recommendations presented herein must be considered *preliminary*, there has been substantial agreement in the two consultations on the importance of, and challenges to, groundwater in relation to water quality in the Great Lakes Basin. It is on the basis of this consensus that the SAB offers preliminary recommendations.

Preliminary SAB Recommendations on Groundwater Issues

The following preliminary recommendations are, for the most part, a reinforcement of the content and direction of recommendations contained in previous advice offered to the IJC. The sources of that advice are outlined following the recommendations. The preliminary recommendations are limited to those the SAB believes are most relevant to the current review and possible revision of the Agreement, and particularly Annex 16 on groundwater:

1. Amend or extend Annex 16 in view of current scientific understandings, calling on the Parties to:

a. Recognize and reflect the relationship between the quantity and the quality of groundwater and the interactions between groundwater and surface water in respect to both quality and quantity.
b. Require systematic, ongoing, basin-scale collection of data following standardized protocols about quantity and quality trends in groundwater.
c. Maintain water budgets for the basin that include major groundwater withdrawals and consumptive uses, and provide frequent reports concerning trends.
d. Support research on spatial and temporal variation in recharge to groundwater, the status of groundwater resources and the role of groundwater recharge, storage and discharge in ecosystem functions of the basin.
e. Recognize the importance of groundwater as a source of drinking water in the basin and, therefore, the high priority that should be given to protection of groundwater through monitoring, wellhead protection, well registration and abandoned well closure programs to ensure protection of human health.
f. Develop funding sources to support groundwater monitoring, the continued operation of programs for the protection and remediation of groundwater, and research activities.

2. Implement concrete plans to meet Party commitments under Annex 16, including:

a. Designating lead agencies responsible for the implementation of Annex 16.
b. Producing a public agreement between the Parties' lead agencies for standardization of mapping, sampling and analytical protocols for use in monitoring contamination in groundwater of the Great Lakes Basin.
c. Based on these protocols, reporting at regular intervals on the sources and quantities of contaminants entering groundwater and the Great Lakes through groundwater.

Previous Advice to IJC on Groundwater Issues

Annex 16 of the GLWQA deals with groundwater. Both the SAB and others have provided advice previously to the Commission on Annex 16. The SAB has not formally reviewed, and therefore does not necessarily endorse, all such advice and associated recommendations, but we do feel it is important that the Commission refer to such advice when formulating the latest advice to the Parties. Following are some sources of previous advice we recommend be considered.

1993 Groundwater Report – (*Groundwater Contamination in the Great Lakes Basin*, IJC, 1993.) The Report concluded, in part, that:

- There is an immediate need to reduce the degree of uncertainty concerning the nature, extent and significance of groundwater contamination in the Great Lakes Ecosystem.
- Many land use practices pose a significant risk to groundwater quality and resources. These practices need to be further assessed and modified as appropriate. Examples include risks of groundwater contamination from underground storage tanks and on-site waste water systems.
- A number of management actions to protect groundwater quality and resources are to be encouraged. Included are the promulgation/implementation of effective well-head protection legislation in Great Lakes basin jurisdictions; and the regular inspection, maintenance and, where required, replacement of septic systems, especially those adjacent to surface water bodies and aquifers vulnerable to groundwater contaminations in the basin.

Protection of the Waters of the Great Lakes – Particularly Recommendation VII, which is specific to groundwater and Annex 16 (*Protection of the Waters of the Great Lakes*, IJC, February 2000.) The August 2004 IJC review of this recommendation (*Protection of the Waters of the Great Lakes*, IJC, August 2004) also should be considered. The SAB finds the following quote from that document captures many of the current issues with groundwater in the basin rather succinctly:

"The Commission observes that the *Boundary Waters Treaty* is silent regarding groundwater. However, apart from the fact that sometimes groundwater and surface water flows may be indistinguishable, the IJC can and has considered groundwater flows under References issued pursuant to Article IX of the treaty and can consider impacts on groundwater flows when deciding whether to approve applications for projects with trans-boundary effects pursuant to Articles III, IV and VIII of the treaty. *The Great Lakes Charter* and *Annex 2001* both define "waters of the Great Lakes basin" as including tributary groundwater that is within the *Charter* boundary. As such, it appears that any water management regime that is developed as a result of the *Annex 2001* process will be applied to both groundwater and surface water withdrawals within the *Charter* boundaries. The Commission cautions that because of the relatively poor state of scientific knowledge concerning the quality, quantity and flow of groundwater, that any regime should be flexible enough to accommodate improvements in that knowledge."

IJC/BEC Report – (*Reporting Under the GLWQA Summary Table*, BEC/IJC, May 2002.) Existing reporting under Annex 16 does not meet the Letter or the Spirit of the GLWQA. Currently no consolidated groundwater information is provided to the IJC, and the information that does exist is site-specific. The report recommended that the Parties should inventory potential sources of groundwater contamination, identify gaps and determine how best to report under this annex.

2003-2005 Priorities Report – As part of its activities during the previous biennium, and in anticipation of the possible review of the Agreement by the Parties, the SAB undertook a review of science and the Agreement. This activity is reported in the 2003-05 Priorities Report to the IJC. It contains one recommendation specific to groundwater that has undergone full review and is, therefore, endorsed by the SAB.

Annex 16 – This Annex needs to better reflect the linkage between groundwater quantity and quality, and water supply and in-stream conditions.

The title and the provisions of the Annex need to reflect the broader pollution prevention focus inherent in current source water protection policies and programs in both countries. Large-scale groundwater assessments should be undertaken beyond those indicated in Annex 16.

Conclusion

The SAB hopes these preliminary recommendations and highlighting of previous recommendations are helpful to the Commission in formulating its advice to the Parties on review of the Agreement. We would be happy to address any questions, comments or suggestions the Commission may have.

Michael Donahue — **U.S. Co-Chair**

Isobel Heathcote — **Canadian Co-Chair**

IJC Great Lakes Science Advisory Board

Acknowledgements, Activities and Meetings, Membership

The capacity of the Science Advisory Board to address priority issues and stay abreast of the latest scientific information is only possible through the dedication of its members, the involvement of the wider Great Lakes scientific community and the participation of interested citizens and agency officials. The Board also routinely seeks outside expert advice to ensure that the most current scientific understanding is available to inform proceedings. The Board wishes to express its gratitude and appreciation for the assistance that all these individuals have contributed.

March 8-9, 2006
Lansing, Michigan
Special Presenters
- Jim Nicholas: Hydrogeological Cycle/Consumptive Use Estimates
- Marc Hinton: Groundwater Recharge and Baseflow in the Basin
- Howard Reeves: Michigan Groundwater Monitoring/Mapping
- Deborah Conrod: Ontario Groundwater Monitoring and Mapping
- Bill Rustem: Michigan Groundwater Economics
- Joan Rose: Groundwater Pathogens
- Ric Falardeau: On-site Wastewater Systems
- James McEwan: Abandoned Wells
- Bill Kappel: New York, Niagara Hydrogeology
- Marcia Valiante: Ontario Groundwater Legislation
- Hugh Whiteley: Urban Groundwater Issues, Stormwater Ponds, Walkerton
- Noah Hall: U.S. Groundwater Policy/Programs and Annex 2001
- Emil Frind: Canadian Groundwater Research/ Modeling/Data Needs
- John Bartholic: U.S. Groundwater Research/ Modeling/Data Needs

June 13-14, 2006
Syracuse, New York
Special Presenters
- Pete Richards: Groundwater Nutrients and Pesticides
- Dave Eckhardt: Groundwater Pharmaceuticals/PCPs
- John St. Marseille: Groundwater Protection
- Doug Joy: On-Site Wastewater Systems
- Hugh Gorman: On-Site Wastewater System Regulations
- Miroslav Nastev: Chateaugay Binational Aquifer, Canada
- Rich Reynolds: Chateaugay Binational Aquifer, United States
- Matt Becker: Niagara, Hydrogeology/Superfund Sites
- Lisa Richman: Niagara River Monitoring/Caged Mussels
- David Sharpe: Canadian National Aquifer Mapping
- Brenda Lucas: Buried Treasure – Groundwater Permitting and Pricing
- Charles Lamontagne: Quebec Groundwater Programs
- Marie Pierre Dagenais: Quebec Groundwater Issues and Policies
- Richard Brazell: New York Groundwater Policies
- Mary Jane Conboy: Ontario Regulations, Abandoned Wells
- Kent Novakowski: Sustainable Wells
- Bill Kappel: Hydrogeology of the Onondaga Trough

November 3, 2006
Milwaukee, Wisconsin
Special Presenters
- Deborah Conrod: Ontario Provincial Groundwater Monitoring Network Program
- Norm Grannemann: Base Flow Due to Groundwater Discharge
- Daniel Feinstein: Groundwater and the Great Lakes Compact
- Mark Borchardt: Viruses in Groundwater and the Public Health Implications
- Chris Olson: Door County On-Site Wastewater System Inspections
- Joseph Janczy: New U.S. Groundwater Rule
- Tom Price and Kevin Shafer: Josey Heights and Walnut Way Neighborhoods

June 8, 2007
Chicago, Illinois
Special Presenters
- Kevin McCray and John Pitz: Groundwater Usage Trends and Forecasting
- Ken Howard: Urban Groundwater
- Steve Hollingshead: Groundwater and the Aggregate Industry
- Kelly Warner: Chemical Quality of United States Groundwater
- Dave Rudolph: Groundwater and Nutrients (Nitrates)
- Ken Bradbury: Aquifers and Viruses
- Kevin Wilson: Groundwater and Diversions
- Tim Morris: Groundwater Allocation in the Great Lakes Basin
- Phil Bus: Sustainable Municipal Groundwater Supply

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APPENDICES

Appendices A through L provide relevant technical and background information in support of the findings and advice presented in this report. These twelve appendices describe contaminants found in groundwater, contaminant sources and progress toward understanding groundwater in the Great Lakes Basin. They were prepared by knowledgeable experts and provided either directly to the Great Lakes Science Advisory Board or via various committees or groups of the International Joint Commission. Appendix M compiles acronyms used in all the appendices.

The appendices are:

A. **Progress on Understanding Groundwater Issues in the Great Lakes Basin**
A contribution by the Council of Great Lakes Research Managers.

B. **Threats to Groundwater Quality in the Great Lakes Basin – Pathogens**

C. **Threats to Groundwater Quality in the Great Lakes-St. Lawrence River Basin – Chemical Contaminants**
A contribution by the Health Professionals Task Force.

D. **Threats to Groundwater Quality in the Great Lakes Basin – On-Site Wastewater Treatment Systems, Septage and Sludge**

E. **Threats to Groundwater Quality in the Great Lakes Basin – Leaking Underground Storage Tanks**

F. **Threats to Groundwater Quality in the Great Lakes Basin – Hazardous Waste Sites**

G. **Threats to Groundwater Quality in the Great Lakes Basin – Abandoned Wells**

H. **Threats to Groundwater Quality in the Great Lakes Basin – De-icing Compounds**

I. **Threats to Groundwater Quality in the Great Lakes Basin – Confined Animal Feeding Operations**

J. **Threats to Groundwater Quality in the Great Lakes Basin – Conveyance Losses**

K. **Threats to Groundwater Quality in the Great Lakes Basin – The Châteauguay Transboundary Aquifer**

L. **Threats to Groundwater Quality in the Great Lakes Basin – Summary of Laws Affecting Groundwater in the Great Lakes Basin**

M. **List of Acronyms**

The Board thanks all who contributed valuable time and information.

Progress on Understanding Groundwater Issues in the Great Lakes Basin

A Contribution by the
Council of Great Lakes Research Managers

CONTENTS

INTRODUCTION

Groundwater, a major natural resource in the Great Lakes Basin, supplies drinking water for 8.2 million people in the basin, and many manufacturing processes and other industrial and agricultural applications use large amounts of groundwater. In addition to human uses, one of the most important functions of groundwater is to help maintain flow in streams, lakes and wetlands by slowly and consistently discharging water during periods of little or no rainfall. Discharge to streams during periods of no surface runoff is essential to support aquatic organisms, especially during periods of drought.

Although groundwater forms a large subsurface reservoir, the groundwater systems in the basin are not a vast pool of contiguous water. Rather, groundwater is contained in many different geologic units, each with its own distinct hydraulic properties. Some units are widely used aquifers that readily transmit water and yield large quantities of water to wells, while others are not commonly used but do yield moderate amounts of water. In some limited parts of the basin, little or no aquifer material exists. Issues generally involve the amount of groundwater available, the quality and/or the connection to an ecosystem (Grannemann, Hunt, Nicholas, Reilly and Winter, 2000).

The amount of groundwater available depends on many climatic and hydrogeologic factors. In confined aquifers, the effects of pumping are manifested rapidly. However, in unconfined or some semi-confined aquifer systems, because of its relatively slow movement, the effects of pumping groundwater in large quantities are manifested slowly. Years may pass before there are measurable effects in either the surface or groundwater systems.

Threats to both groundwater quality and quantity can come from human activities on the land surface, the effects of over-pumping or natural conditions underground. The quality can be altered by either point or non-point sources of contamination that enter from the land surface and infiltrate to the groundwater system. Some of the more common contaminants are hydrocarbons, solvents, pathogens, pesticides, herbicides and fertilizers. Groundwater quality also may be diminished by over-pumping, which may induce natural, but generally unwanted, chemical constituents into the fresh groundwater system. These constituents may include brine, arsenic and radium. Large-scale groundwater withdrawal also can redirect, or significantly reduce, the discharge of groundwater to streams, lakes and wetlands, thus depriving the surface water of a generally high-quality, constant temperature source of water. The resulting changes can alter the amount of surface water and also ecosystems that rely on groundwater discharge. The flow of many streams in the Great Lakes Basin, especially those in watersheds with highly porous soils, consists largely of groundwater discharge to the streams. Hence, a high percentage of water flowing to the Great Lakes consists of water that infiltrates the land surface, enters the groundwater system, flows underground for varying distances, discharges to a stream or lake and then continues its path to the Great Lakes as streamflow. Therefore, to be comprehensive, management strategies for protecting the quality of Great Lakes water must incorporate the groundwater flow component. In short, the Great Lakes cannot be protected without protecting the groundwater resources in the basin.

PURPOSE AND SCOPE

The importance of groundwater in the Great Lakes Basin is now more fully understood than in 2000 when the Council of Great Lakes Research Managers and the International Joint Commission decided to evaluate the status of groundwater resources in the basin. In the reports listed below, issued over the past several years, both the Commission and the Council have emphasized the need for research related to groundwater.

- *Protection of the Waters of the Great Lakes – Review of the Recommendations in the February 2000 Report*. Recommendation VII – Groundwater. International Joint Commission, August 31, 2004
- *Priorities 2001-2003. Priorities and Progress under the Great Lakes Water Quality Agreement*. Section 4.3.5 – The Effect on Ground Water. Council of Great Lakes Research Managers, September 2003
- *11th Biennial Report Great Lakes Water Quality*. Section 9. International Joint Commission, September 2002
- *Priorities 1999-2001. Priorities and Progress under the Great Lakes Water Quality Agreement*. Section 3.4 – Understanding the Interaction of Ground Water and Surface Water in the Great Lakes Basin. Council of Great Lakes Research Managers, September 2001
- *Protection of the Waters of the Great Lakes*. Recommendation VII. International Joint Commission, February 2000

The groundwater research recommendations in these reports emanate from many interrelated environmental issues including land-use change, source-water protection and the effects of water withdrawals and climate change on groundwater levels and quality. The recommendations include seven interrelated research topics:

- Mapping hydrogeological units to help identify the extent of aquifers and confining units.
- Systematic estimation of natural recharge of water to the groundwater system.
- Groundwater discharge to surface water as an important source of baseflow to streams, lakes and wetlands.
- The role of groundwater in supporting ecological systems.
- The effects of land-use change and population growth on groundwater availability and quality.
- Groundwater withdrawals near boundaries of hydrological basins.
- Estimates of the level and extent of consumptive use of groundwater.

The topics in this appendix on the status of groundwater research in the basin, as it relates to these seven topics, are grouped into two themes: description of natural systems and description of human impacts on natural systems. Most of the work reviewed deals with groundwater resources at the regional scale. Evaluation of groundwater issues is complicated by the fact that, generally, decisions about groundwater use are made at the local level (well field or drainage district), while the impacts and effects of those decisions are increasingly felt at the regional level. It is now recognized that the effects of many independent local management decisions have consequences on the basin's water resources at a much larger scale. This is probably the most profound change in the understanding of groundwater resource management since the Commission and the Council began evaluating groundwater resources.

Mapping Hydrogeological Units

Recent Research

Groundwater is present throughout the Great Lakes Basin, but the amount of water available from the groundwater system depends on the water-bearing characteristics of the rocks and sediments that contain the groundwater. Maps of the extent and hydraulic properties of these hydrogeological units are important ways to more completely understand the groundwater system. The largest portion of groundwater stored in the basin is contained in unconsolidated material deposited at or near the land surface as a result of large-scale glacial ice advances and retreats during the last two million years (Coon and Sheets, 2006). Glacial debris that was deposited directly from the glacial ice is composed of mixtures of clay, silt, sand, gravel and boulders, which generally are poor aquifers. However, glacial sediments that were deposited in streams whose flow originated as meltwater from the glacial ice are composed primarily of sand and gravel. These deposits generally constitute productive aquifers which form a near-surface aquifer system that is present in much of the basin. Although discontinuous, "their ubiquity has a regional effect on groundwater resources and, therefore, allows them to collectively be treated as a regional system" (Coon and Sheets, 2006). As an aquifer system, the glacial deposits contain far more water in storage than any other regional aquifer system in the basin.

Because most of the basin's groundwater is stored in this aquifer and because more wells are drilled into it than any other geologic unit, the need to develop detailed, three-dimensional maps of the glacial deposits is increasingly important. Such maps have been compiled for a few areas such as near Toronto, Ontario (Sharpe, Russell and Logan, 2007), Berrien County, Michigan (Stone, 2001), and Lake County, Illinois (Stiff, Barnhardt, Hansel and Larson, 2005). Most of the mapping on the U.S. side of the border is done by the Geological Surveys of the eight Great Lakes states. In addition, the Central Great Lakes Geologic Mapping Coalition, formed by the state geological surveys of Illinois, Indiana, Michigan and Ohio and the U.S. Geological Survey (USGS) to produce detailed, 3-D geologic maps of surficial materials in the glaciated areas of these four states, is helping to coordinate consistent geologic mapping in the basin (USGS, 1999). These efforts complement other ongoing cooperative efforts among the state surveys and the USGS to produce detailed geologic maps of the glaciated portions of the Great Lakes region. An effort to coordinate mapping in Canada and the U.S. also has been proposed.

In addition to new geologic maps, other scientists have improved techniques to use publicly available well-log information to improve understanding of geology and hydraulic properties of commonly used aquifers (Groundwater Conservation Advisory Council, 2006). Because the quality of groundwater determines whether or not the water can be used for certain purposes, some work is now being undertaken to describe the quality of water from glacial deposits as part of the USGS's National Water-Quality Assessment Program (Warner and Arnold, 2005). More work on groundwater quality has been done at the local level without placing the results of water-quality studies into a broader context. As analyses of the effects of groundwater use on the regional scale become more common, water-quality analyses at the regional scale also will become more common.

Consolidated bedrock underlies the unconsolidated glacial deposits or outcrops at the surface throughout the basin. However, because not all the bedrock units store and transmit water readily, they are only considered aquifers in about half of the basin. The non-aquifer bedrock is only used for low-volume withdrawals when water from other sources is insufficient. Some bedrock aquifers in the region extend far beyond the watershed boundaries, thus requiring detailed information about the relation of groundwater flow inside and outside the basin. Although this relationship has been evaluated for a number of years, new information was published by Feinstein, Hart, Eaton, Krohelski and Bradbury (2004), and additional work is underway by the Southern Lake Michigan Regional Water Supply Consortium (2007) and the USGS (Grannemann and Reeves, 2005). A wide variety of sources, such as new maps and more complex evaluation of information from well logs, provides input for this work.

It is estimated that there is about the same volume of groundwater stored in the aquifers of the U.S. side of the basin as there is surface water in Lake Michigan (Coon and Sheets, 2006). This estimate is based on hydraulic properties of geologic units from existing studies of six regional aquifer systems in the basin. Because saline water underlies fresh water nearly everywhere in the basin, the estimate is delineated into fresh-water and saline-water components as indicated by Coon and Sheets: "Summation of the volumes in the many regional aquifers of the basin indicates that about 1,340 cubic miles of water is in storage; of this, about 984 cubic miles is considered fresh water (water with dissolved-solids concentration less than 1,000 mg/L)." This large amount of stored groundwater makes it important to comprehensively evaluate groundwater as one of the region's most valuable resources.

Recommended Future Research

Geologic and hydrogeologic mapping of principal aquifers needs to continue to determine regional variability of rocks and glacial deposits as well as the hydraulic properties of these aquifers and confining units. Mapping will help determine the local and regional impacts of groundwater flow on surface water bodies and the ecological implications of changes in groundwater input to streams. Specifically, previous work on geologic mapping of glacial deposits by the state and provincial surveys in conjunction with the Geological Survey of Canada and USGS needs to be enhanced.

Estimation of Natural Groundwater Recharge

Recent Research

Better estimates of the rates of groundwater recharge are needed in order to understand the importance of groundwater resources in the basin. Several estimates of groundwater recharge in parts of the basin have been reported (Holtschlag, 1996; Cherkhauer, 2001; Dumouchelle and Schiefer, 2002; Wolock, 2003; Gebert, Radloff, Considine and Kennedy, 2007; Delin and Risser, 2007; Delin, Healy, Lorenz and Nimmo, 2007. From a basinwide perspective, however, the first known integrated study of long-term average groundwater recharge to shallow aquifers on both the Canadian and U.S. portions of the basin was presented by Neff, Piggott and Sheets (2005), who used streamflow separation and assumed that baseflow of a stream originated as groundwater recharge. By using empirical relations between baseflow characteristics and surficial geologic materials, they concluded that the highest shallow groundwater recharge rates occurred in snow shadow areas east and southeast of each Great Lake. The lowest recharge rates occurred in the eastern Lower Peninsula of Michigan, southwest of Green Bay, near the southwestern shore of Lake Erie, in portions of southeast Ontario and west of Toronto (Neff et al., 2005). Methods to estimate recharge rates are summarized in Delin and Risser (2007).

Recommended Future Research

Neff et al. (2005) suggested that alternative methods that do not rely on indirect estimation of recharge by baseflow analysis could be used to determine the spatial and temporal scale of recharge. Gebert et al. (2007) used some of these alternative methods on a smaller sub-basin scale; these could be transferred to the larger, basin-wide scale. Long-term effects of anthropogenic activities and global climate change on recharge also could be investigated. Using precipitation as input for recharge estimates will make the predicted rates of recharge under climate change more reliable than using baseflow as input.

The relations between groundwater recharge and development (both urban and agricultural) also need to be researched more thoroughly. Urban development covers part of the land surface with pavement and building materials that may cause less water from precipitation to infiltrate the land surface and recharge the groundwater system. Similarly, the effects of tile drainage on recharge in agricultural areas also need to be more thoroughly researched. Studies to quantify the effects of development on recharge have not been conducted other than a few studies that show the effects of urban and agricultural development on baseflow of streams.

Groundwater Discharge to Surface Water

Recent Research

Streams interact with groundwater in three ways: They gain water from inflow of groundwater through the streambed, they lose water to groundwater by outflow through the streambed, and both, gaining in some reaches and losing in others (Winter, Harvey, Franke and Alley, 1998). In the humid Great Lakes Basin, many more streams gain water from groundwater discharge than lose water. In recent years, the relation between groundwater flow and stream flow has been more carefully determined mainly by using various baseflow separation techniques and groundwater flow models. Holtschlag and Nicholas (1998) published a spatially limited baseflow separation study which covered approximately 14% of the basin. A more comprehensive basinwide analysis of baseflow was published by Neff, Day, Piggott and Fuller (2005), which incorporated analysis of baseflow on both the U.S. and Canadian sides of the border. Groundwater issues in the region are related to the fact that the international border runs through the Great Lakes. Therefore, exploitative use of groundwater on one side of the border automatically has effects on the other side because it changes the amount of water flowing to the Great Lakes. At this time, groundwater withdrawals have not had any measurable impact on Great Lakes water levels.

Groundwater discharge to streams can be better understood if the changes in stream flow over longer intervals are better known. To help interpret long-term changes, Hodgkins, Dudley and Aichele (2007) analyzed both the mean annual and the 7-day low-flow runoff in the basin. These two summary statistics are related to the changes in groundwater discharge to streams. Using a network of stream flow gages with long-term records that are not substantially affected by regulation, Hodgkins et al. (2007) determined that mean annual runoff increased by 2.6 inches from 1955 to 2004. The increases were fairly consistent throughout the basin, with the only decreases occurring in the western Upper Peninsula of Michigan and upper Wisconsin. Mean annual 7-day low-flow runoff also increased during this period by an average of 0.048 cubic feet per second per square mile. They also determined that precipitation in the basin was 10% lower for the period 1915-1935 than for the most recent 20 years of record analyzed. The long-term amount of precipitation is the most important factor controlling groundwater discharge to streams and needs to be better understood in order to evaluate the impact of development.

Recommended Future Research

Neff et al. (2005) recommended that long-term trend analysis of baseflow be done for the basin. This will help determine whether changes are happening in groundwater inflow to streams and provide monitoring strategies to track these changes. Some aspects of this work are being done by Hodgkins and others as part of a basinwide study of water availability and use (Grannemann and Reeves, 2005).

The Role of Groundwater in Supporting Ecological Systems

Recent Research

Groundwater is essential to maintain stream flow during periods of low or no precipitation as well as to maintain wetlands in many hydrologic settings. This relatively constant source of water is recognized as the most important factor to maintain ecosystem function in many streams and wetlands (Masterson and Portnoy, 2005). The availability of suitable thermal habitat for fish in streams is strongly related to the amount of groundwater discharged to a given stream segment. An assessment tool for estimating the impact of groundwater withdrawal on fish in Michigan streams is currently under development.

Recommended Future Research

The effects of groundwater withdrawal on the ecosystem function of streams are probably the most limiting factor associated with the use of groundwater in most of the Great Lakes Basin. Techniques to evaluate the effects of water withdrawal on fish should be further developed and expanded to incorporate more species. Water managers should coordinate these techniques among states and provinces so that common or complementary methods are used in all jurisdictions (Marbury and Kelly, 2009).

DESCRIPTION OF HUMAN IMPACTS ON NATURAL SYSTEMS

Effects of Land-Use Change and Population Growth on Groundwater Availability and Quality

Recent Research

The way land is used has the potential to affect both groundwater quality and quantity. Generally, population growth results in more demand for water. In areas where groundwater is the source for municipally supplied water, treated wastewater is discharged to surface water, which results in a redistribution of water from the groundwater system to the surface water system. Altered land use may directly influence the ability of precipitation to recharge shallow aquifers. Two examples are tile drainage in agricultural settings that may intercept water that could infiltrate to the water table, and urban development, such as paving roads and building structures that intercept precipitation causing more surface runoff that, subsequently, reduces groundwater recharge. These effects could manifest themselves as higher measured baseflow in streams and lower groundwater levels, but studies to quantify these impacts have not been done in many places throughout the basin.

Several analyses of human impacts on water resources have been done in Canada. The Grand River watershed in Ontario is an example of the type of analysis that leads to a better understanding of the relations between land use and groundwater resources. 80% of the residents in the Grand River watershed use groundwater as their source of potable water (Grand River Conservation Authority, 2003). Between 1940 and 2003, more than 37,000 wells were constructed in the watershed. Most were drilled for domestic supply; however, municipal supply is the largest user of groundwater. Recharge to the groundwater system is significantly higher in areas underlain by glacial outwash and moraines. These areas are also the places where urban development is most highly concentrated, therefore creating a conflict between land use and protection of the groundwater resources that are needed for development.

Recommended Future Research

Assessing groundwater availability and use at appropriate scales is important for understanding the effects of changes in land use and population growth on groundwater resources. Consistent and improved monitoring and data collection are required in order to estimate groundwater use and long-term trends in land use as well as the relation between groundwater resources and land use.

Groundwater Withdrawals Near Boundaries of Hydrological Basins

Recent Research

Sheets, Dumouchelle and Feinstein (2005) investigated the effects of hypothetical groundwater withdrawal near regional groundwater divides to help identify the rates and locations of withdrawals that impact shifting groundwater divides in a variety of locations in the basin.

The effect of large groundwater withdrawals from deep, mostly confined aquifers in the Chicago and Milwaukee areas has caused the groundwater divide in the Cambrian-Ordovician aquifer to shift westward because pumping is taking water out of storage. Although the amount of water taken is relatively small compared to the amount of water stored in the basin, the repercussions of the withdrawal are important because most of the water is withdrawn inside the Great Lakes drainage divide, but after use much of the remaining treated water is discharged to the Mississippi River Basin. In spite of the fact that a large volume of groundwater exists, in many situations depletion of a small part of the total volume in storage can have large effects that become limiting factors for groundwater withdrawal (Feinstein et al., 2004; Sheets and Simonson, 2006).

Limited studies of shallow bedrock aquifers show that the positions of groundwater divides in these units, unlike the deeper aquifers, tend to be similar to the surface water divides. The Silurian-Devonian aquifers generally have groundwater divides that follow the surface water divides, with substantial differences in a few locations (Sheets and Simonson, 2006). Generally, groundwater divides in the glacial-deposit aquifers conform to the surface water divides.

Recommended Future Research

Improved groundwater flow models are currently being developed for the Lake Michigan Basin and the metropolitan areas near Chicago. Use of these models will help water-resource managers decide how to respond to the effects of large-scale groundwater withdrawals. Models need to be developed for other areas in the basin to evaluate shifting groundwater divides due to pumping. Long-term monitoring of groundwater levels in areas where groundwater withdrawals are near regional groundwater divides will be needed to verify the model analysis and assure water-resource managers that correct decisions can be put in place to protect and sustainably use groundwater.

Estimates of the Level and Extent of Consumptive Groundwater Use

Recent Research

Water resource planners and managers want to know the amount of consumptive water use in the Great Lakes Basin to help understand the impact of human use of water on the hydrologic system. Consumptive use is water that is evaporated, transpired or incorporated into products or crops; consumed by humans or livestock; or otherwise removed from an immediate water environment (water body, surface or groundwater source, basin). When water is consumed and unavailable for use, interest increases in measures to document current levels of consumptive use and to develop policies that will optimize the use and reuse of water as much as possible.

The Great Lakes Commission compiles water-use and consumptive-use data provided by the Great Lakes jurisdictions. Water use during 2002 and consumptive-use data by water-use category are the most recent basinwide information available. The consumptive-use estimates are computed by using consumptive-use coefficients. Preliminary discussions with state agencies indicated that refinement of consumptive-use data and coefficients is an area of great interest and value to water-supply managers (Grannemann and Reeves, 2005). The USGS is working on two reports on consumptive-use coefficients. This first, by Shaffer and Runkle (2007), is a compilation of consumptive-use coefficients by water-use categories. That report contains:

- An annotated bibliography of references with consumptive-use coefficients
- An appendix with detailed consumptive-use coefficient tables from selected references
- Consumptive-use coefficients for domestic and public-supply, industrial (including industrial use by major standard industrial classification codes), thermoelectric power, irrigation, livestock, commercial and mining water-use categories
- A selected statistical analysis
- Summary tables by geographical area and water-use category for the Great Lakes Basin and areas climatically similar to the basin, plus selected references for elsewhere in the world

The statistical analysis (Kimberly Shaffer, written communication) includes the median and the 25th and 75th percentiles of consumptive-use coefficients by water-use category and provides a starting point for facilities managers, water managers and scientists to compute water consumption and return flow.
The second consumptive water-use report compares the consumptive-use coefficient statistics (median and 25th and 75th percentiles) computed by Shaffer and Runkle (2007) to consumptive-use coefficients computed from monthly water-use and return-flow data for Ohio as well as monthly water-use data for Indiana and Wisconsin (public supply only). That report also analyzes the monthly water-use data to determine if there is monthly variability in consumptive use and consumptive-use coefficients by water-use category.

Recommended Future Research

Water-use analysis is becoming more important as stresses on water resources increase. Additional work on consumptive water use is especially important to future water resources development. New estimates of consumptive use by water-use sector such as irrigation, municipal use, domestic use and industrial use are needed to more fully understand the impact of groundwater withdrawals in the Great Lakes Basin.

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Threats to Groundwater Quality in the Great Lakes Basin — Pathogens

CONTENTS

INTRODUCTION

Fecal pollution and microbial contamination, commonly from non-point sources, continue to be one of the most frequently identified causes of impairment of Great Lakes Basin groundwater. Pathogens enter the basin ecosystem from septage, sludge, manure and biosolids land spreading; leaking sewer infrastructure and on-site waste water systems; landfills; cemeteries; injection wells; waste and stormwater lagoons; and surface water, all of which can impact groundwater quality (Figure 1).

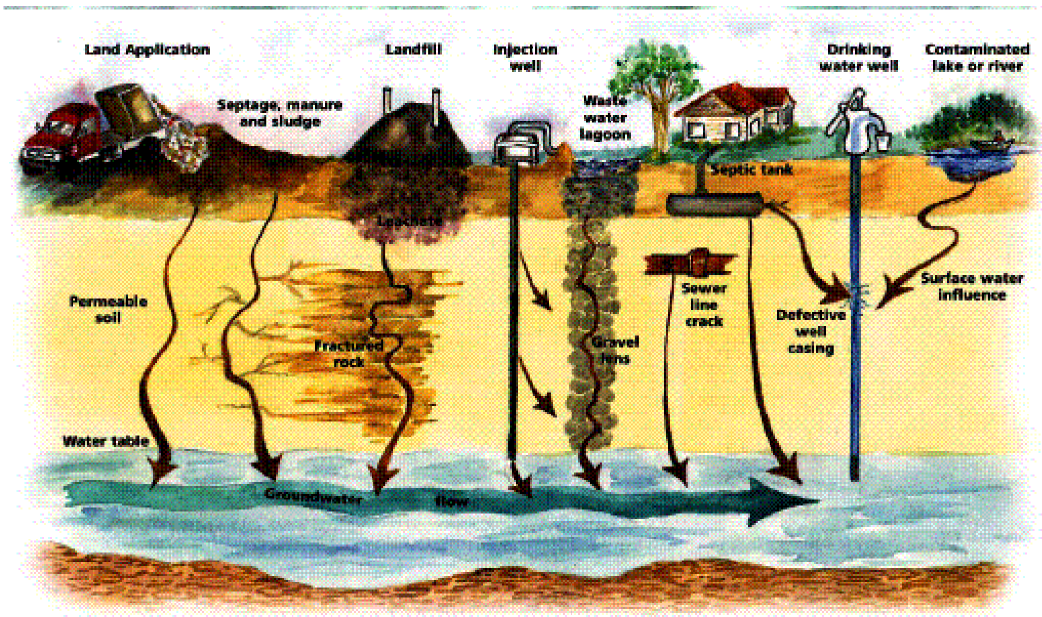


Figure 1. Pathogen sources and infiltration routes into groundwater

Exposure to groundwater pathogens threatens human health in the basin. Epidemiologic studies demonstrate linkages between exposure to contaminated water and occurrence of endemic and epidemic waterborne diseases (Millson et al., 1991; Moorehead et al., 1990; Goss, Barry and Rudolph, 1998; Raina et al., 1999; Blackburn et al., 2004; Liang et al., 2006). In fact, a single exposure to groundwater-borne pathogens may result in illness, hospitalization or death. Individuals reliant on groundwater, or those living in small communities who rely on groundwater for their potable water supply or those reliant on private wells experience the greatest level of risk associated with waterborne diseases.

Waterborne diseases due to contaminated groundwater continue to occur in the U.S. and Canada, devastating the health and economies of affected communities. Contaminated groundwater is the most commonly reported source of waterborne disease in the U.S., associated with 64% of drinking-water-borne disease outbreaks from 1989 to 2002. In the more recent U.S. data (2001-2002), groundwater contamination accounted for 92% of drinking water outbreaks, often occurring in small communities (Blackburn et al., 2004). U.S. data from 2003-2004 show that known microbe contamination accounted for 50% and 53% of groundwater outbreak sources, respectively. The remaining pathogens are unknown and assumed to be viral. *Campylobacter* causes many of the known microbial outbreaks. In fact, *Campylobacter* accounted for 2 of 3 (in 2003) and 4 of 13 (in 2004) known outbreaks, respectively (Liang et al., 2006). Recent Canadian research shows similar groundwater contamination effects (Locas, Barthe, Barbeau, Carriere and Payment, 2007). A survey conducted on 181 Ontario families demonstrated a link between consumption of groundwater and gastrointestinal (GI) illness (Goss et al., 1998; Raina et al., 1999). In Orangeville, Ontario, 241 cases were caused by *Campylobacter jejuni* and were linked to the consumption of water coming from a municipal system drawing its water from six deep wells without any treatment (Millson et al., 1991). In Penticton, British Columbia, 3,000 cases of giardiasis were reported following the consumption of a mix of surface water and groundwater that was chlorinated but not filtered (Moorehead et al., 1990).

PATHOGENS

Bacteria, viruses and protozoans are the main categories of pathogens encountered in groundwater. Prions represent an emerging concern. The U.S. Safe Drinking Water Act amendments of 1996 required the U.S. Environmental Protection Agency (EPA) to identify every five years new chemicals and microorganisms for potential regulation. The Contaminant Candidate List (CCL), based on information about known and suspected health risks and the occurrence of the contaminant in water, addresses 13 microorganisms including *Aeromonas hydrophila*, adenoviruses, Coxsackie viruses, and *Helicobacter* and the blue green algae toxins associated with Cyanobacteria (LeChevallier et al., 1999; Balbus, Embrey and Parkin, 2002). The CCL requires that information on health risks and occurrence in water (potential exposure) be acquired and, with that information, the development of rules for these contaminants' control may ensue.

Bacteria

The bacteria of greatest concern in groundwater include *Escherichia coli* (including O157:H7), *Campylobacter* and *Helicobacter*. These bacteria primarily originate from sewage, animals and animal manure (Table 1).

Enterohemorrhagic *E. coli* O157:H7 causes waterborne diseases ranging from mild, watery or bloody diarrhea to life-threatening conditions, such as hemolytic uremic syndrome (HUS) and thrombotic thrombocytopenic purpura (TTP) (Tserenpuntsag, Chang, Smith and Morse, 2005). Two to seven percent of infected individuals develop HUS and, of those, 33% are left with chronic renal failure and 3% to 5% die. The population most likely to develop TTP – the elderly – experience a mortality rate as high as 50%. Health Canada estimates that about 90,000 illnesses and 90 deaths are associated with drinking water each year (American Society for Microbiology, 1999). Evidence suggests that irrigation wells near four spinach farms may have played a role in the *E. coli* bacterial outbreak that tainted bagged spinach and subsequently killed three people and sickened at least 205 people in 2006 (Windsor Star, 2007).

Campylobacter jejuni causes a spectrum of diseases in humans. Infection starts in the GI tract but can become extraintestinal, particularly in immunocompromised hosts (Blaser, 1997; Ketley, Guerry and Panigrahi, 1996). In clinical reports describing primary infections with *C. jejuni* in developed countries, infection with mucosal disease predominates with symptoms of diarrhea, abdominal pain and blood in the stool. Infection with systemic spread, infection without disease with short-term bacterial persistence and infection with resistance and no bacterial persistence occur infrequently. In some cases the disease spectrum includes severe inflammatory illness, mild secretory diarrhea or an asymptomatic carrier state.

Helicobacter pylori (gram-negative, micro-aerophilic bacterium) is a ubiquitous microorganism infecting half the world's population. As the primary cause of peptic ulcers, chronic gastritis and associated with MALT lymphoma and stomach cancer, the World Health Organization classified it as a Class I carcinogen (Blaser, 1996; Aruin, 1997). About 50% of the U.S. population are thought to be symptomatic or asymptomatic carriers, even though the source of human infection is not well understood. Water supplies contaminated with fecal material may be a potential source of *H. pylori* transmission (Hulten, Enroth, Nystrom and Engstrand, 1998). The association between consumption of untreated groundwater positive for *H. pylori* and infection in the community has been demonstrated (Rolle-Kampczyk et al., 2004).

Triclosan overuse is cited as one of the key factors in widespread development of antimicrobial resistance (Environmental News Service, 2005; Eckardt, personal communication). It is used as an antibiotic in a broad range of products from textiles and plastics to cleaning and personal care products (Williams, 2006). Over 95% of triclosan in consumer products eventually goes down the drain. Widespread use has led to the appearance of triclosan residues in umbilical cord blood of infants and in the breast milk of nursing mothers (Williams, 2006). According to a British Environment Agency (2006) report, triclosan is present in sewage effluent and sewage sludge, and it also has been found at some groundwater monitoring sites. The U.S. EPA considers triclosan a high risk for human health and the environment (Williams, 2006).

Historically, major epidemics of cholera and typhoid fever were correlated to improper disposal of wastewater. Dr. John Snow (1813-1858) was the first to make a linkage between human waste contamination of the city water supply and a devastating cholera epidemic in London, England. When he famously removed the pump handle from the community well, the cholera epidemic halted. Snow published a brief pamphlet, *On the Mode of Communication of Cholera*, suggesting that cholera is a contagious disease. Snow postulated that water contaminated with human body excreta was a means of disease transmission (CDC, 2006).

The relationship between disease and water transmission prompted major water monitoring initiatives. In a seminal study in 1918, the International Joint Commission carried out the most extensive bacte-

Table I. Bacterial Outbreaks Associated with Animal Manure
Examples where manure has been implicated as the source of pathogens.
Source: Guan and Holley, 2003.

Location and Date	Type of Manure	Pathogen(s)	Human Morbidity and Mortality
1979-1981, Maritime Provinces	Sheep manure ±	*Listeria monocytogenes*	34 cases of perinatal listeriosis and 7 cases of adult disease
July 1985, U.K.	Cow manure ±	*Escherichia coli O157:H7*	49 cases including 1 death
Oct. 24 - Nov. 20, 1991, southeastern Massachusetts	Cattle manure ±	*E. coli O157:H7*	23 cases, no deaths
Sept. 23 - Oct. 1, 1992, Maine	Cow and calf manure ±	*E. coli O157:H7*	4 cases, 1 death
October 1992, Africa	Cattle carcass and manure ±	*E. coli O157:H7*	Thousands of cases, some deaths
March-April 1993, Milwaukee, Wisconsin	Cattle manure ±	*Cryptosporidium*	403,000 cases
October 1993, Maine	Calf manure	*Cryptosporidium*	160 primary cases
Summer, early 1990s, Germany	Hog manure ±	*Citrobacter freundii*	1 death, 8 HUS, 8 gastroenteritis cases and 20 asymptomatic cases
June 4, 1995, Ontario	Cattle manure ±	*E. coli O157:H7*	1 case of bloody diarrhea
June 1996, New York	Poultry manure ±	*Salmonella Hartford* and *Plesiomonas shigelloides*	About 30 cases, 1 hospitalization
June-July 1997, Somerset, U.K.	Cow manure§	*E. coli O157:H7*	8 cases
Summer 1999, Scotland, U.K.	Sheep manure§	*E. coli O157:H7*	6 cases
May-June 2000, Ontario	Cattle manure§	*E. coli O157:H7* and *Campylobacter spp.*	1,346 reported cases, 6 deaths
March-May 2001, Saskatchewan	Animal or human waste ±	*Cryptosporidium parvum*	1,907 cases, no deaths

± Suspected as the source of contamination.
§ Confirmed as the source of contamination.

rial examination of water the world had ever known. The need for bacterial monitoring was underscored. According to the Commission the most important type of pollution is bacterial contamination of drinking supplies. Sewage-polluted drinking water constitutes an actual or potential threat to health, so much that the presence of bacterial organisms of waterborne disease in the sewage of an urban community should always be assumed (IJC, 1918).

Today, the most common microorganisms monitored in groundwater include total coliform bacteria and *E. coli*. However, recent interest has been expressed in the use of enterococci and coliphage as alternative indicators, as well as direct virus monitoring.

Specific types of bacteria known as coliform bacteria have been used for over 100 years as indicators of microbial water safety, fecal contamination and disinfection efficacy for drinking water and wastewater treatment as well as recreational waters. Coliform bacteria are normally found naturally inhabiting the intestines of animals and humans and are shed in the feces of these animals. An indicator as defined is usually not a pathogen, but its presence indicates the potential for the presence of pathogenic organisms (Griffin, Lipp, McLaughlin and Rose, 2002). Historically, total coliform and then the subgroup fecal coliform bacteria were the indicators used to monitor for fecal contamination in waters. Yet the deficiencies of this system for viruses and parasites in regard to determining the risk, treatment and overall microbial water quality have been noted, since there is little correlation between these indicators and the pathogens of concern.

Researchers investigating several bacterial indicators and bacteriophages showed that the contamination and the best indicator system was aquifer dependent (Lucena et al., 2006). It has been recommended that more than one indicator, including a bacteriophage (a virus that infects bacteria), should be used to assess microbiological quality in certain aquifers.

Viruses

Viral pathogens continue to be a challenge from a public health perspective (Rose and Gerba, 1986; Lee, Levy, Craun, Beach and Calderon, 2002; LeChevallier et al., 1999; LeChevallier, 1999). There are hundreds of different viruses which can be excreted in high concentrations and subsequently detected in sewage (Rose et al., 2001). They are stable in the environment and are readily transmitted to groundwater aquifers. Viruses cause a wide range of clinical symptoms ranging from acute diarrhea to meningitis to myocarditis (Hass, Rose and Gerba, 1999). Proposed regulations suggest natural disinfection as a possible mechanism to treat microbe-impacted groundwater under favorable conditions. However, the usefulness of current models employed to predict viral transport and natural attenuation rates is limited by the absence of field-scale calibration data (Yates and Jury, 1995). Recently, viral agents associated with septic tanks have been implicated in endemic diarrheal disease in rural areas in Wisconsin, and children were shown to be at particularly high risk (Borchardt, Chyou, DeVries and Belongia, 2003). The coliform indicator bacteria did not prove to be a sufficient indicator of risk.

All the viruses in Table 2 cause disease in humans. Enteric viruses (those that replicate in the human GI tract) come only from human sewage. They can cause both acute and chronic disease affecting GI tract, liver, heart and meninges. Adenoviruses, Calciviruses, Picornaviruses and Rotaviruses cause hundreds of thousands of cases per year. The exception is Poliovirus, since the vaccination program has reduced the number of infections. The enteroviruses include Coxsackie viruses which are on the CCL. They can cause many types of disease and often can be detected in sewage-contaminated water.

Table 2. Enteric Viruses.
Adapted from American Water Works Association (AWWA), 1999.

Adenoviruses (Respiratory adenovirus and Enteric adenovirus)
Coronaviruses (Enteric conronavirus)
Reoviruses (Reovirus and Rotavirus)
Calciviruses (Calcivirus and Noroviruses)
Astroviruses
Parvovirus
Picornavirus (Coxsackie virus A, Coxsackie virus B, ECHO virus, Hepatitis A virus, Poliovirus)

Viruses are stable and widespread in groundwater due to several factors: Their survivability is favored by low temperatures, moisture and absence of ultraviolet light; their nano-size and negative charge favors transport though soil; and they have the documented ability to move as deep as 67 meters and migrate horizontally as far as 1600 meters. John and Rose (2005) quantitatively reviewed the survival and inactivation rates of public health-related microorganisms in groundwater (Table 3). Virus inactivation has been shown to be temperature dependent with greater inactivation at greater temperatures; however, this occurs largely at temperatures greater than 20ºC, whereas most Great Lakes Basin groundwater is about 10ºC (Table 3). A study by Yates and Gerba (1985) estimated that virus inactivation could take as many as 200 to 400 days where groundwater temperature averages between 8.5ºC and 11ºC (Figure 2).

Using improved molecular techniques (i.e., polymerase chain reaction), monthly samples from 29 groundwater sites in the continental United States, the Virgin Islands and Puerto Rico were analyzed for one year for enteroviruses, hepatitis A virus, Norwalk virus and reoviruses (Fout, Martinson, Moyer and Dahling, 2003). Human enteric viruses were detected in 16% of the groundwater samples analyzed, with reoviruses being the most frequently detected virus group (Fout et al., 2003). Other types of groundwater viruses, such as the adenoviruses, should be monitored since they are more prevalent in sewage. In another national study using more precise tests (i.e., using specific primers) for enteroviruses used in RT-PCR, 40 of 133 samples (30.1%) tested positive for the presence of enterovirus RNA (Abbaszadegan, Stewart and LaChevallier, 1999).

Protozoans

The most common protozoans in waterborne outbreaks are *Giardia* and *Cryptosporidium*. Under appropriate conditions (human GI tract), they can produce infection. When found in groundwater, these protozoa signify direct influence of surface water. Their size (2 - 50 μm) is larger than bacteria and viruses which normally makes them more susceptible to removal by filtration. They are more resistant to disinfection than bacteria or viruses. These two protozoa are usually found in domestic wastewater (10^2 to 10^5 / litre) (Bitton, 1999). When they are found in groundwater, the well is probably under the direct influence of surface water and requires special attention and treatment.

Prions

Human prion infections including Creutzfeldt-Jakob Disease (CJD), variant Creutzfeldt-Jakob Disease (vCJD), Kuru and Fatal Familial Insomnia are relatively

Table 3. **Relative Effects of Experimental Temperature on Inactivation Rates as Described in Individual Studies.**
Source: John and Rose, 2005.

organism	effect on inactivation rate	conditions contrasted	reference
MS-2 (coliphage)	increased	w/increasing temp.	Yates et al. (*19*)
MS-2 (coliphage)	increased	w/increasing temp.	Yates and Gerba (*18*)
MS-2 (coliphage)	increased	w/increasing temp.	Yates et al. (*20*)
MS-2 (coliphage)	increased	at 20 vs 10 °C	Blanc and Nasser (*24*)
poliovirus 1	increased	w/increasing temp.	Yates and Gerba (*18*)
poliovirus 1	increased	w/increasing temp.	Yates and Gerba (*19*)
poliovirus 1	increased	w/increasing temp.	Yates et al. (*20*)
poliovirus 1	increased	at 25 vs 5 °C	Sobsey et al. (*21*)
poliovirus 1	increased	w/increasing temp.	Nasser and Oman (*35*)
poliovirus 1	increased	at 20 vs 10 °C	Blanc and Nasser (*24*)
echovirus	increased	at 25 vs 5 °C	Sobsey et al. (*21*)
hepatitis A	increased	at 20 vs 10 °C	Blanc and Nasser (*24*)
hepatitis A	increased	at 25 vs 5 °C	Sobsey et al. (*21*)
hepatitis A	increased	w/increasing temp.	Nasser and Oman (*35*)
coxsackievirus B1	increased	at 28 vs 15 °C	Gordon and Toze (*37*)
E. coli in DI-water-saturated soils	increased	at 37 vs ≤20 °C	Sjogren (*32*)

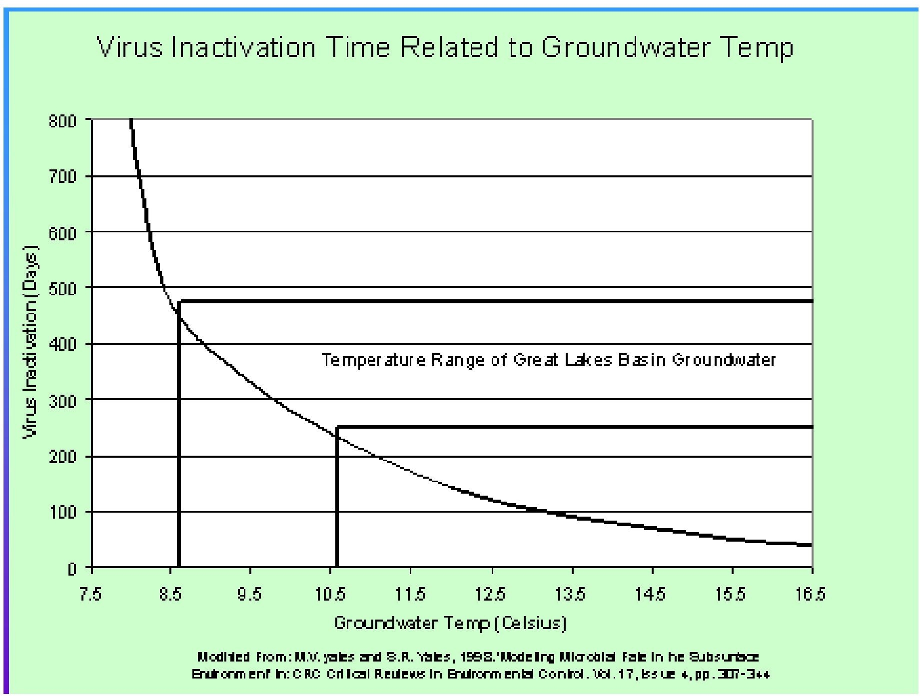


Figure 2. **Virus inaction time related to groundwater temperature**

rare. Since prions are very resistant to biodegradation, concern has been raised about their environmental persistence and possible spread of infection through groundwater contamination.

Little is known about the epidemiology of prions and various prion infections. Previous research indicated that particles are removed by gravity in a wastewater treatment plant. The prions settle out to the bottom solids, and clean water at the top gets disinfected and discharged. Biosolids or "sludge" is sometimes used by farmers as a nutrient-rich fertilizer. It is also landfilled. For those reasons, landfills will not accept carcasses of deer suspected of having the prion infection chronic wasting disease (CWD), and yet 1.5 million road-killed dear are buried each year and some may have CWD (Kolb, 2006).

The U.S. EPA is currently funding research into prion behavior in solid waste landfill and water treatment plants (Taylor, 2007). New research may help determine what to do with prion-contaminated waste so that it does not enter the environment, including groundwater.

SPECIFIC EPISODES

Walkerton

In 2000 in Walkerton, Ontario, the largest ever Canadian multi-bacterial waterborne outbreak associated with a contaminated municipal water supply occurred (Public Health Agency of Canada, 2000; Krewski et al., 2002). Of more than 2,000 cases, 1,346 patients had gastroenteritis after drinking groundwater from a municipal well. Stool samples confirmed that 167 patients had *E. coli* O157:H7 and 116 people had *Campylobacter spp.* Sixty-five patients were admitted to the hospital and, of these, 27 developed HUS. Six people died as a result of the outbreak. A series of circumstances led to an outbreak of this magnitude including heavy spring rains accompanied by flooding, presence of *E. coli* O157:H7 and *Campylobacter spp.* in the environment due to application of cattle manure near the poorly maintained municipal well and inadequately disinfected well water.

Put-in-Bay

At Put-in-Bay, South Bass Island, Ohio, in the summer of 2004, a large groundwater-associated outbreak, caused by contamination from sewage, infected ~1,450 individuals, both residents and visitors. Extensive groundwater contamination on the island was likely caused by transport of microbiological contaminants from sewage discharges to the lake and to the subsurface from wastewater treatment facilities and septic tanks, after extreme precipitation events in May, June and July 2004 (Fong et al., 2007). The level of precipitation was 200% above the 50-year average for May (Figure 3). This deluge likely raised the water table, saturated the subsurface and, along with very strong Lake Erie currents, forced a surge in water levels and rapid surface water-groundwater interchange throughout the island. Landsat images showed a massive influx of organics and turbidity surrounding the island. Shortly after these events the peak of the illnesses was reported. This combination of factors and information can be used to examine vulnerabilities in other coastal groundwater systems.

Sixteen groundwater wells that provided potable water on the island were tested for fecal indicator bacteria, viruses and parasites (Fong et al., 2007). All wells were positive for both total coliform and *E. coli*. Seven wells tested positive for enterococci and *Acrobacter*, an emerging bacterial pathogen; F+-specific coliphage was present in four of the wells (Figure 4). Three wells were positive for all three bacterial indicators, coliphages and Arcobacter; adenovirus DNA was also recovered from two of these wells. A cluster of the most contaminated wells was noted on the southeast side of the island.

LA CROSSE MUNICIPAL WELLS – A LINK TO VIRUSES IN GROUNDWATER

A 2004 study conducted by the Marshfield Clinic Research Foundation in La Crosse, Wisconsin, located near the Wisconsin River, focused on municipal well susceptibility to enteric virus contamination from surface water. The objective was to relate the amount of surface water contributions to the frequency of virus detection in La Crosse wells. The researchers sampled for human enteric viruses monthly for one year (March 2001 - February 2002). Samples were taken at five sites prior to chlorination. Hydrogen and oxygen isotopes were used for estimating the amount of surface water in wells. The results indicated incidence of enteric viruses at every sample site despite testing negative for indicators of sanitary quality (i.e., male-specific and somatic colipahges, total coliform bacteria, *Escherichia coli* and fecal enterococci) (Figure 5). Extrapolating these results, approximately one-third of groundwater pumped

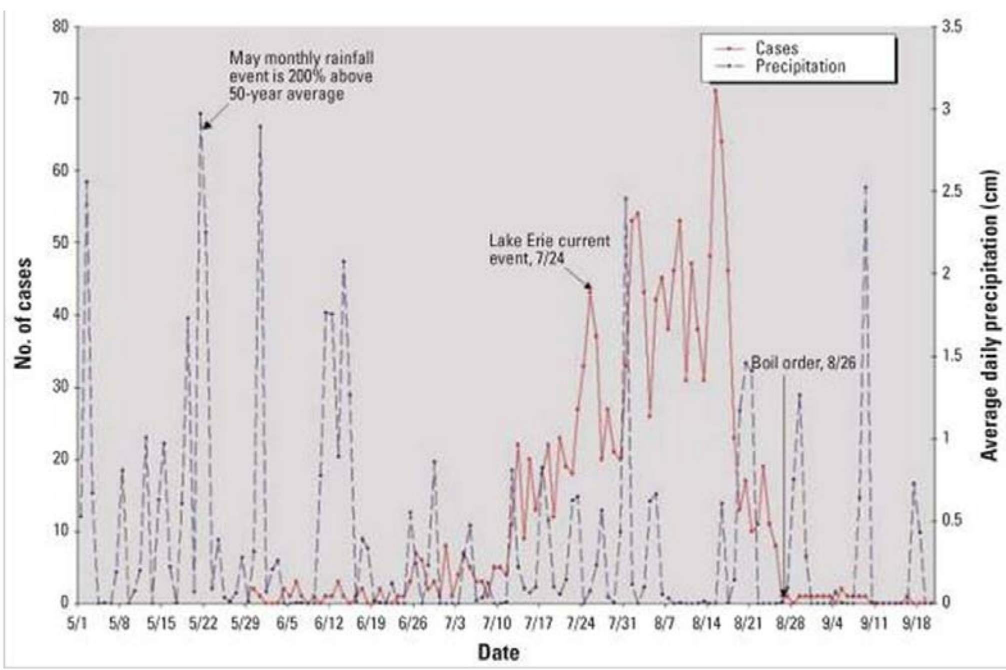


Figure 3. Illnesses associated with Lake Erie rainfall and a wind-driven lake event

Figure 4. Percentage of contaminated wells on Bass Island

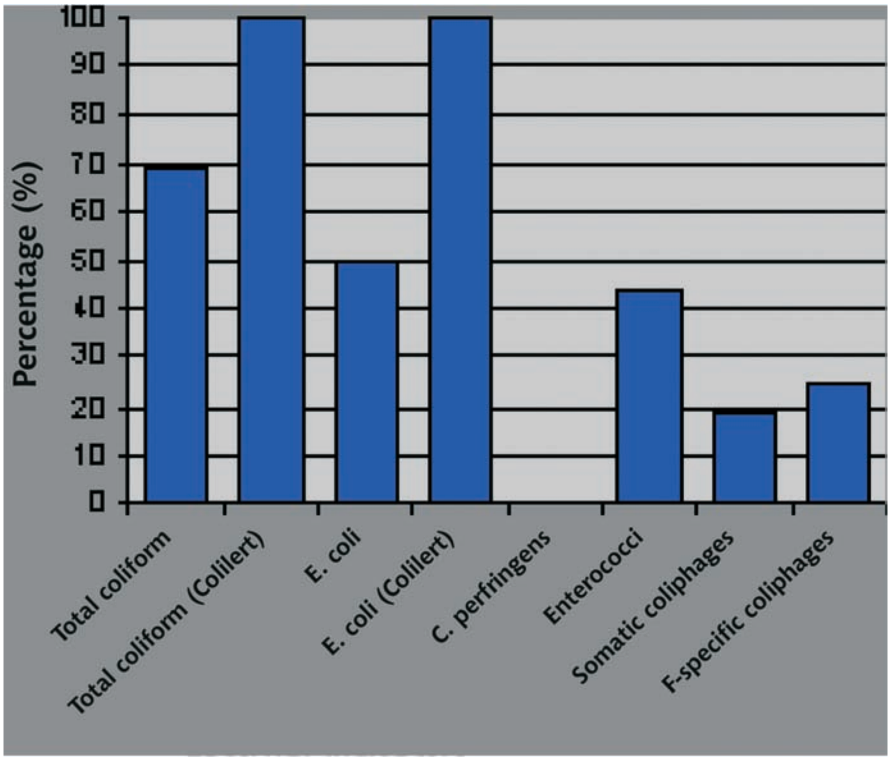
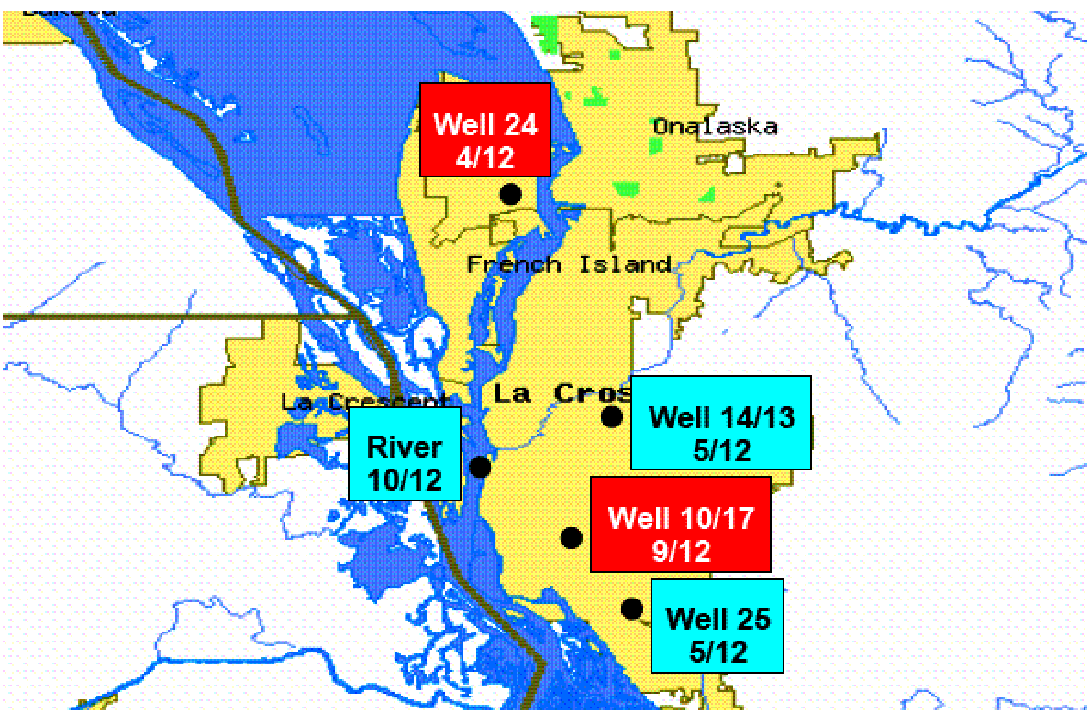


Figure 5. Incidence of enteric viruses at five sample sites in Wisconsin.



from alluvial sand-gravel could be vulnerable to virus contamination (Borchardt, Haas and Hunt, 2004).

Another study by Marshfield Clinic Research conducted in 2002 was the first in the U.S. to systematically monitor private wells for virus contamination. The objective was to estimate the incidence of viruses in Wisconsin household wells located near septage land application sites or in rural subdivisions served by septic systems (Borchardt, Bertz, Spencer and Bactigelli, 2003). Fifty wells in seven hydrogeological districts were sampled four times a year, once each season. The sampling sites included 24 land-spreading sites and 26 septic-system sites. Among the 50 wells, four (8%) were positive for six different types of viruses (Borchardt et al., 2003). The implication of this study is that if an 8% contamination rate is generalizable, then as many as 1.2 million households in the United States are exposed to viruses via their well water.

These two studies are crucial to the discovery that:

- Human viruses are common in groundwater, even in deep wells in a confined aquifer.
- Bacteria indicators of water sanitary quality are not correlated with virus presence.
- Viruses are responsible for groundwater-related disease outbreaks, but the level of sporadic endemic illness attributable to virus-contaminated groundwater is unknown.

PROTECTION OF GROUNDWATER SOURCES TO PROTECT PUBLIC HEALTH

As stated on the U.S. EPA Web site:

The Environmental Protection Agency is promulgating a National Primary Drinking Water Regulation, the Ground Water Rule, to provide for increased protection against microbial pathogens in public water systems that use ground water sources. This final rule is in accordance with the Safe Drinking Water Act as amended, which requires the Environmental Protection Agency to promulgate National Primary Drinking Water Regulations requiring disinfection as a treatment technique for all public water systems, including surface water systems and, as necessary, groundwater systems. The Ground Water Rule establishes a risk-targeted approach to target groundwater systems that are susceptible to fecal contamination, instead of requiring disinfection for all groundwater systems. The occurrence of fecal indicators in a drinking water supply is an indication of the potential presence of microbial pathogens that may pose a threat to public health. This rule requires groundwater systems that are at risk of fecal contamination to take corrective action to reduce cases of illnesses and deaths due to exposure to microbial pathogens.

The Ground Water Rule will require monitoring that will identify groundwater-based water supply systems that are susceptible to fecal contamination. These higher risk systems are required by the rule to monitor and, when necessary, take corrective action to remove microbiological contamination. Corrective action can include: correcting all significant deficiencies, providing an alternate source of water, eliminating the source of contamination or providing treatment that reliably achieves at least 99.99% (4-log) treatment of viruses (using inactivation, removal or a state-approved combination of 4-log virus inactivation and removal) for each contaminated groundwater source.

Full compliance with the rule is required by December 1, 2009.

Given the reported lack of correlation of viral contamination with bacterial indicators, it is not clear that the new U.S. EPA Ground Water Rule will prove a fully adequate mechanism to protect public health.

CONCLUSIONS

Seven conclusions are drawn regarding pathogens in groundwater in the Great Lakes Basin.

1. **Very few studies on groundwater quality in the Great Lakes are available. More data are needed.** In the 1993 Summary Report, *Groundwater Contamination in the Great Lakes Basin*, the Commission recognized the need to reduce the degree of uncertainty concerning the nature, extent and significance of groundwater contamination in the Great Lakes ecosystem (IJC, 1993). Specifically, the Commission recommended that special attention be given to "the need for fundamental research concerning persistence, transport and fate of pathogens and contaminants in and through groundwater aquifers." Studies since then have improved understanding in this area, but there is still plenty to be learned. Recent research on viruses underlines how little is currently known about the relationship between groundwater and human disease transmission.

2. **Groundwater monitoring should include coliphage in addition to *E. coli*.** Application of new methods for microbial monitoring will allow for prioritization on a science risk-based approach and result in improvements and protection of the Great Lakes Basin groundwater.

3. **Seasonal assessment of groundwater contamination during high-rain events and spring melt should be undertaken.** For instance, information on health risks and occurrence in water (potential exposure) should be acquired, and with that information the development of rules for control of these contaminants may ensue.

4. **A Great Lakes enteric virus groundwater survey is needed.**

5. **New technologies including polymerase chain reaction should be used.**

6. **The role of septic tanks, leaky sewers and animal wastes in the contamination of groundwater should be assessed.** In Ontario, septic tanks are currently regulated under the building code, with no mention of environment, nitrogen, pathogens or groundwater protection. Enforcement is delivered by the municipalities and building departments and therefore is highly variable across the province.

7. **New groundwater treatment methods need to be developed and used.** Standard chlorination treatment procedures of raw water for drinking purposes are limited in their ability to kill viruses. Filtration reduces viral load but does not kill viruses. Ultraviolet (UV) technologies are effective at destroying viruses in water that is not turbid. UV-C, specifically wavelength 254, is most suitable for the disinfection because it is the most effective against micro-organisms such as bacteria, fungi and viruses. The recent U.S. EPA Ground Water Rule requires a 4-log reduction in adenoviruses. It allows states to use UV reactors as part of their treatment systems, but currently real-time monitoring of treatment efficacy by this method is not available. The best protection requires real-time monitoring of treatment efficacy.

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GLOSSARY

Note: The definitions for a number of the terms below are drawn from the British Columbia Drinking Water Protection Act and the associated Drinking Water Protection Regulation. Although the exact terminology may vary, the definitions are generally applicable across Great Lakes jurisdictions.

4-3-2-1 treatment objective – A treatment train that achieves 4-log (99.99%) removal or inactivation of viruses, a 3-log (99.9%) removal or inactivation of *Giardia* and *Cryptosporidium* cysts, incorporates two treatment barriers (e.g., filtration and disinfection) and achieves turbidity equal to or less than 1 NTU.

Action Plan for Safe Drinking Water in British Columbia – The British Columbia government's comprehensive framework for protecting drinking water supplies and public health. Developed in 2002, the Action Plan is online at www.health.gov.bc.ca/cpa/publications/safe_drinking_printcopy.pdf .

Aquifer – An underground zone or stratum of permeable rock or loose material where water accumulates and which can yield useful quantities of water to wells or springs.

Bacteriophage – Virus that infects bacteria.

Clinical Microbiology Proficiency Testing – The program used to evaluate the performance of water bacteriology laboratories. For more information, refer to: http://www.interchg.ubc.ca/cmpt.

Coliform bacteria – A large group of bacteria, commonly found in topsoil, bodies of water and animal (fecal) material.

Connection – The line from the water main to a dwelling, campsite or premises.

Cryptosporidium – A small (4 to 6 μm diameter) protozoan parasite with a complex life cycle. The species found most commonly in mammals, *Cryptosporidium parvum*, has the ability to infect a broad range of hosts.

Infection of a suitable host species results from ingestion of the parasite in its transmissible stage, the oocyst that is hardy and persists in the environment for weeks. The illness, cryptosporidiosis, consists of watery diarrhea and, occasionally, vomiting. Diarrhea typically lasts for 10 to 14 days in people and cattle, but may last for several months. No treatment is available.

Disinfection – A water treatment specifically designed to destroy or inactivate pathogenic organisms and thereby prevent waterborne diseases, which are the most significant health risk associated with drinking water. Primary disinfectants are added to disinfect the water before it enters the water supply distribution system. Secondary disinfectants are used to prevent regrowth of bacteria in the distribution system. Commonly used disinfecting agents are chlorine and related chloramine compounds; there is increasing interest in the use of ozone as a primary disinfectant. Considerations in choosing disinfectants include disinfecting power, cost of use and effects on taste and odour of drinking water. Minimizing by-products associated with disinfectant use is also a concern. Some by-products are possibly carcinogenic, although research findings are not clear.

Disinfection by-products – Secondary chemicals produced when a disinfectant reacts with organic matter in water. For example, when chlorine is added to water, it reacts with organic matter to form trihalomethanes. Because they are formed from chlorine, trihalomethanes are referred to as "chlorinated disinfection by-products." If water is treated to remove the organic matter prior to disinfection, such as through filtration, a lesser amount of by-product will be formed.

Distribution system – The pressurized piping system that carries water from a drinking water treatment facility to the premises of consumers.

Drinking water officer – A specialized health professional. In British Columbia, the drinking water officer is the medical health officer, but the latter can delegate duties to another qualified person. For more information, see www.health.gov.bc.ca/protect/dwoguide.pdf .

***E. coli* (*Escherichia coli*)** – A type of fecal coliform bacteria whose presence in water indicates recent animal contamination and the possible presence of pathogenic microorganisms. The test for *E. coli* is the "Gold Standard" method for identifying fecal contamination.

Endemic Disease – An infectious disease that is present in the community at all times but normally at low frequency.

Epidemic Waterborne Disease – Any infectious disease that develops and spreads rapidly to many people.

Fecal coliforms – A sub-group of coliforms found almost exclusively in the intestinal wastes of humans and animals, but capable of growing elsewhere in the environment. If found in water, they are an indicator that it has been contaminated with sewage or other intestinal wastes
and may be a potential risk, if containing disease-causing organisms. Water containing fecal coliforms is generally unsafe to drink. See *E. coli*.

Freshet – The flood of a river from heavy rain or snow melt.

Giardia – A protozoan parasite found widely in many mammalian intestines. Infection with *Giardia* – an illness called giardiasis, inappropriately nicknamed "beaver fever" – can cause diarrhea, abdominal cramps, nausea or vomiting, weight loss and fatigue lasting many weeks. It can be carried by humans as well as by certain domestic and wild animals.

Groundwater – Water found underground in the saturated zone of an aquifer. Groundwater is a source of well water and often surface water (e.g., springs).

Guidelines for Canadian Drinking Water Quality – A comprehensive compilation of recommended limits for substances and conditions that affect the quality of drinking water, developed by the Federal-Provincial-Territorial Committee on Drinking Water and published by Health Canada. Available at www.hc-sc.gc.ca/waterquality.

Health hazard – In relation to drinking water, a condition or thing that endangers public health or prevents or hinders the prevention or suppression of disease. Also, a prescribed condition or thing that fails to meet a prescribed standard.

Mandatory standards – Conditions that water quality is legally required to meet in order to be considered potable.

Membrane filtration – A technique that permits removal of particles from a drinking water source on the basis of their molecular size and shape with the use of pressure and specially designed semi-permeable membranes.

Meninges (Singular – menynx) – Membranes covering the brain and the spinal cord.

Meningitis – Infectious disease characterized by inflammation of the meninges, usually caused by a bacterial infection; symptoms include headache, stiff neck, fever and nausea.
Microbiological pathogen – A disease-causing agent, especially microorganisms such as viruses, bacteria or protozoa, which can be present in municipal, industrial and non-point source discharges.

Monitoring – A series of observations over time for the purpose of detecting change. Requirements can relate to the sampling, transportation, testing and analysis of drinking water samples.

Multi-barrier approach – An integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap in order to reduce risks to public health.

Myocarditis – Inflammation of the myocardium, the muscular tissue of the heart.

Operating permit – A permit issued to a drinking water supplier that sets out the terms and conditions that must be respected when operating the system. The terms and conditions may apply to treatment requirements; equipment and operating requirements; the qualifications and training of people operating, maintaining and repairing equipment; monitoring requirements; water quality standards; and reporting requirements. If the supplier fails to meet the terms and conditions, the operating permit may be revoked.

Operational failure – A breakdown of equipment or processes in the treatment or distribution of drinking water.

Operator certification – The process of establishing that a water treatment or distribution operator has the appropriate experience, training, knowledge and skills to run the type of drinking water system on which they work. Water systems are rated by level of complexity; operators are certified to corresponding levels.

Potable water – Water fit for human consumption.

Public water supply system – Any drinking water system that serves more than one single-family residence is considered a water supply system.

Prions – Tiny proteinaceous particles, likened to viruses and viroids, but having no genetic component, thought to be an infectious agent in bovine spongiform encephalopathy, Creutzfeldt-Jakob disease and similar encephalopathies.

Primers – A short sequence of RNA or DNA from which DNA replication can initiate. May be either a synthetic DNA or RNA or a length of RNA synthesized *in vivo* by primase.
Small water system – A water system serving fewer than 500 people.

Source to tap – A way of looking at the entire water supply system, from the source water in a watershed, through the treatment and distribution systems to the point at which it reaches the consumer.

Source water – The body of water from which a drinking water supply originates. Source waters can be surface water or groundwater supplies.

Surface water – Water from a source which is open to the atmosphere, including streams, lakes, rivers, creeks and springs. Drinking water originating from a surface water source, or a groundwater source that may be under the influence of surface water and is therefore at risk of being contaminated by pathogens, must be disinfected.

System assessment – The process and results of identifying, inventorying and assessing a drinking water source, including the land uses and other activities and conditions that may affect it, the treatment and operation of the drinking water supply system, the monitoring requirements for the source and system and the threats to drinking water from source to tap.

Total coliforms – In drinking water, the level of total coliforms indicates whether water has been contaminated from an unsanitary source and/or properly disinfected. It is not used for public health but as an indicator of water quality.

Turbidity – Cloudiness or haziness in water, usually due to suspended particles of silt or clay. Such particles affect the quality of drinking water by interfering with disinfection and impairing the appearance of the water.

Water license – A license which entitles its holder to divert and use, for the purpose and during the time stipulated, the quantity of surface water specified in the license; store surface water; construct, maintain and operate the works authorized under the license and necessary for the proper use of the water or of power produced from it; and alter or improve a stream or channel.

Watershed – The entire area drained by a waterway, or that drains into a lake or reservoir. Also called catchment basin or catchment area.

Threats to Groundwater Quality in the Great Lakes-St. Lawrence River Basin — Chemical Contaminants

A Contribution by the Health Professionals Task Force

CONTENTS

INTRODUCTION

Many chemical contaminants can be found in groundwater either because they are naturally occurring or because they have originated from human activity. This appendix describes the regulatory framework in Canada and the United States to limit exposure to chemical contaminants in drinking water. It also briefly gives the health-related grounds upon which guidelines and regulations have been established for the chemicals of most concern. This appendix also reviews epidemiological studies on health effects related to chemicals in groundwater in Great Lakes-St. Lawrence River Basin populations. These studies, however, represent only a small portion of individual exposures to chemicals in groundwater. Many individuals do not have their wells checked for chemical contamination. This testing is more expensive than routine checking for microbial contamination. The number of individuals made sick by chemicals in their well water is not known. Public drinking groundwater supplies, however, are routinely tested for chemical contaminants.

There is an abundance of data on chemical contaminants in groundwater, much of it generated by state and provincial departments and ministries of the environment as a result of monitoring, *inter alia*, hazardous waste sites, landfills and spills. The U.S. Environmental Protection Agency (EPA) provides an interactive database called STORET for ambient environmental data relating to water quality. STORET includes information on marine and freshwater chemical and physical parameters as well as biological monitoring data. Data entered before mid-1999 is stored in a Legacy STORET. Data since then are stored on personal computers across the United States by the agencies generating the data. The data are uploaded monthly to the main database but also remain stored on the local servers. The U.S. EPA provides the software to generate and upload the data. The database can be searched through the STORET Web site (U.S. EPA, 2004).

Monitoring programs for groundwater contaminants are now in place in Ontario and in some of the Great Lakes states. These programs gather data on the distribution of chemicals in groundwater, especially those of natural occurrence or due to widespread non-point sources like pesticides and fertilizers. This information, however, is generally not compiled into a single summary that gives a comprehensive picture of all the chemical contaminants in groundwater. An exception is the annual report of the Groundwater Coordinating Council in Wisconsin (Wisconsin DNR, 2006). Although these reports do not contain all the data, the description of the groundwater resource gives a very good picture of the state of the groundwater in Wisconsin.

This appendix focuses on those chemicals that are likely to be found in groundwater sources in the Great Lakes states, Ontario and Quebec at concentrations that may exceed human health guidelines. It does not provide a comprehensive review of data available through the Internet on chemical contaminants in the basin. It covers United States-wide data on pesticides in groundwater and chemically related outbreaks of waterborne disease as an indicator of the likelihood of such problems in Great Lakes states groundwater.

The naturally occurring chemicals most likely to cause health problems for humans are arsenic, fluoride, manganese, uranium, other radionuclides and radon. Pesticide use on agricultural land has contaminated many drinking water supplies. This problem is more severe for surface water than groundwater. Atrazine, aldicarb, aldrin and dieldrin are discussed here. Nitrates from manure and artificial fertilizer are the most widespread groundwater contaminant in the Great Lakes-St. Lawrence River Basin.

Industrial sites in use or abandoned (brownfields), hazardous waste sites, municipal and illegal landfills have contaminated groundwater in many locations in the basin. Almost any chemical is a possible contaminant, but the most common are chemicals used in great quantities, especially liquids like chlorinated solvents (trichloroethylene and tetrachloroethylene) and hydrocarbon solvents such as toluene and the xylenes. In Ville Mercier, Quebec, for example, the disposal of industrial wastes into lagoons in an old gravel pit over many years rendered the water supplies of thousands of residents in the region unusable. Water has to be pumped from a well 10 kilometres away to replace the area's supply (Environment Canada, 2004).

A major source of groundwater contaminants comes from underground storage tanks for gasoline, heating oil and other liquid chemicals. The contaminants from leaking underground storage tanks include gasoline degradation products – BTEX (benzene, toluene, ethylbenzene and xylene), lead from old leaded gasoline and other octane enhancers (MTBE and ethanol). Ethanol is not a toxicity problem in groundwater, but it does slowly dissolve the seals in old tanks making them more likely to leak. Leaking tanks create a problem only in the immediate area and in the downstream plume, but the tanks are widespread. At the time of their report in 2006, the Sierra Club documented a backlog of 36,135 cleanups for leaking underground storage tanks in the eight Great Lakes states. Many tanks reached the end of their lifespan but were not pumped out when taken out of use (Sierra Club, 2006).

Road salt has significant toxic effects on vegetation. Sodium in drinking water is a health concern for those on low-sodium diets. Various de-icing compounds used at airports represent more of a risk to surface water than groundwater, but this problem is very localized.

CANADIAN AND UNITED STATES DRINKING WATER GUIDELINES AND REGULATIONS

The Guidelines for Canadian Drinking Water Quality (GCDWQ) (Health Canada, 2007a) and the *Guideline Technical Documents* (GCDWQ, 2007) are prepared by the Federal-Provincial-Territorial Committee on Drinking Water and approved by the Canadian Council of Ministers of the Environment. The guidelines are the basis for drinking water standards in several provinces including Ontario and Quebec. Ontario has had enforceable standards since 2000 that are now in Ontario Regulation (O. Reg.) 169/03 under the Safe Drinking Water Act (2002). The *Guideline Technical Documents* are produced and published by Health Canada with input from provincial and territorial experts. The technical documents are referenced mm/yyyy according to the date of their initial acceptance. Many of the earlier guidelines have been reviewed and reaffirmed. Guidelines exist for microbial, chemical, physical and radiological parameters. The guidelines for chemical and physical parameters set out a health-based Maximum Acceptable Concentration (MAC) or aesthetic objective (AO) or Operational Guidance Value (OG) (see Annexes A and B).

Under the 1996 Safe Drinking Water Act the U.S. EPA established legally enforceable National Primary Drinking Water Regulations (NPDWR) (U.S. EPA, 2007a). These regulations set standards with which all public drinking water supplies must comply. The standards for chemical contaminants apply to surface and groundwater. The Groundwater Rule introduced by the U.S. EPA in 2006 sets the regulatory standards for microbial contaminants in groundwater. These standards come fully into force by 2009. The U.S. EPA also sets out National Secondary Drinking Water Regulations (NSDWR) based on cosmetic (e.g., tooth or skin discolouration) or aesthetic effects. These regulations are not federally enforceable, but many have been adopted as mandatory by individual states. The primary regulations set out standards as Maximum Contaminant Levels (MCL) and Maximum Contaminant Level Goals (MCLG). The goal for carcinogens in drinking water is zero. The NPDWR set out required treatment techniques (TT) for some parameters, especially microbial ones (see Annexes C and D).

CHEMICALS OF CONCERN

Arsenic

Arsenic has not been demonstrated to be essential for human nutrition. It is one of the few substances that epidemiological studies have shown to cause cancer in humans through consumption of drinking water. The consumption of elevated levels of arsenic is causally related to the development of cancer at several sites, particularly skin, bladder and lung. Because trivalent inorganic arsenic has greater reactivity and toxicity than pentavalent inorganic arsenic, it is generally believed that the trivalent form is the carcinogen.

Arsenic is classified as a known human carcinogen by the United States National Toxicology Program (NTP, 2005) and as carcinogenic to humans by the International Agency for Research on Cancer (IARC, 2007). There is a wide variation in the carcinogenic dose response to arsenic in animals. Inorganic arsenic is more carcinogenic than its organic forms. Arsenic has long been recognized as a skin carcinogen. Recent research has suggested that the risk of internal cancers in humans is greater than previously thought. As a consequence the standards for arsenic in drinking water have been lowered in a number of jurisdictions (GCDWQ, 05/2006).

In the context of drinking water guidelines Health Canada considers a risk of 1.0×10^{-6} to 1.0×10^{-5} as "essentially negligible." The target concentration for arsenic in drinking water for Health Canada is 0.3 µg/L. The upper lifetime cancer risk at this concentration is estimated at 1.9×10^{-6} to 1.39×10^{-5}. This cancer risk is based on studies of a southwestern Taiwanese cohort with high levels of arsenic in the drinking water. There are uncertainties with respect to the mode of action of arsenic in the body that may cause this estimate to be high. Some studies of United States cohorts have not demonstrated a cancer risk at 10.0 to 50.0 µg/L arsenic concentrations in drinking water.

Advanced municipal scale treatment technologies can reduce arsenic concentrations to 1.0 to 5.0 µg/L. Residential treatment devices have been certified to reduce arsenic to 10 µg/L. The detection limit for arsenic is 3.0 µg/L. The MAC has to be achievable at reasonable cost. Given these considerations and the practical difficulty to achieve levels of 0.3 µg/L at reasonable cost for residential and small municipal drinking water systems, the Canadian Federal-Provincial- Territorial Committee on Drinking Water recommended a MAC of 10 µg/L (GCDWQ, 05/2006). This MAC is above the concentration considered "essentially negligible" for lifetime cancer risk (0.3 µg/L). The estimated cancer risk at this MAC is 3.0×10^{-5} to 3.9×10^{-4}. The MCLG for arsenic in the U.S. NPDWR is zero (because it is a carcinogen). The enforceable MCL is 10 μg/L for the same reasons as in Canada. Ontario set its Drinking Water Standard at 25 μg/L because of the difficulty for small drinking water systems to achieve a lower mandatory standard (Gibson, personal communication).

The United States Geological Survey (USGS) published the results of arsenic concentrations in 800 wells in the northern United States (USGS, 2007a). High concentrations of arsenic are found in eastern Wisconsin and southeastern Michigan. In the early 1990s the Wisconsin Department of Natural Resources (DNR) started investigations of arsenic levels in groundwater in northeastern Wisconsin. 3.5% of wells had concentrations greater than 50 μg/L, the standard at that time. The highest concentration was 15,000 μg/L. A program of drilling wells into a deeper aquifer with less arsenic began. 3,900 wells were tested in Outagamie and Winnebago counties in 2002-2004. About 20% of the well water samples were above the current standard of 10 μg/L. The Wisconsin DNR, with the Wisconsin Geological and Natural History Survey (GNHS), started a program to map concentrations in groundwater so that new wells could be drilled into the low arsenic deeper aquifer. These wells require casings to prevent arsenic-laden water from the shallow aquifer entering into them (Wisconsin DNR, 2006).

Fluoride

Fluoride concentrations in groundwater depend on the type of rock through which the water percolates. Fluoride compounds are widely distributed in the limestone and dolomitic rock that underlies much of the Great Lakes-St. Lawrence River Basin. It is frequently present in well water. Fluoride is the contaminant most frequently detected in groundwater by the Ontario Provincial Groundwater Monitoring Network (Grgic, personal communication). Fluoride was at one time considered an essential element for human nutrition, but attempts to demonstrate that it is required for growth and reproduction in laboratory animals have failed. Health Canada now recommends that guidelines for fluoride in drinking water should "only be based on the beneficial effect on dental caries." Fluoride at levels of total intake above 200 μg/kg bw (micrograms per kilogram body weight) per day has been shown to cause skeletal fluorosis (GCDWQ, 08/1996). The possibility that fluoridation of drinking water might increase the incidence of osteosarcoma in humans has not been confirmed (Bassin, Wypij, Davis and Mittleman, 2006; Hillier et al., 2000). There is limited evidence that fluoride can cause osteosarcoma in rats. Fluoride is not listed for carcinogenicity by the NTP (2005). IARC (2007), based on existing evidence, considers fluoride not classifiable as to its carcinogenicity to humans.

Fluoride does produce dental fluorosis. This condition is a permanent hypomineralization of dental enamel as the tooth develops. The tooth becomes discoloured when fluorosis is mild, but when it is severe the enamel actually erodes causing tooth pain and impaired chewing ability. After 5 - 6 years of age, the risk of fluorosis in children ceases. The maximum daily intake below which there is no significant risk of fluorosis has been estimated at 122 μg/kg bw per day. Based on the 122 μg/kg bw per day maximum intake from all sources, for a 13 kg child (at which the risk of fluorosis is greatest) for whom 50% of fluoride intake comes from drinking water and who drinks 0.8 litres a day, the MAC would be 1.0 mg/L. The MAC has been set at 1.5 mg/L because of the cost of reducing fluoride concentration in drinking water below this level (GCDWQ, 1996).

In the 1990s the dental community began active health promotion efforts to reduce excess fluoride toothpaste ingestion by children. The GCDWQ recommended that the 0.8 to 1.0 mg/L concentration for fluoridation of drinking water remain, but that it was not necessary to reduce the MAC from 1.5 to 1.0 mg/L. There would likely be no significant reduction in fluoride-associated health effects with this reduction of the objective (GCDWQ, 1996).

The MCLG and MCL for fluoride is 4 mg/L. U.S. EPA does not consider the health risks below 4 mg/L to warrant an enforceable standard. It has set a secondary drinking water standard for fluoride of 2 mg/L because of the risk of cosmetic effects on teeth between 2 and 4 mg/L (U.S. EPA, 2007a).

Nitrates and Nitrites

Nitrites are used in foods as preservatives to prevent botulism. Nitrite and nitrate ingestion in food exceeds the intake through drinking water. Nitrates in food are found primarily in vegetables. Nitrites react with amides and amines in the stomach to produce nitrosamides and nitrosamines. Nitrosamides are direct-acting carcinogens and nitrosamines are converted into carcinogens by cytochrome P450. The presence of vitamin C and other agents in vegetables can block the nitrosation of nitrate into nitrite in the stomach. Studies have therefore tried to assess possible human carcinogenic effects related to nitrate in drinking water, even though it provides only a small portion of nitrate intake unless levels in drinking water are very high. The IARC evaluation indicates that there is inadequate evidence in humans for the carcinogenicity of nitrate in food or drinking water. There is limited evidence in humans that nitrite in food is associated with stomach cancer. However, there is sufficient evidence that nitrite in combination with amides or amines causes cancer in experimental animals. Since nitrate can be converted to nitrite in the human stomach, the overall IARC evaluation is that ingested nitrate or nitrite under conditions that result in endogenous nitrosation is probably carcinogenic to humans (IARC, 2007).

The guidelines and regulations for nitrate and nitrite in drinking water are set based on the risk of methemoglobinemia for infants (blue baby syndrome). Blue baby syndrome can occur when nitrate measured as nitrogen concentration in drinking water is above 10 mg/L. Nitrate is converted to nitrite in the acid environment of the stomach. Nitrite interferes with the ability of infants' red blood cells to carry oxygen to the tissues. This risk exists for infants under six months of age (Centers for Disease Control and Prevention, 2003). The risk is eliminated by breast-feeding or by using water supplies without nitrate to reconstitute infant formula rather than contaminated well water.

U.S. EPA has established a MCL of 10 mg/L for nitrate measured as nitrogen in drinking water. The MCL for nitrite is set at 1 mg/L measured as nitrogen (U.S. EPA, 2007a). Canada's MAC is 45 mg/L nitrate which is roughly equivalent to 10 mg/L measured solely as nitrogen (45 mg of nitrate contains 10.2 mg of nitrogen). If nitrite is measured separately, the MAC is 3.2 mg/L nitrite (GCDWQ, 06/1987).

In a 1994 study the Wisconsin GNHS and the Department of Health and Family Services (DHFS) found that in an estimated 9% to 14% of private water wells the concentration of nitrate exceeded 10 mg/L. In 2005 the Wisconsin DNR integrated three extensive databases to map nitrate concentrations throughout the state in private wells. 11.6% of the most recent private water samples from 48,818 wells equaled or exceeded 10 mg/L nitrate in the groundwater. The highest exceedences were in Calumet, Columbia, Dane, LaCrosse and Rock counties where exceedences of the nitrate standard were in the 20% to 30% range (Wisconsin DNR, 2006).

Radionuclides

Radionuclides, in particular radium-226/228, are present in groundwater largely due to the decay of uranium and thorium. Both human and animal studies indicate that radiation exposure at low to moderate doses can increase the long-term incidence of cancer. Animal studies in particular suggest that the rate of genetic malformations may be increased by radiation exposure (World Health Organization, 2006).

The guidelines for radionuclides in drinking water in Canada are found in Annex B and for the United States in Annex D. As a routine measure drinking water is screened for gross alpha and gross beta radiation. The MAC for gross alpha radiation is 0.1 Bq/L. The MCL is 15 pCi/L. The Canadian and United States MAC and MCL are roughly equivalent (0.1 Bq = 17 pCi). The MAC for gross beta radiation is 1.0 Bq/L (GCDWQ, 02/1995). The MCL is 4 millirems/year (U.S. EPA, 2007a). If these guidelines are not exceeded, the likelihood that the MAC or MCL for specific radionuclides will be exceeded is very low. U.S. EPA has a MCL of 5 pCi/L specifically for the total of radium isotopes 226 and 228. No measurable radiological health effects are expected from consumption of drinking water if the concentrations of radionuclides are below the guideline and regulation levels.

Radionuclides exceed the drinking water standard for gross alpha and radium in many public drinking water systems in eastern Wisconsin. The radionuclides are found in the Cambro-Ordovician rock in a band that is roughly coincident with the Maquoketa subcrop pattern. This aquifer has radium concentrations as high as 30 pCi/L. Nearly 60 public drinking water systems exceed the gross alpha standard. Radium and its progeny are the primary alpha emitters causing these exceedences (Wisconsin DNR, 2006).

Radon

Underground rock containing natural uranium continuously releases radon into groundwater. Radon is released from water as it is used. Highest exposures from this source often occur with showering. Aeration with release of the radon into an unconfined environment will rapidly reduce the concentration of radon in the air. The use of radon-containing groundwater supplies not treated for radon removal for general domestic purposes will increase the levels of radon in the indoor air, thus increasing the dose from inhalation.

Radon-222 and its short-lived decay products caused about 19,000 deaths due to lung cancer in the United States in 1998 (NRC, 1999). The United States National Academy of Sciences (NRC, 1999) reports an approximate 100-fold smaller burden of lung cancer from exposure to radon in drinking water in the home, about 160 cases. The report also assessed that the risk of stomach cancer caused by drinking water that contains dissolved radon is extremely small, at about 20 deaths.

U.S. EPA was directed by the 1996 Safe Drinking Water Act to establish an MCL for radon. In 1999 the U.S. EPA issued a proposed rule with two options, an MCL of 300 pCi/L and an Alternative MCL of 4000 pCi/L. The AMCL would apply to communal water supplies serving 10,000 persons or fewer that were associated with a state or operator multimedia mitigation program. Removal of radon from water requires a costly aeration system. 99% of the population risk is associated with radon that enters homes and buildings directly from the ground rather than in the water. The multimedia mitigation program would reduce the burden of lung cancer associated with radon exposure to a greater extent than a lower MCL even though there is not a precise correlation between homes and buildings with high indoor radon levels and groundwater radon concentrations. Health Canada (2007b) has proposed a reduction in the Canadian indoor air guideline for radon, but Canada has not established a guideline for radon in drinking water (GCDWQ, 05/1995).

USGS has published the results of radon and uranium concentrations in 800 wells in the northern United States (2007b). High concentrations of radon and uranium are found in eastern Wisconsin and southeastern Michigan. Roughly 50% of Wisconsin's public water systems would exceed a radon standard of 300 pCi/L. Wisconsin has a radon-in-air program that would control total exposure to radon by inhalation. In this case the standard is 4,000 pCi/L (Wisconsin DNR, 2006).

Uranium

Uranium occurs naturally in the Earth's crust in many regions in the basin. It is a common groundwater contaminant. Uranium isotopes are radioactive but have a long half-life. Therefore they contribute only a small portion of the radioactivity associated with radionuclides in groundwater. Uranium is toxic to the kidney at concentrations for which the radiological risk is negligible. A MAC of 20 µg/L has been established based on this toxicity. There have been no adequate chronic studies of uranium nephrotoxicity in animals. A Tolerable Daily Intake (TDI) of 0.6 µg/kg bw per day for uranium is based on a 91-day study in rats with a lowest observed adverse effect level (LOAEL) of 60 µg/kg bw per day and an uncertainty factor of 100. At this TDI for a 70 kg individual with 35% of uranium intake coming from drinking 1.5 L of water per day (the other source being food) the MAC is calculated to be 10 µg/L. Given the difficulty in removing uranium from drinking water in the treatment process, the MAC has been set at 20 µg/L (GCDWQ, 10/1999). A value of up to 30 µg/L may be protective of kidney toxicity because of uncertainty regarding the clinical significance of the changes observed in animal studies. The MCL for uranium is 30 µg/L (U.S. EPA, 2007a).

In the summer of 2007 Cameco found that uranium and arsenic were leaking into the ground below its uranium hexafluoride plant at Port Hope, Ontario. The plant shut down and repairs are underway. Four wells were drilled to monitor movement of the uranium in groundwater beyond the footprint of the building. Excess uranium has been detected in one of the monitoring wells (Cameco, 2007).

Pesticides

Pesticide contamination of groundwater sources often results from agricultural activities, improper storage or disposal, and spills. The 2006 USGS report *Pesticides in the Nation's Streams and Ground Water, 1992-2001: A Summary* showed that there is widespread occurrence of pesticide contamination in United States surface and groundwater. This National Water Quality Assessment (NAWQA) survey had several unique features. It looked at pesticide and pesticide metabolite contamination in available untreated water resources, not post-treatment drinking water. It surveyed a wide range of land-use and hydrogeological settings throughout the United States rather than focusing on known hot spots. It focused on non-point source contributions from pesticide application in agricultural, urban and other settings. It targeted the specific land use settings that are the most extensive or are most important to water quality. As such the survey is very informative of the factors critical to good water quality. However, extrapolation from the survey to resources not measured must be done with care. Concentrations of pesticides were measured to the lowest economically and technically feasible level. Most of the detected pesticides in water were well below any human health, wildlife or aquatic ecosystem guidelines. Filtered water was analyzed so that measurements of pesticides that adhere to particulates may have been underestimated. This is a bigger problem with surface water rather than groundwater. The survey included many of the most heavily used herbicides and insecticides and their metabolites but only a fraction of all pesticides and their metabolites.

Concentrations of one or more pesticides exceeded human health benchmarks in about 1% of the drinking water wells sampled: 17 of 2,356 domestic wells and 8 of 364 public supply wells (USGS, 2006). Most of the exceedences were in observation wells rather than wells used for drinking water. Of the total 83 exceedences, 72 were because of dieldrin, 4 atrazine, 4 dinoseb, 2 lindane, and 1 diazinon. Aldrin (which breaks down into dieldrin in the environment) is no longer used in the United States and Canada, but dieldrin is extremely persistent in the environment. These exceedences were throughout the United States. Exceedences of the dieldrin human health benchmark are now less likely than at the time of the survey and will continue to decline. The survey included two study units in the Great Lakes Basin: the Western Lake Michigan drainages and the Lake Erie-Lake St. Clair drainages. Human epidemiological studies in the basin reported in the peer review literature have found health effects related to atrazine and aldicarb exposures.

Atrazine

Atrazine is an extensively used pre- and post-emergence weed control agent, especially for corn crops and rapeseed in Canada, corn and sorghum in the United States. Its use will likely increase with the increased production of corn to make ethanol. In some areas it is the pesticide most likely to be found in concentrations above health criteria in groundwater. Most human exposure is through drinking water rather than residues in food. Nausea and dizziness have been reported after drinking water contaminated with unspecified levels of atrazine. Atrazine is considered not classifiable as to its carcinogenicity to humans by IARC (2007) and it is not on the NTP (2005) carcinogen list. Atrazine has been shown to be carcinogenic in rats. It is genotoxic in only a few test systems. Atrazine has been shown to produce changes in mammalian steroid metabolism (GCDWQ, 04/1993) and is a known endocrine disruptor (State Environmental Resource Center, 2004). The acceptable daily intake (ADI) for atrazine is based on the no observed adverse effect level (NOAEL) for several endpoints divided by an uncertainty factor of 1,000. The MAC has been set on this basis at 5 µg/L for the sum of atrazine and its metabolites (GCDWQ, 04/1993). The MCL for atrazine is 3 µg/L (U.S. EPA, 2007a).

A survey of 1,285 farm wells in Ontario by Agriculture Canada in the fall of 1991 found that atrazine was the most common of four pesticides detected. 7.1% of wells contained atrazine or deethylatrazine, one of its metabolites. The median concentrations were 0.4 µg/L for atrazine and 0.35 µg/L for deethylatrazine; the maximum concentrations were 18.0 and 4.4 µg/L respectively. A repeat survey in the summer of 1992 found a higher percentage of detections, 10.5% (126 wells) and 6.3% (76 wells), respectively (GCDWQ, 04/1993).

In July 2005 the results for nearly 16,000 private wells tested by an immunoassay screen for atrazine were mapped by the Wisconsin Department of Agriculture, Trade and Consumer Protection. 40% of private wells had atrazine detections; 1% of private wells were above the MCL of 3 µg/L for atrazine and three of its metabolites. 7,000 well-water samples were tested by full gas chromatograph techniques. 25% had detectable atrazine; 5 % were above the MCL (Wisconsin DNR, 2006).

Aldicarb

Aldicarb is an insecticide that was widely used to control a variety of insects, mites and nematodes. Its use in Canada and the United States is now restricted. Aldicarb is one of the most acutely toxic pesticides, producing symptoms of dizziness, weakness, diarrhea, nausea, vomiting, sweating, abdominal pain, blurred vision, headache, muscular fasciculations, convulsions, paralysis and dyspnea. It is rapidly eliminated from the body so that episodes of acute poisoning are usually short lived. Several studies of a Wisconsin rural population showing an immunological effect had some methodological limitations. The dose of aldicarb was not calculated on a body weight basis; half the control group was on municipal water rather than low aldicarb well water. The presence of other contaminants in the well water was not determined in the original study. There is some evidence of immunotoxic effects of aldicarb in animal studies. Aldicarb has not produced increased tumour incidence in carcinogenicity bioassays in rats and mice. Aldicarb is considered not classifiable as to its carcinogenicity to humans by IARC (2007) and it is not on the NTP (2005) carcinogen list. Aldicarb has an estimated NOAEL of 10 µg/kg bw per day for inhibition of red blood cell cholinesterase and sweating based on the LOAELs observed for these acute effects in a human volunteer study with men and women. The ADI of 1 µg/kg bw per day has an uncertainty factor of 10 for the variability in human populations. The MAC is calculated at 9 µg/L based on the ADI of 1 µg/kg bw per day for a 70-kg adult drinking 1.5 litres of water per day with a 20% allocation of exposure to drinking water (GCDWQ, 02/1987). There is no current U.S. EPA MCL for aldicarb.

Aldrin and Dieldrin

Aldrin and dieldin are chlorinated hydrocarbon insecticides that have not been used except as an underground termiticide since the mid-1970s, and that use ceased in about 1990. Aldrin is converted to dieldrin in the environment. Dieldrin is more stable and highly persistent. Aldrin and dieldrin bioaccumulate in adipose tissue. They are highly toxic to the human central nervous system and liver. In samples of human breast milk (n = 497) a Canada-wide survey found 94% contained detectable levels of dieldrin (detection limit 0.04 ng/g). The median concentration was 0.26 ng/g. Aldrin and dieldrin are considered not classifiable as to their carcinogenicity to humans by IARC (2007) and they are not on the NTP (2005) carcinogen list. The ADI of 0.0001 mg/kg bw per day for both pesticides is based on a NOAEL of 0.025 mg/kg bw per day in rat studies with an uncertainty factor of 250. The MAC of 0.0007 mg/L is calculated with this ADI for a 70-kg adult drinking 2 litres of water a day with 20% of aldrin or dieldrin exposure allocated to drinking water (GCDWQ, 1994). There is no current U.S. EPA MCL for aldrin or dieldrin.

Chlorinated solvents

Chlorinated solvents, such as tri- and tetrachloroethylene, are widely used for metal degreasing and dry cleaning. These volatile organic compounds (VOCs) enter groundwater sources through leaking underground storage tanks, pipeline facilities, the improper disposal of dry cleaning products, hazardous chemical spills and abandoned or poorly designed landfill sites. These chemical compounds are only sparingly soluble in water but are miscible with water. When discharged or spilt onto the ground they rapidly soak through the soil and, where the aquifer is vulnerable to surface contamination, they enter the aquifer. The rate of degradation of these chemicals is extremely slow. They have caused significant pollution of groundwater used for drinking water.

In the past, waste solvents were disposed of into shallow pits, in the expectation that they would evaporate. Although no longer common, this practice resulted in significant areas of historical pollution of groundwater dating back many decades. In some cases, the subsequent development of the aquifer as a drinking water source has resulted in these chemicals being drawn to the groundwater abstraction point after an extended period of pumping. Remediation efforts to effectively remove these solvents and other VOCs from contaminated soil and groundwater can prove quite costly.

Trichloroethylene

Trichloroethylene (TCE) has been shown to be carcinogenic in studies on rats and mice. There is evidence of an association between TCE in drinking water and cancer in humans, but the presence of other chemicals in the contaminated drinking water makes the association specifically to TCE less certain. IARC (2007) considered TCE probably carcinogenic to humans. The NTP (2005) considers TCE to be reasonably anticipated to be a human carcinogen. The human studies do not give a precise estimate of the risk. Based on a study of kidney cancer in female rats, a MAC for TCE of 22 µg/L in drinking water would give an essentially negligible risk of cancer of 1×10^{-6}. TCE, however, is also a reproductive toxin producing cardiac malformations in animals and humans. The benchmark estimate for a NOAEL based on the LOAEL in a key study gives a MAC of 5 µg/L for TCE. The MAC was therefore set at this lower level (GCDWQ, 05/2005). The MCL is also 5 µg/L and the MCLG is zero (U.S. EPA, 2007a).

Tetrachloroethylene

Tetrachloroethylene, also known as perchloroethylene or PERC, has been widely used for dry cleaning and metal cleaning. Epidemiological studies of dry cleaners and launderers have not separated tetrachloroethylene exposure sufficiently from other chemical exposures nor have they been able to accurately estimate the cumulative dose of tetrachloroethylene exposure. The study results for human cancers are inconsistent and insufficient to establish that tetrachloroethylene is a human carcinogen. Studies in rats and mice have given positive results for some tumours, but there are metabolic differences in the metabolism of tetrachloroethylene in rats and mice compared to humans. However, IARC (2007) considered tetrachloroethylene probably carcinogenic to humans. The NTP (2005) considers tetrachloroethylene to be reasonably anticipated to be a human carcinogen. Health Canada has not used carcinogenicity as the basis for its MAC. The TDI for tetrachloroethylene has been set at 14 µg/kg bw day based on a NOAEL of 14 µg/kg bw per day for increased liver and kidney body weight ratios in rats with an uncertainty factor of 1,000. The MAC has been calculated at 30 µg/L based on this TDI: 14 µg/kg bw per day for a 70-kg adult with 10% of exposure coming from 1.5 L of drinking water per day and a further reduction of 50% because of the high dermal absorption of tetrachloroethylene (GCDWQ, 10/1995). The MCL is 5 µg/L based on the probable carcinogenicity of tetrachloroethylene. The MCLG is zero (U.S. EPA, 2007a).

Volatile Organic Compounds

Volatile organic compounds (VOCs) are a group of common industrial and commercial chemicals such as gasoline, industrial solvents, paints, paint thinners, drain cleaners and household products such as stain removers or air fresheners. Fuel leaks from large storage tanks are a significant source of groundwater contamination in many areas of the basin, particularly where the storage and handling of fuels is poor. Many VOCs can pool on the surface of aquifers, causing long-term contamination. The more volatile fuels (e.g., gasoline) contain compounds that will dissolve in water, in particular, the BTEX compounds. Drinking water contaminated with these fuels can be aesthetically unacceptable to consumers at concentrations that do not present a significant health risk.

Leaks of petroleum products have been increasing over the last two decades because underground steel tanks installed in large numbers in the 1950s and 1960s have become corroded. Before 1980, most underground tanks were made of steel. Without adequate corrosion protection, up to half of them leak by the time they are 15 years old. One litre of gasoline can contaminate 1,000,000 litres of groundwater (Environment Canada, 2000). This problem is particularly severe in areas where there is a high use of groundwater. In many cases, the problem is noticed long after the aquifer is contaminated, for example, when residents start tasting or smelling gasoline in their drinking water or noticing oily slicks in their toilet tanks.

There are 72 active licensed landfill sites in Wisconsin. All are required to monitor groundwater. The

Wisconsin DNR keeps track of about 20,000 leaking underground storage tanks and 4,000 waste facilities. 59 different VOCs have been detected in Wisconsin groundwater; 34 of these compounds have health standards. Studies of Wisconsin landfills found that 27 of 45 unlined municipal and industrial landfills had VOC contamination in groundwater, as did 21 of 26 unlined municipal solid waste landfills. Six engineered landfills with liners and leachate collection systems showed no contamination in groundwater. 1,1-dichloroethane was the VOC that was most frequently detected (Wisconsin DNR, 2006).

In a well water survey in 1998 and 1999 by the Wisconsin DHFS, eight private wells down-gradient of 17 small closed landfills in Ozaukee County had VOC concentrations above the U.S. EPA MCLs. A further study in 1999 of 16 old closed landfills divided evenly among the five Wisconsin DNR regions in the state tested 113 wells; 31 had measurable VOCs and 14 had concentrations above the drinking water standards.

Extensive contamination of groundwater has occurred in areas of industrial concentration in the Great Lakes basin. The Grand Calumet River Area of Concern has 52 sites listed under CERCLA, of which five are Superfund sites. There are 423 hazardous waste sites in the Area of Concern. More than 150 leaking underground storage tanks have been reported since mid-1987. The groundwater beneath the Area of Concern has been extensively contaminated with organic compounds, heavy metals and petroleum products. The U.S. EPA estimates that at least 16.8 million gallons of oil float on top of the groundwater. This contamination threatens areas of the Grand Calumet River from which contaminated sediment has been removed (U.S. EPA, 2007c).

The situation is similar in all the Great Lakes states and the provinces of Ontario and Quebec. Older closed landfills often contaminate the private wells down gradient from the site. Some but not all these sites are monitored. Better information exists for the major hazardous waste sites. There are scattered unapproved disposal sites that do not come to attention unless neighboring wells begin to show a problem.

Benzene

Benzene like most solvents causes acute central nervous system symptoms at high levels of exposure: dizziness, headache, drowsiness and nausea. At low concentrations benzene is toxic to the haematopoietic system, causing thrombocytopenia, aplastic anemia and several forms of leukemia. Benzene is classified as a known human carcinogen by the NTP (2005) and IARC (2007). The MAC for benzene in drinking water as a human carcinogen is based on lifetime cancer risk and the available practicable treatment technology to remove it from drinking water. The MAC is 5 μg/L. The estimated lifetime risk for benzene exposure (based on mouse and rat studies) is 3.1×10^{-6} to 3.4×10^{-5} at this concentration. This MAC is under review. Routine treatment processes do not remove benzene well, but concentrations of 1 μg/L can be achieved with packed tower aeration and granular activated carbon adsorption. Benzene can be measured in the laboratory down to 5 μg/L within reasonable limits of accuracy and precision (GCDWQ, 04/1986). The MCL is also 5 μg/L. The MCLG is zero (U.S. EPA, 2007a).

Toluene, Ethylbenzene and Xylenes

Canada has not set an MAC for gasoline or for its constituents such as toluene, ethylbenzene and xylenes other than benzene. Most of the toxicological information on the alkylbenzenes and xylenes is based on exposure by the inhalation route. The exposures known to produce significant central nervous system effects for these compounds are several orders of magnitude greater than concentrations with a disagreeable odour and taste. When these compounds enter groundwater, they retain their offensive taste and smell at very low concentrations. Individuals are not likely to drink extensive amounts of such water and therefore unlikely to suffer harm. However, these compounds render the water undrinkable and therefore low concentrations of toluene, ethylbenzene and/or xylene require alternative drinking water supplies or point source treatment. The Canadian aesthetic objective for ethylbenzene is 0.0024 mg/L, for toluene 0.024 mg/L and for total xylenes 0.3 mg/L (GCDWQ, 02/1986). The U.S. EPA has set MCLs that are health based at much higher concentrations: ethylbenzene 0.7 mg/L, toluene 1.0 mg/L and xylenes 10.0 mg/L (2007a). None of these VOCs is on the NTP (2005) carcinogen list; they are considered unclassifiable as to carcinogenicity by IARC (2007).

OTHER CHEMICALS

Sodium

Sodium is a very soluble natural element found in groundwater. It also enters groundwater because of the widespread use of road salt and brine rising up in oil and gas wells. The maximum recommended daily dietary allowance for sodium is 2,400 mg. However, many individuals are on sodium-restricted diets because of cardiovascular conditions. The GCDWQ (12/1992) set a guidance value of 200 μg/L. At this level public health authorities routinely advise consumers of the drinking water and physicians that an alternative source of drinking water may be warranted. The U.S. EPA has an outdated guidance level of 20 mg/L. Although such a level might have a benefit at the population level in reducing hypertension and cardiovascular disease, it is unrealistic. Sodium has been put on the Contaminant Candidate List for reevaluation (U.S. EPA, 2007b).

Hardness

The hardness of water is expressed in terms of the amount of calcium carbonate – the principal constituent of limestone – or equivalent minerals that would be formed if the water were evaporated. Water is considered soft if it contains 0 to 60 mg/L of hardness, moderately hard from 61 to 120 mg/L, hard between 121 and 180 mg/L and very hard if more than 180 mg/L of dissolved solids. Very hard water is not desirable for many domestic uses; it will leave a scaly deposit on the inside of pipes, boilers and tanks. Hard water can be softened at a fairly reasonable cost, but it is not always desirable to remove all the minerals that make water hard. Extremely soft water is likely to corrode metals, although it is preferred for laundering, dishwashing and bathing. Softened water contains an increased concentration of sodium that makes it unsuitable as drinking water. Hardness levels for residential water are targeted at 80 to 100 mg/L calcium carbonate. Levels above 500 mg/L are unacceptable for domestic purposes (GCDWQ, 1979).

Calcium and magnesium are essential to human health. A large body of scientific information demonstrates a beneficial relationship between high levels of hardness and the development of stronger bone structure. Some studies have demonstrated a reduction in certain types of cardiovascular disease in populations using hard water as their drinking water supply (Monarca, Donato, Zerbini, Calderon and Craun, 2006). This effect may be related to the magnesium rather than the calcium in the drinking water of populations with overall low magnesium in their diet (Durlach, Bara and Guiet-Bara, 1985). These effects are biologically reasonable but have not been demonstrated conclusively.

Methyl *Tert*-Butyl Ether

Methyl *tert*-butyl ether (MTBE) is added to gasoline to increase the octane level and to reduce carbon monoxide and hydrocarbon emissions by vehicles. MTBE has been the most commonly used fuel oxygenate (GCDWQ, 07/2006). The release and distribution of MTBE in the aquatic environment has raised concern about the compound's occurrence in drinking water, due to its low taste-and-odour threshold and the potential impact on human health (Kolb and Puttmann, 2006). Potential and documented contamination of water resources by MTBE has become a cause for public concern and increasing controversy. MTBE readily dissolves in water, can move rapidly through soils and aquifers, is resistant to microbial decomposition and is difficult to remove in water treatment. Beginning in the early 1990s, when lead was removed from gasoline, MTBE has been added in much higher concentrations (up to 15%) to enhance gasoline combustion and reduce tailpipe emissions in the United States. Methylcyclopentadienyl manganese tricarbonyl has been used for this purpose in Canada.

The U.S. EPA has not established drinking water regulations for MTBE. In December 1997 the U.S. EPA issued a Drinking Water Advisory for MTBE at levels of 20 to 40 μg/L, primarily for taste and odour considerations. Based on present knowledge, the U.S. EPA believes this provides a wide margin of safety (U.S. EPA, 1997). 30% of the United States population lives in areas where MTBE is regularly used. Concentrations in tap water in excess of 2 μg/L are unlikely (Stern and Tardiff, 1997). A MAC for MTBE has not been set in Canada (GCDWQ, 07/2006).

Manganese

Manganese is an essential element required for normal body functions. Manganese deficiency is rare; the body's needs are fulfilled through dietary intake with retention of 3% to 5% of ingested manganese. Most knowledge on the effects of excess exposure comes from studies of workers exposed to manganese dust or patients with chronic liver dysfunction, which results in higher manganese retention (for review see Mergler and Baldwin, 1997). The nervous system is the major target organ; effects are on a continuum: subtle changes, particularly in motor functions and mood are observed at lower levels of exposure and manganism, a degenerative neurologic disorder with many similarities to Parkinson's Disease, at high levels of exposure. Until recently, little attention has been paid to manganese in drinking water, but reports suggesting increased infant mortality (Hafeman, Factor-Litvak, Cheng, Van Geen and Ahsan, 2007), intellectual deficits (Wasserman et al., 2006), and increased hyperactive behaviour in children (Bouchard, Laforest, Vandelac, Bellinger and Mergler, 2007) associated with elevated manganese in drinking water have given rise to new concern and questioning of the current drinking water guidelines (Ljung and Vahter, 2007).

Manganese at levels of 150 μg/L stains laundry and plumbing fixtures and causes undesirable tastes in beverages. This problem can occur at concentrations as low as 20 μg/L, but it is difficult to reduce manganese concentrations below 50 μg/L. The GCDWQ (11/1987) set an aesthetic objective of 50 μg/L. The U.S. EPA secondary standard is also 50 μg/L (2007a).

Table 1. Chemical Contaminants in Groundwater

Chemical	GCDWQ MAC – mg/L AO – aesthetic objective	U.S. EPA MCL – mg/L
Arsenic Health Effects – increased risk of several cancers; possible increased incidence of circulatory, cerebrovascular, and kidney diseases and diabetes	0.010	0.010 MCLG = zero
Fluoride Health Effects – fluorosis with pain and tenderness of the bones; children may get mottled teeth	1.5	4.0 primary standard 2.0 secondary standard
Nitrate/Nitrite Health Effects – risk of methaemoglobulinemia in infants below the age of six months	45.0 total nitrate/nitrite = 10 mg/L nitrate-nitrogen; if nitrite is measured separately, nitrite should not exceed 3.2 mg/L	10.0 mg nitrate measured as nitrogen 1.0 mg nitrite measured as nitrogen
Radionuclides Health Effects – various cancers	See Annex B	See Annex D
Radon Health Effects – ingestion increases the possibility of internal organ cancer, specifically stomach cancer. Inhalation of radon gas released from use of household water increases the chances of lung cancer over the course of a lifetime	A MAC for radon in drinking water has not been established	Proposed MCL 300 pCi/L. AMCL 4,000 pCi/L where a multimedia management program is in place
Uranium Health Effects – kidney toxicity; increased risk of cancer	0.020	0.030
Atrazine Health Effects – cardiovascular damage, reproductive problems	0.005	0.003
Aldicarb Health Effects – inhibition of red blood cell cholinesterase; possible immunotoxicity	0.009	No MCL
Aldrin/Dieldrin Health Effects – central nervous system and liver toxicity; bioaccumulates	0.007 total aldrin + dieldrin	No MCL
Trichloroethylene Health Effects – liver toxicity; increased cancer risk	0.005	0.005 MCLG = zero
Tetrachloroethylene Health Effects – liver and kidney toxicity; probable human carcinogen	0.030	0.005 MCLG = zero
Benzene Health Effects – aplastic anemia; decrease in blood platelets; increased risk of haematopoetic cancers	0.005	0.005 MCLG = zero
Ethylbenzene Health Effects – liver and kidney toxicity	AO ≤ 0.0024	0.7
Toluene Health Effects – nervous system, liver and kidney toxicity	AO ≤ 0.024	1.0
Xylenes Health Effects – nervous system toxicity	AO ≤ 0.3	10.0
Sodium Health Effects – intake greater than 1.0 gram/day increases risk of hypertension and cardiovascular disease in susceptible individuals	≤ 200.0	20 mg/L guidance level under review; on Contaminant Candidate List
Hardness Health Effects – probable cardiovascular health benefit	Total dissolved solids ≤500 mg/L	Total dissolved solids ≤ 500 mg/L
Manganese Health Effects – possible neurobehavioural effects in children	≤50.0 AO	50.0 secondary standard
Methyl *tert*-butyl ether Health Effects – uncertain; serious effects unlikely at concentrations in drinking water that do not have an offensive odour or taste	No guideline	0.02 - 0.04 special drinking water advisory

Agriceuticals, Pharmaceuticals and Personal Care Products

Antibiotics and a variety of other pharmaceuticals for animals (agriceuticals) are widely used in agriculture. They are present in the manures used for land spreading and enter the environment in that way. Human use of pharmaceuticals and personal care products has put many chemicals into the human waste stream, in part to municipal landfills but primarily to sewage treatment plants. Many of these chemicals are not broken down by wastewater treatment processes and are discharged with the wastewater into rivers, streams or the nearshore environment of lakes. Some can be broken down by newer technologies (Christen, 2007). They are present in biosolids that are spread on land. They sometimes have direct access to groundwater in situations like abandoned wells that provide direct access into groundwater for chemicals leaching out of the manures and biosolids.

The USGS has done extensive surveys of their presence in surface and groundwater. They have been detected primarily in surface waters. The most common chemicals found in surface water have been coprostanol (a fecal steroid), caffeine, cholesterol, DEET, tri(2-chloroethyl) phosphate (a fire retardant), 4-nonylphenol and triclosan (USGS, 2002). Triclosan, an antimicrobial disinfectant, is used in many consumer products under a variety of trade names. Concern has been raised that it may be a threat to human health because of trace amounts of dioxin it contains as an impurity and because it can be converted to dioxins when exposed to sunlight. The most serious concern, however, is its potential to promote the development of antibiotic-resistant bacteria (Glaser, 2004). Antibiotic-resistant bacteria, including pathogenic ones, are frequently found downstream of wastewater treatment plants (Ash, 2004).

Schwab et al. (2005) carried out health risk assessments for 26 active pharmaceuticals and/or their metabolites that have been found in U.S. surface and groundwater. Fourteen different drug classes were covered. ADIs that took into consideration sensitive subpopulations were calculated from the toxicological information available on the active pharmaceutical ingredients. Predicted no-effect concentrations were then calculated for drinking water and fish consumption. No appreciable risk to human health associated with the trace amounts in water and fish was found for any of the 26 compounds.

Summary

Table 1 summarizes the MACs and MCLs for the contaminants discussed above. The health effects listed are those upon which the MACs and MCLs were established and/or other effects likely to occur at concentrations in the range of the MACs and MCLs. These chemicals have a number of other serious health effects at higher concentrations.

GREAT LAKES-ST. LAWRENCE RIVER BASIN HUMAN HEALTH EFFECT STUDIES

A literature search on MEDLINE for groundwater/ground water limited by the keyword "water pollutants/chemical" and a separate search limited by the keyword "adverse effects" and searches for well water with the same limiters found 11 epidemiological studies in which all or part of 9 study populations residing in the Great Lakes-St. Lawrence River basin were exposed to specific contaminants in groundwater. Of these, four looked at arsenic, one at atrazine, two at aldicarb and two at nitrate exposure. One study each looked at exposure to fungicides/herbicides and manganese. Seven of the studies were done in Wisconsin. Only one was done in Canada.

Arsenic

Knobeloch, Zierold and Anderson. (2006) conducted a survey of residents in 19 rural townships in the Fox River valley in Wisconsin. Study participants provided well water samples and completed a questionnaire regarding their residential history, well water consumption and family health. The study collected information from 6,669 residents. The study examined samples from 2,233 household wells. Well water arsenic ranged from less than 1.0 to 3,100 µg/L. The median level was 2.0 µg/L. 11% of the wells had arsenic levels above 20 µg/L; 80% were below the U.S. EPA drinking water standard of 10 µg/L. In residents over 35 years of age who had consumed water with elevated arsenic levels for at least 10 years, there was a significant increase in a history of skin cancer. For those with arsenic levels between 1.0 and 9.9 µg/L compared to those less than 1.0 µg/L there was a significant 80% increase in skin cancer risk. For those with arsenic concentrations equal to or greater than 10 µg/L compared to those less than 1.0 µg/L, the risk for skin cancer was 90% higher. Haupert, Wiersma and Golring. (1996) reported in a 1992-1993 study that Wisconsin residents with an estimated intake of arsenic equal to or greater than 50 µg/day were significantly more likely to report a diagnosis of skin cancer.

Zierold, Knobeloch and Anderson (2004) reported on the rates of 9 chronic diseases in a survey of 1,185 Wisconsin residents who provided private well water samples and were part of the larger study population in the Fox River Valley by Knobeloch et al. (2006). They had been drinking their well water for at least 20 years. Respondents whose well water arsenic level was equal to or greater than 2 µg/L had statistically significant elevated rates of depression, high blood pressure, circulatory problems and bypass surgery.

Meliker, Wahl, Cameron and Nriagu (2007) studied residents in southeastern Michigan looking for elevated risks for 23 diseases in six contiguous counties where there were moderately elevated levels of arsenic in the drinking water. From 1983 through 2002, arsenic levels for 9,251 well-water samples were determined by the Michigan Department of Environmental Quality. The mean arsenic concentration was 11 µg/L and the population-weighted median was 7.58 µg/L. Significantly elevated mortality rates were found in both men and women for all diseases of the circulatory system, cerebrovascular diseases, diabetes and kidney diseases. Although the ecological design of this study provides only weak evidence for a causal association, the authors concluded that it provides some of the first evidence that low to moderate levels of arsenic in drinking water may be associated with common causes of mortality.

Atrazine

McElroy et al. (2007) examined the association between atrazine exposure and breast cancer among women living in rural Wisconsin. Cases of breast cancer in women 20-79 years of age incident between 1987 and 2000 were identified (n= 3,275). Female controls of similar age were randomly selected (n= 3,669). Three random statewide assessments of atrazine in well water had been conducted in 1994, 1996 and 2001. These data were used to map atrazine levels in groundwater. The atrazine exposure for study participants was estimated based on the combined results of the three years of sampling. The number of wells exceeding the U.S. EPA standard of 3 µg/L ranged from 0 to 3% in different agricultural regions of the state. No significant association between atrazine exposure and breast cancer was found. This result could be a false negative because of the small numbers who were exposed above the U.S. EPA standard or because of the imprecision in the estimates of actual exposure to atrazine.

Aldicarb

Fiore et al. (1986) studied 50 women ages 18 to 70 residing in Portage County, Wisconsin. Aldicarb had been shown to be an immune suppressant in laboratory mice. None of the study women had any known medical reason for immune dysfunction. All used well water as their drinking water supply. Twenty-three had detectable levels of aldicarb in their well water. The mean level was 16.1 µg/L; 12 in the 1-10 µg/L range and 11 in the 11-61 µg/L range. The study found that 27 individuals drank water from a municipal well that had not had any detectable aldicarb in the previous 4 years. T lymphocyte subsets were measured in study participants. The exposed women had a significantly increased absolute number of T8 cells, increased percentage of total lymphocytes as T8 cells, decreased percentage of total lymphocytes as T4 cells and a decreased T4:T8 ratio. These findings are indicative of some form of immune dysfunction. There was a statistically significant negative correlation between the well water concentration of aldicarb and the T4:T8 ratio. There was also a statistically significant negative correlation between calculated aldicarb ingestion and T4:T8 ratio. Although this change in T4:T8 ratio was not associated with any known clinical immunodeficiency and its long-term implications are not known, this study shows the potential biological impact of low-level pesticide exposure in drinking water.

Mirkin et al. (1990) reported on a follow-up study of 45 of the 50 women in Portage County who participated in the Fiore et al. (1986) study. Of these, 18 of the formerly exposed and 27 of the formerly unexposed women took part in the follow-up study. Only 5 of the 45 women were currently exposed to aldicarb. These 5 women had an increased percentage of lymphocytes in their blood with an increased number of T8 cells. Within this small number of exposed women there was a dose-response relationship between aldicarb ingestion and this increase. No contaminant other than aldicarb was found in the drinking water that could explain these findings.

Herbicides/Fungicides

Greenlee, Arbuckle and Chou (2003) reported on a study that looked at agricultural and residential exposures and the risk of infertility in women. The study examined 322 cases and controls selected from patients at a large medical clinic in central Wisconsin. Between 1997 and 2001, women and their partners responded to a telephone interview that assessed their state of health and occupational and lifestyle exposures. Women who had mixed and applied herbicides at any time two years prior to attempting to become pregnant had significantly reduced fertility. Mixing and applying fungicides by either partner prior to attempting pregnancy had a non-significantly increased risk for female infertility. Residences using groundwater compared to municipal water had significantly reduced infertility in women.

Nitrates

Craun, Greathouse and Gunderson (1981) reported on a study of 102 children in Washington County, Illinois, 1-8 years old. Their well water contained 22-111 mg/L (nitrate), at levels greater than the U.S. EPA 10 mg/L drinking water standard. Nitrate is converted to nitrite in the stomach. Nitrite reacts with hemoglobin in red blood cells to produce methemoglobin. Methemoglobin reduces the oxygen carrying capacity of the blood, causing blue baby syndrome. None of the children had significantly elevated methemoglobin levels and there was no dose-response relationship between methemoglobin and nitrate levels. This study supports the conclusion that the known risk for blue baby syndrome from nitrate/nitrite exposure is limited to very young infants.

Rademacher, Young and Kanarek (1992) conducted a case-control study of Wisconsin residents who died of gastric cancer from 1982-1985 compared with deaths from other causes. The level of nitrates in the drinking water of the study participants was determined. Private water sources were tested. Levels in municipal water were determined from the historical record. Matched-pair analysis was conducted using 0.0-0.5, 0.6-2.5, 2.6-5.0, 5.6-10.0 and >10.0 mg/L nitrate concentrations as the exposure levels. No association between nitrate in drinking water and gastric cancer was found at any of these levels. Most of the exposure levels were below the United States and Canadian 10 mg/L drinking water standard.

Manganese

Bouchard et al. (2007) studied 24 boys and 22 girls 6-15 years of age. Drinking water for 28 of the children living in a small Quebec community came from a well with a mean concentration of 500 µg/L manganese (W1); drinking water for the remaining 18 children came from a well with a mean manganese concentration of 160 µg/L (W2). The children were assessed for hyperactivity, oppositional behaviour, cognitive problems/inattention and ADHD using the four subscales of the Revised Conners' Rating Scale (RCRS) tool. The RCRS has separate questionnaires for parents and teachers. The children who drank from W1 had significantly higher hair manganese levels than those who drank from W2. Hair manganese concentration was significantly associated with oppositional behavior and with hyperactivity as seen in the classroom, but not observed by parents in non-school situations. The hypothesis of an association between manganese exposure and neurobehavioral effects in children warrants further study.

Summary

This report reviews the epidemiological studies that have been done on health effects related to chemicals in groundwater in specific Great Lakes-St. Lawrence River Basin populations. These studies support an increased risk of skin cancer and some chronic diseases for Great Lakes basin residents with exposure to elevated levels of arsenic in their drinking water. There was also evidence of a possible effect of exposure to pesticides in well water on fertility and immune function as well as an effect of manganese on children's behaviour. Monitoring for the presence of chemicals in groundwater has increased in recent years. Further studies of human populations exposed to the hazardous chemicals in groundwater as identified in these studies are needed to assess and address any health implications.

There are few studies available to review for this report. They represent only a small portion of the likely individual exposure to chemicals in groundwater for Great Lakes basin residents. While public drinking groundwater supplies are routinely tested for chemical contaminants, many individuals do not have their wells checked for chemical contamination. Such testing is more expensive than more routine testing for microbial contamination. Detailed monitoring and epidemiologic studies are needed to determine the full extent of individuals who have been made sick by chemicals in their well water.

OUTBREAKS AND CASE REPORTS OF ILLNESS

Since 1971 the Centers for Disease Control and Prevention (CDC), the U.S. EPA and the Council of State and Territorial Epidemiologists have maintained a collaborative Waterborne Disease and Outbreak Surveillance System that tracks outbreaks of waterborne disease related to drinking water (WBDOs). The data from this surveillance system is published in *The Mortality and Morbidity Weekly Report* (MMWR). This report focuses primarily on communicable disease outbreaks including those that are waterborne through drinking water, but it also gathers information on a voluntary basis from the states on outbreaks of illness caused by chemicals in drinking water. As such the information is not complete, since the outbreak has to be recognized, reported to state authorities and then reported to CDC before it is included in the MMWR record. The MMWR also sometimes publishes reports of individual cases of illness related to chemical exposure. *Canada Communicable Diseases Report* is a similar publication in Canada but, as its name implies, its scope is limited to communicable disease.

In 2003-2004 MMWR reported eight outbreaks related to chemicals in drinking water affecting 27 persons. Three outbreaks were related to copper in drink mix/soda machines; three involved contamination of bottled water by bromate and other disinfection by-products, cleaning products or gasoline by-products; and two were related to discharges of sodium hydroxide into community water supplies. Two were in Minnesota, one in New York (MMWR, 2006).

In 2001-2002 there were five outbreaks affecting 39 persons. One was related to copper in a church's well water in Minnesota; one to copper and other metals in school well water in Minnesota; one to industrial copper contamination in river/stream water in Ohio; one to ethylene glycol contamination of a school's well water supply in Florida; and one to ethylbenzene, toluene and xylene in bottled spring water in Florida. Reported outbreaks of disease related to contamination in raw groundwater itself are very few (MMWR, 2004).

Figure 1 shows the record of various kinds of waterborne outbreaks reported in MMWR since 1971 (MMWR, 2006). Very few of these have related to chemical contamination, fewer still to groundwater and few occurred in the Great Lakes Basin. The United States-

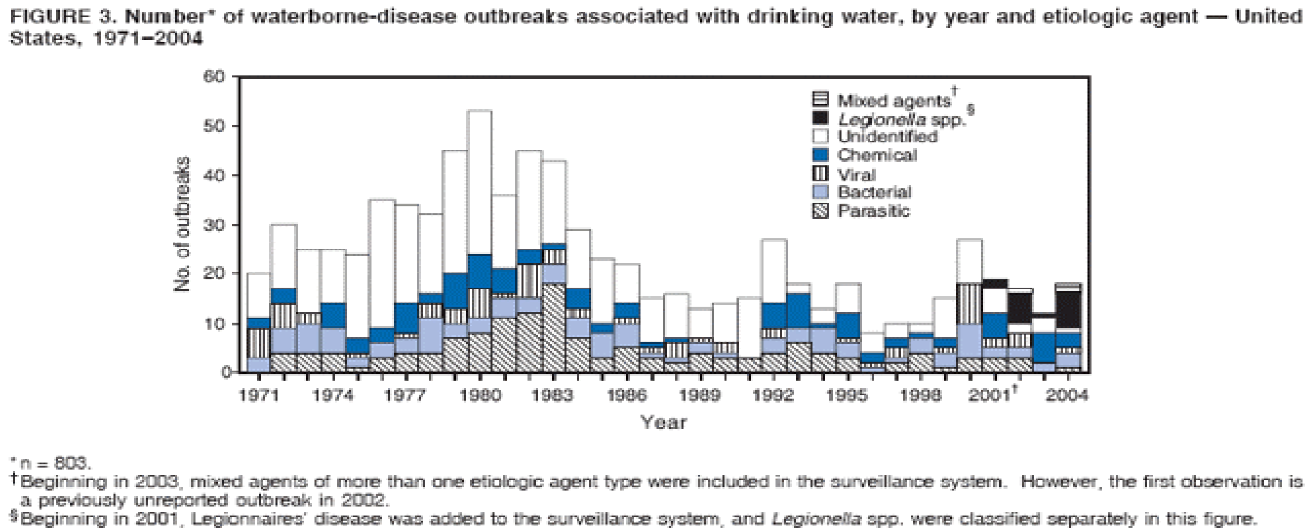

Figure 1. Number* of waterborne-disease outbreaks associated with drinking water by year and etiologic agent – United States 1971-2004.

wide data reveal very few reported outbreaks of disease related to chemicals in groundwater. There may well be many unreported cases, especially of milder illness.

Knobeloch et al. (2000) reported on two cases of blue baby syndrome in Wisconsin. Both babies were bottle-fed. The formula was reconstituted with water from private wells with levels of 22.9 and 27.4 mg/L nitrate at the time of the infants' illness.

MMWR (1993) reported a case of blue baby syndrome in a six-week-old girl in Wisconsin. The well water had a concentration of 39.6 mg/L nitrate-nitrogen. Elevated copper levels also were found in the tap water. A reverse osmosis unit on the plumbing system failed to reduce nitrate levels in the drinking water adequately to prevent blue baby syndrome. The tap water was used to reconstitute infant formula.

SURVEILLANCE AND MONITORING FOR CHEMICALS IN GROUNDWATER

Ontario Provincial Groundwater Monitoring Network

The Ontario Provincial Groundwater Monitoring Network (OPGMN) is a partnership program of the Ontario Ministry of the Environment with the local conservation authorities and local municipalities where there are no local conservation authorities (OPGMN, 2007). The OPGMN now has 423 wells that are located in various areas, including contaminated sites. The local conservation authorities or municipalities collect water from these wells. The wells are monitored for the ambient (baseline) groundwater quantity, flow and quality of specific aquifers. This information helps establish baseline conditions and assess how groundwater is affected by land use and water use.

The OPGMN monitors groundwater for chemical exceedences in accordance to the Ontario Drinking Water Quality Standards (O. Reg. 169/03) under the Safe Drinking Water Act, 2002. The program also uses the Guidelines for Canadian Drinking Water Quality and the Ministry *Guidelines for Use at Contaminated Sites in Ontario* to determine which chemicals are of interest and may exceed the "upper limit" (threshold value used when a chemical is not included in O. Reg. 169/03). The information collected is intended to help identify trends and emerging issues and provide guidance to local decision-making authorities in their resource management decisions. Two of the pesticides of note that were detected from the monitoring wells are chlorpyrifos and diazinon. The OPGMN has reported that none of the pesticides detected are in exceedence of the Ontario Drinking Water Quality Standards (Grgic, personal communication).

CONCLUSIONS

Chemical contamination of groundwater is a threat to the health of residents in the Great Lakes-St. Lawrence River Basin. The chemicals of widespread concern are arsenic, fluoride, radionuclides, radon, uranium and manganese in certain geological areas, and nitrates/nitrites and atrazine in agricultural areas where they have been used extensively. Many chlorinated solvents and other VOCs are a concern either because of disposal in landfills, hazardous waste sites, spills or leaking underground storage tanks. Trichloroethylene, tetrachloroethylene and benzene are the most serious concerns. Groundwater is not a major route of exposure to pesticides, but atrazine may be the exception.

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ANNEXES

Annex A – Guidelines for Canadian Drinking Water Quality – Summary Table: Guidelines for Chemical and Physical Parameters
http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/chemical-chimiques-eng.php

Annex B – Guidelines for Canadian Drinking Water Quality – Summary Table: Guidelines for Radiological Parameters
http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/radio-eng.php

Annex C – U.S. Environmental Protection Agency National Primary Drinking Water Regulations: Inorganic Chemicals
http://www.epa.gov/safewater/contaminants/index.html#inorganic

Annex D – U.S. Environmental Protection Agency National Primary Drinking Water Regulations: Radionuclides
http://www.epa.gov/safewater/contaminants/index.html#rads

Threats to Groundwater Quality in the Great Lakes Basin — On-Site Wastewater Treatment Systems, Septage and Sludge

CONTENTS

BACKGROUND

The first underground septic systems were used by the French in the 1870s (CDC, 2006). By the mid-1880s, two-chamber, automatic siphoning tank systems, the ones commonly used today, were installed in the United States (CDC, 2006). More than a century later, these on-site wastewater treatment systems (OWTS) are proliferating in the Great Lakes Basin due to expanding and widely distributed populations that lack access to centralized sewer systems (CDC, 2006). (See Table 1.) The term on-site wastewater treatment system refers to systems utilizing sub-surface disposal. They range in size from individual single-family systems to systems serving businesses, commercial developments, institutions or groups of homes with flows up to 10,000 gallons per day.

Today's residential septic tanks are typically made of concrete, steel, fiberglass, polyethylene or other approved material, which hold 1,000 gallons or more of wastewater (CDC, 2006). In areas with on-site disposal systems, most of the liquid waste will enter the groundwater (Howard, 2002). In Bermuda, for example, septic discharge provides 35% of the total aquifer recharge (Howard, 2002).

NUMBER OF SEPTIC SYSTEMS

One-quarter to one-third of homes in the U.S. use septic systems (CDC, 2006), and approximately one-third of new residential homes in the U.S. are constructed with septic or other forms of on-site wastewater treatment systems (Rafter, 2005). In Canada many rural homes also rely on septic systems (Canada Mortgage and Housing Corp., 2007). In Michigan approximately 50% of new homes are constructed with septic tanks (Fishbeck, Thompson, and Carr and Huber Inc., 2004). In Minnesota it is estimated that approximately 86% or 535,000 homes rely on on-site systems; of these, an estimated 144,000 were failing and 64,000 posed an imminent threat to public health and safety (McDilda, 2007). Septic tank deterioration is a major concern. In Door County, Wisconsin, 80% to 90% of tanks in the area come out of the ground looking like Swiss cheese (Dayton, 2008). It is estimated that $1.2 billion is needed in order to address the state's septic problems and an additional $3.4 billion to address sewer and wastewater treatment plant issues (Wallace, Nivala and Brandt, 2006).

Maryland is estimated to have 420,000 septic tanks with an additional 1,000 installed each year (Murray, 2004). In 2004 a bill was passed implementing a $30 annual fee for homeowners with septic tanks.

Table 1. Number of On-Site Systems by State and Province
Source: Adapted from presentation by Ric Falardeau at the Science Advisory Board's Groundwater Consultation, Lansing, Michigan, March 2006.

State / Province	Total Number of Systems	Permits per Year	Number of Systems in Counties that Border the Great Lakes[1]
Illinois	ND	ND	50,000
Indiana	800,000	14,500	50,000
Michigan	1,400,000	35,000	455,000
Minnesota	535,000	17,500	35,000
New York	ND	ND	200,000
Ohio	1,000,000	20,000	110,000
Ontario	1,200,000[2]	25,000[3]	ND
Pennsylvania	ND	ND	25,000
Wisconsin	680,000	21,000	110,000

[1] In the U.S. 100% of the 67 county or regional agencies that border a Great Lake and that regulate OWTS were surveyed. In Ontario, the only province bordering the Great Lakes, one office was surveyed at each level within a bordering region: a regional (unincorporated area), township or county level and/or municipal level (building department) office. The total U.S. and Canada survey attempted 80 offices of which 74 (93%) responded. Adapted from Gorman and Halvorsen, 2006.
[2] Estimate; actual number unknown (Doug Joy, personal communication at the Syracuse Groundwater Consultation).
[3] Number of new or replacement systems per year; 5% are advanced technology (Doug Joy, personal communication).
ND – No data

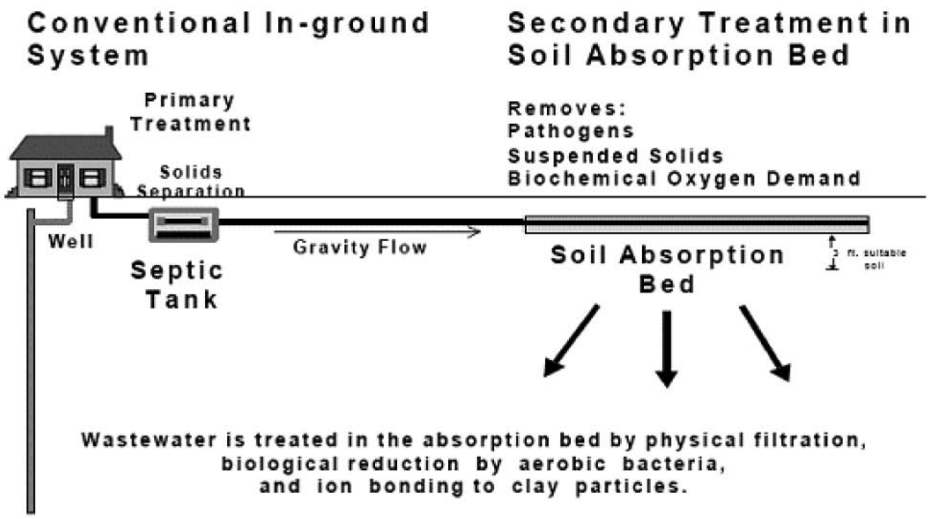

Figure 1.
Source: General Descriptions of Common Types of Onsite Sewage Systems, 1999.

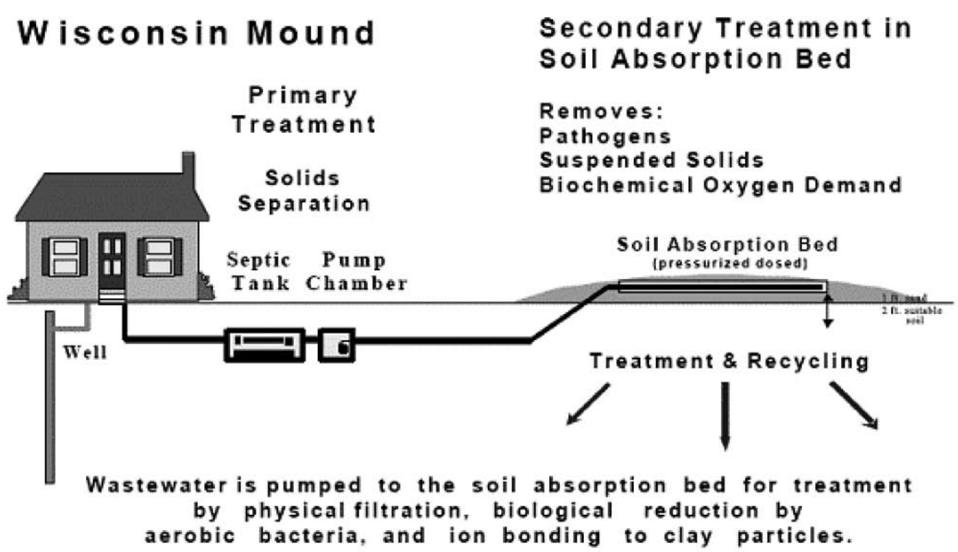

Figure 2.
Source: General Descriptions of Common Types of Onsite Sewage Systems, 1999.

Approximately $12 million per year is raised of which 60% is utilized for septic system upgrades (Maryland Department of the Environment, 2008).

Septic systems are especially prevalent in small rural communities with low to moderate income. Often residents believe they are connected to a municipal treatment plant and therefore do not maintain their septic systems, resulting in system failures and groundwater contamination (Clean Water Fund, 2007). An estimated one million gallons of untreated waste leaks from improperly maintained, inadequate and old septic tanks every day in Kent County, Michigan, alone (Clean Water Fund, 2007). There are an estimated 677 and 679 unsewered communities in Indiana and Minnesota, respectively (Wallace et al., 2006). Of the unsewered communities in Indiana 88% have fewer than 200 homes and 90% of households are considered to be low to moderate income (Wallace et al., 2006). In the article "The High Price of Ignorance" it was stated that "[i]n some rural communities, a user's share of capital costs for a centralized sewer system can exceed a homeowners property value, causing financial collapse" (McKenzie, 2005). Additionally, most of the residential septic systems located in Indiana's Great Lakes counties are situated in terrain that is not suitable for proper septic system foundations (Table 2).

TYPES OF SEPTIC SYSTEMS

On-site disposal systems are used in areas where distance between houses makes installing a sewer system too expensive, or in some suburban areas where municipal governments have not yet provided sewers (CDC, 2006). Conventional and mound septic systems are the two primary types used in the Great Lakes Basin. The conventional system (Figure 1) contains a septic

Table 2. Indiana Counties – Septic Systems

County	% Households with Onsite Wastewater Disposal (Septic)	Number of Households with Onsite Wastewater Disposal (Septic)	County Area (Acres)	Density of Septic Systems (Acres per septic system)	% Area with Soils Having "Severe Limitations" for Septic Systems
Lake	10.0%	18,274	396,962	21.7	96.0%
Porter	31.0%	14,444	334,267	23.1	83.0%
LaPorte	43.0%	18,002	389,865	21.7	74.0%

Source: Adapted from presentation by Mike Molnar at the IJC Nearshore Workshop, March 2008. Based on Natural Resources Conservation Service (NRCS) Soil Survey information, calculated by Bill Hostetter, Soil Scientist in the Indiana NRCS State Office. "Severe Limitations" are based on NRCS criteria, which are more restrictive than those required by the Indiana State Department of Health.

Percent and number of households with on-site wastewater disposal (septic systems) are from the 1990 Census.

tank and a soil absorption bed. In the tank, solids settle to the bottom and are partially broken down by bacteria. The top layer of liquid effluent discharges via gravity to the soil absorption bed (Wisconsin Department of Commerce, 1999). The soil absorption bed removes some pathogens, organic material and suspended solids from the effluent by physical filtration, aerobic microorganisms and soil cation exchange capacity. The effectiveness of the conventional system depends on the permeability of native soils and the slope and drainage pattern of the site (Wisconsin Department of Commerce, 1999). Conventional systems require maintenance and pumping to ensure that the tank remains watertight and to remove accumulated solids.

In the Great Lakes region the most attractive sites for new homes, such as along environmentally sensitive inlets and inland lakes, have low-permeability soils and high water tables, making them unsuitable for conventional, gravity-fed septic systems (Gorman and Halvorsen, 2006). Homeowners in these areas often use alternative OWTS technologies and techniques

Case Study: State of Saginaw Bay On-Site Wastewater Treatment Systems

Source: Kart, 2006.

> "When a wastewater treatment plant discharges to the Saginaw River, it makes headlines. When a septic system discharges, there is silence."

Some homes in Gladwin County, Michigan, have septic systems, but many do not work. Other homes have no system at all; waste is often dumped directly into ditches. The untreated sewage contaminates surface and groundwater since it contains pathogens such as *E. coli* and viruses which are a human health threat.

This situation is repeated throughout many small towns of the Saginaw Bay region which were built without sewers and before modern OWTS regulations. In nearby Denmark Township, Tuscola County, *E. coli* levels have tested as much as 300 times higher than state water quality standards allow (Kart, 2006). Unfortunately, many occurrences happen in low-income areas, where the resources of residents (retired and unemployed) are already stretched.

Since the publication of Kart's article in 2006 the situation has not improved and may even be getting worse (Ferretti, 2007). A report by Rose, a microbiologist, indicates that the problem may be increasing with increasing discharge from sewage and septic tanks (Ferretti, 2007). Despite excessive amounts of algae the Department of Environmental Quality (DEQ) has yet to list Saginaw Bay as impaired (Kart, 2008).

(Gorman and Halvorsen, 2006). Any system more complicated than a septic tank with a gravity-fed drainfield is considered to be alternative, for example, a mound system. According to a survey of regulators in the Great Lakes region, nearly all jurisdictions permit the use of alternative systems, but a significantly smaller percentage have codes that regulators feel are adequate standards for alternative systems (Gorman and Halvorsen, 2006). Alternative OWTS (Figure 2) use components such as pumps, aerators, filters and controls which require regular maintenance and are more prone to failure (Gorman and Halvorsen, 2006). In the Great Lakes region, where many new homes are being constructed in sensitive areas, effective programs for regulating OWTS are more important than ever (Gorman and Halvorsen, 2006).

The mound system, the most common type of alternative OWTS in the Great Lakes region, consists of a septic tank, a pump chamber and a soil absorption bed. It is used where native soil is thin and/or the water table close to the surface, thus requiring that the absorption bed be embedded in a raised mound of sand (Figure 2). Clarified effluent is pumped from the septic tank via the pump chamber in controlled pressurized doses to the soil absorption bed. The sand acts as a medium for aerobic bacterial digestion and secondary treatment of effluent. Since this system distributes water in controlled pressurized doses, there is less chance for localized clogging. Nonetheless, solids must be pumped periodically from both the septic tank and the pump chamber. Additionally, special maintenance and site preparation are required to ensure that effluent does not leak at the base of the mound (Wisconsin Department of Commerce, 1999).

The permitting of alternative systems involves two key challenges: the added difficulty of assessing the ability of these designs to perform, and the increased importance of maintenance (because of the greater use of pumps, filters and controls than conventional systems) to ensure proper operation. Since these systems are located on highly desirable but highly environmentally sensitive land, the consequences of failure increase. These challenges are compounded because alternative OWTS are used in areas less suited to on-site wastewater treatment and are therefore less capable of buffering contamination related to failure.

Even trained individuals have difficulty in evaluating the suitability of an alternative system for a particular site. Lack of communication at point of sale increases the likelihood that homeowners acquiring alternative OWTS will be unfamiliar with the relatively high level of maintenance required for this type of system (Gorman and Halvorsen, 2006). Wisconsin is often cited as having a particularly good OWTS code. Their approach accommodates alternative technologies but requires maintenance contracts and connects OWTS permitting to planning efforts. Wisconsin implements uniform standards and criteria for the design, installation, inspection and management of OWTS so that the system is safe and will protect both public health and the water. The regulation, which does not dictate the selection of certain OWTS, instead sets parameters, options, prohibitions and limitations for the design of OWTS (Wisconsin Department of Commerce, 2007).

GROUNDWATER CONTAMINATION FROM SYSTEM FAILURE AND SEPTAGE DISPOSAL

The U.S. Environmental Protection Agency (EPA) considers OWTS a significant source of groundwater contamination (Gorman and Halvorsen, 2006). The close proximity of on-site wastewater systems and water wells in developed areas, reliance on poor soils for on-site disposal, relatively shallow water table depth (less than 15 feet for most of the Great Lakes Basin) and the general lack of awareness by homeowners about proper septic tank maintenance pose a significant threat to public health (Lovato, personal communication). In fact, septic systems are the perceived source of non-point groundwater pollution in 81% of watersheds and represent the number-one cause of non-point groundwater pollution in Michigan (Falardeau, 2006). Density of septic systems is correlated to occurrence of viral waterborne disease (Mark Borchardt, personal communication). Tracers from failing septic systems can emerge from groundwater to surface water within 1 to 2 hours of a flush (Joan Rose, personal communication).

Other related sources of non-point pollution include land application of septage from both septic tank pumping and "porta johns," municipal sewer infrastructure breaks and leaks, illicit connections and "pit" latrines and outhouses. An estimated 120 million gallons of raw septage are pumped from septic tanks in Michigan alone each year, and half is applied to land disposal sites with little or no treatment (Fishbeck et al., 2004). Raw septage from temporary toilets is also often land-applied in Great Lakes jurisdictions. Ontario has banned land application of raw sewage/septage, but not treated sewage or biosolids (McLeod, 2003). More than half of the about 300,000 tonnes of Ontario biosolids produced each year is spread on land (Ontario MOE, 2006). The Canadian government had originally proposed a ban on all land application of untreated septage to be in place by 2007 (ECO, 2005; Mason and Joy, 2003). This deadline has since been pushed aside awaiting the creation of additional treatment facilities (Kovessy, 2008).

Capturing and burning methane gas from septage and sewage treatment plants not only help to decrease raw sewage but also can reduce demand for potable water supply, reduce the size of in-ground disposal, reduce nitrogen loading in groundwater and be a source of revenue (Algie, 2006; Harsch, Ip, Jowett, Straw and Millar, 2005).

Case Study: Wainfleet Boil Water Advisory Page/ Wainfleet Water and Sewer Project
Source: http://www.regional.niagara.on.ca/living/water/wainfleetwater.aspx

Many rural homes have both on-site septic systems and private water wells. When the septic systems do not function properly there is the risk that the septic system will contaminate the wells. A case in point is the southern part of the Township of Wainfleet, part of the Region of Niagara in Ontario. This area is a community of more than 1,200 residential lots along the shore of Lake Erie that depend on on-site septic systems. Most of the homes are also on private water wells. The majority of the homes were cottages that were just used in the summer season. They were mostly on small lots not really suited for year round sewage disposal. Many of the cottages have been upgraded and newer homes added. Many of the homes are now in year-round use. Well water surveys have indicated that many of the septic systems no longer function properly. Microbial contamination has been detected in most of the private water wells.

Extensive microbial contamination of the groundwater has occurred. On April 10, 2006, the local Medical Officer of Health issued a boil water advisory for this community that remains in effect. The Long Beach private water system and properly maintained wells that regularly tested negative for bacteria were excluded. A class environmental assessment completed in 2005 recommended that municipal water and sewage services be extended from Port Colborne and local water distribution and sewage collection systems be constructed. Because of the high cost to the municipality and to the homeowners alternative solutions are still under consideration.

Lawn sign opposing municipal water and sewer service installation in Wainfleet, Ontario. Photo credit: D.W. Alley, 2008

CONTAMINANTS FROM ON-SITE SYSTEMS, SEPTAGE AND SLUDGE

Pharmaceuticals and personal care products (PCPs) often reach groundwater via OWTS and septage/sludge. Both the solid and the liquid phases of wastewater contain pharmaceuticals. These substances cause human and wildlife health effects such as endocrine disruption, antibiotic resistance, and infertility. Common household products (e.g. laundry detergents, PCPs and household cleaners) discharged to septic systems may be a significant source of nonionic surfactants (alkylphenol polyethoxylates) that break down in the environment to form chemicals that can mimic estrogen (Rudel, Melly, Geno, Sun and Brody, 1998). Fish having both male and female sexual characteristics have been found in the South Platte River and Boulder Creek, downstream from a large sewage plant ("Androgynous fish," 2004; Cocke, 2004; "Deformed fish," 2004). Triclosan, an antibacterial agent found in many soaps and PCPs, reacts with chlorine (found in most treated water) to form chloroform, a potentially toxic chemical (Cunningham, 2007). Triclosan is also linked to emergence of anti-microbial-resistant bacteria.

Other contaminants of growing concern include silver nanoparticles, nitrogen and phosphorus (Choi and Hu, 2008). Studies/projects are being conducted in order to develop septic systems that better remove these excess nutrients (Finneran, 2008; Harsch et al., 2005). Although some areas are beginning to implement nitrogen standards (Wakulla County, Florida), issues of monitoring still have to be addressed (Dietzmann, 2007a).

AGING AND FAILING SEPTIC SYSTEMS IN THE BASIN

In a recent survey only 5.5% of well owners indicated that they understood that septic systems could affect groundwater quality (Ontario MOE, 2006). About 25% of OWTS are poorly maintained and operated, have exceeded their design life of 30 years and are failing (Gorman, personal communication). Failure of septic systems is defined by any of the following: systems backing up into the home, systems discharging to the ground surface, systems with direct discharge to surface waters, systems impacting groundwater supplies and systems with indirect discharge to surface waters (Falardeau, 2006). According to the Michigan public health code, "Failure or potential failure of septic tank disposal systems poses a threat to the public health, safety and welfare; presents a potential for ill health, transmission of disease, mortality and economic blight; and constitutes a threat to the quality of surface and subsurface waters of this state."

Table 3. Washtenaw County, Michigan, Time of Sale – Historical Comparisons.

Year	Number of Evaluations	Percent Failure
2003	807	18
2002	881	20
Overall	3,451	17

Table 4. Wayne County, Michigan, Transfer Evaluation Summary, February 2000 - December 2003.

Year	Number of Evaluations	Number of Failures	Percent Failure
2000	108	22	20.37
2001	100	32	32.0
2002	121	31	25.6
2003	112	31	22.67
Total	441	116	26.30

Washtenaw County, Michigan, time-of-sale records reveal that of the 3,451 evaluations since 2000 17% of septic systems had failures of some type (Table 3). A Wayne County, Michigan, transfer evaluation summary from February 2000 to December 2003 shows that of 441 evaluations there were 116 failures (Table 4). The number of failures is increasing as the number of U.S. systems older than their 30-year life span continues to increase (Gorman, personal communication). Considering the large number of septic systems in the Great Lakes region, the potential for widespread groundwater contamination is immense.

In some communities authorities are offering grants to upgrade septic systems. For example, the Essex Region Conservation Authority (ERCA) is offering grants of up to $5,000 (ERCA, 2008; "ERCA offers," 2008). There are an estimated 12,000 faulty septic systems in the Essex County, Ontario, region ("Clean water," 2006). In the nearby community of Lakeshore faulty septic tanks from 400 homes in the community are believed to be the main cause of water pollution contaminating Lake St. Clair (Rennie, 2006).

Other undertakings include a $400,000 supplemental environmental project by Fort Wayne, Indiana, to eliminate failing septic systems (USEPA, 2007).

FAILURE PREVENTION – REGULAR MAINTENANCE AND BACKWASH FLUSHING

Careful landscaping of the soil absorption bed, awareness of inputs (e.g., wastes disposed in sinks, garbage disposals and toilets should be easy to break down) and regular pumping, maintenance and upgrades will prolong septic tank life (Septic Tanks, 2004; Veritec Consulting, 2004; Manitoba Conservation, 2006). A typical family will discharge enough material fibers or lint down the drain to carpet a living room every year. These fibers are a major cause of clogged pipes or plugged absorption bed soil, causing septic systems to fail (Septic Tanks, 2004). Garbage disposal systems are also extremely hard on septic systems (Rafter, 2005). To prevent failures, septic tank pumping frequency should be based on tank capacity and household size (Table 5).

A study by Veritec Consulting (2004), commissioned by Manitoba Conservation (2006), was designed to provide information to assist homeowners installing septic fields to more appropriately size their absorption fields and to identify options to reduce wastewater load. Veritec concluded that reducing the flow of wastewater through the septic tank by installing water conserving fixtures (e.g., low-flush toilets and dual-flush technology, front-loading clothes washers and low-flow shower heads), spacing out water use throughout the day of week (i.e., avoid doing all laundry on one day) and keeping fixtures in good repair can help prolong septic life. See http://www.gov.mb.ca/conservation/envprograms/wastewater/maintenance/index.html. The reduction allowed time for solids to

Table 5. Septic Tank Pumping Frequency Based on Tank and Household Size.

Septic Tank Pumping Frequency Based on Tank and Household Size

Tank Size (gallons)	Household Size (number of people)					
	1	2	3	4	5	6
500	5.8	2.6	1.5	1.0	.7	.4
750	9.1	4.2	2.6	1.8	1.3	1.0
900	11.0	5.2	3.3	2.3	1.7	1.3
1000	12.4	5.9	3.7	2.6	2.0	1.5
1250	15.6	7.5	4.8	3.4	2.6	2.0
1500	18.9	9.1	5.9	4.2	3.3	2.6
1750	22.1	10.7	6.9	5.0	3.9	3.1
2000	25.4	12.4	8.1	5.9	4.5	3.7
2250	28.6	14.0	9.1	6.7	5.2	4.2
2500	31.9	15.6	10.2	7.5	5.9	4.8

Number of Years

**Pumping frequencies are estimated in years. The figures assume there is no garbage disposal in use – if one is in use, it may increase pumping frequency up to 50 percent.*

Source: The Groundwater Foundation, 2006.

settle out and lessened the chance of solid particles being carried over to the drain field. Less water in the drain field meant better aeration for the soil microbes at work in the system.

Appropriate design, building, installation and maintenance are important to avoid system failure and vary depending on amount and characteristic of wastewater. For example, the wastewater generated by a restaurant has a typical biological oxygen demand (BOD) of 1,000 and a content of fats, oils and greases of 200 milligrams per liter. Comparatively, a typical household has a BOD of 200 and 20 milligrams per liter of fats, oils and greases (Vere, 2007). Predicting wastewater flow quantity also is extremely important. A number of studies have been conducted to help provide more accurate estimates (Stephens, 2007). Regular inspection and maintenance are essential to ensure a properly functioning system. It has been recommended that all systems be maintained by professional operators (Ip, Jowett and Laidman, 2004).

Water softener backwash increases the amount of sodium relative to the amount of magnesium and calcium, or the sodium absorption ratio (SAR). Previous studies found that soils that are 15% clay swell and become less permeable when SAR exceeds 10. A study from the Canada Mortgage and Housing Corporation (CMHC) reports that even effluent with a SAR not greater than 10 can cause "hydraulic failure" due to the incapacity of the absorption bed to drain properly (CMHC, 2006). Clay content and age of the system were listed as the primary reasons for septic failure (CHMC, 2006). The impact of flushing water softener backwash on weeping tiles is also a concern (Crabbe, 2007). Although one study on the effect of water softener backwash discharge on tank performance indicated that it had no significant effect upon the biological or physical functioning of the septic tank, elevated chloride concentrations could accelerate corrosion of tanks (Kinsley, Crolla and Joy, 2005). Seventeen states have banned such flushing. All states in the Great Lakes Basin except Michigan have enacted such a ban.

Another concern regarding water softener brine is that it may cause septic tanks to discharge greater amounts of solids, grease and oil into the dispersal field. This can result in plugging of the drainfield (Gross and Bounds, 2007).

ON-SITE SYSTEM REGULATION

A wave of OWTS codes was created in the 1970s by the Great Lakes jurisdictions (Gorman and Halvorsen, 2006). These permit systems were established to verify proper installation. In creating these codes, the regulatory authorities falsely assumed use of conventional septic systems, that the owners would take responsibility for pumping and maintaining their systems and that the OWTS would last until it was replaced by a municipal sewer system (Gorman and Halvorsen, 2006). In some Great Lakes jurisdictions (e.g., Ohio), regulators are still operating under the 1977 code (Gorman and Halvorsen, 2006).

In many rural areas the transition to a central sewage system has been postponed for multiple reasons. Central sewage systems are costly, and much of the financial burden is borne by homeowners (e.g. for Billings Township, approximately $9,300 per homeowner for a new sewage plant and hook-up into the new system) (Kart, 2006). In an effort to restrict urban sprawl, some jurisdictions have implemented growth management legislation banning municipal sewers in rural areas near urban centers (e.g., Washington State Growth Management Act) (Laschever, 2006).

In 1999, Karen Mancl from the Department of Food, Agriculture and Biological Engineering conducted a study to assess the approval practices for on-site wastewater treatment in Ohio. She concluded that programs implemented by the local health departments lack uniformity, modern practice and technology and do not have in place a system of checks and balances to protect public health from the approval of inappropriate sewage treatment plants.
Similar conclusions were drawn from a survey of U.S. and Canadian administrators in Great Lakes jurisdictions. The survey was designed to assess the capabilities of OWTS regulator programs to meet the U.S. EPA Voluntary National Guidelines for Management of On-site and Clustered (Decentralized) Wastewater Treatment Systems. The survey revealed that the capacity to meet the guidelines varies. In fact, some jurisdictions (e.g., Michigan) have no statewide regulation for septic system installation, inspection and maintenance (Falardeau, 2006; Michigan Office of the Governor, 2004). Most states do not require on-site inspection of septic systems. It has been estimated that between 60% and 70% of all on-site systems in the U.S. are not inspected (Rafter, 2005). In Ontario, regulations for septic systems are currently found under the building code, with no mention of environment, nitrogen, pathogens or groundwater protection. It is delivered by municipalities and building departments and therefore is highly variable across the province (Doug Joy, personal communication).

Door County, Wisconsin, is the peninsula separating Green Bay from Lake Michigan. It has the greatest length of shoreline of any county in the United States and is a major tourism location. The geological setting includes generally shallow soil over heavily fractured, karst dolomite bedrock. Travel times of groundwater through the crevices of the bedrock are very short and hence there is a high potential for immediate and widespread contamination of groundwater from surface sources. Contaminated groundwater has been a major problem. Agricultural chemicals, manure and wastewater from houses are the principal sources. There are 14,000 septic-tank systems in the county and about 3,500 holding tanks. Publicity about contaminated water has created difficulty for the tourism industry (Chris Olson, Assistant to the County Sanitarian, personal communication, 2006 Milwaukee Groundwater Consultation).

Recognizing the health hazard posed by failing septic systems, Door County acted to protect groundwater by enacting an ordinance requiring inspection of the wastewater system before sale of a property could be completed. The state advised that such an ordinance was beyond the power of the county but did not challenge the ordinance in court. This inspection requirement initially detected a high proportion of failing systems, and replacement was almost always required. More recently the proportion of defective systems in the point-of-sale inspections has been dropping about 20% every five years and is now well under 50%. County Realtors originally opposed the ordinance but now regard it as a very effective measure (Chris Olson, personal communication).

In 2004, Door County expanded the program to include inspection of all systems. Using overlays of depth to bedrock, type of soil and type of bedrock five classes of risk of contamination were identified. Mapping was done to show which parcels of land fell within each risk class. Site inspections were begun for properties that fell within parcels with the highest risk. Inspections have now progressed to the second (lower) risk category. Full inspection of all systems is expected to be completed by 2009. Any system that fails must be replaced by the landowner. After inspection, whether the system has passed or been replaced, the landowner must follow the maintenance schedule required by the county and keep records of the maintenance operations done on the system (Chris Olson, personal communication).

Ingham County, Michigan, adopted a similar set of regulations entitled the Ingham County Regulation for the Inspection of Residential On-Site Water and Sewage Disposal Systems at Time of Property Transfer. Under this rule, homeowners are required to hire certified private inspectors or contact the Health Department to inspect and evaluate septic systems before any residential home property is transferred. Ingham County charges $300 for a full inspection plus a $150 administration fee (Ingham County Health Department, 2006).

Similar programs have not been implemented universally in the Great Lakes Basin states. Ontario plans to follow suit with a similar regulation as, in part two of the Walkerton Inquiry, Justice O'Conner recommended that septic systems should be inspected as a condition for transfer of a deed. Currently, such regulation is not universal across the province.

In a series of articles entitled Point-Of-Sale Inspections – Productive or Pointless?, Elizabeth Dietzmann examined the pros and cons of implementing mandatory point-of-sale inspections (Dietzmann, 2006; 2007b; 2007c). Many are opposed to mandatory inspections. The Michigan Association of Realtors is opposing a bill prohibiting the transfer of property with an on-site disposal system unless the system has been inspected and a written copy of the inspection report is provided to the prospective transferee (Dietzmann, 2006). Other issues include that failing systems can sometimes pass an inspection, for example, by awaiting the mid-summer "dry season," or by disconnecting the washer from the main sewer line or emptying the tank (Dietzmann, 2006). Who should perform point-of-sale inspections is also an issue (Dietzmann, 2007b). The articles concluded that, "[W]hile there can be problems with performance standards of point-of-sale inspections, and they are no guarantee that a septic system will perform in the future, point-of-sale inspections are an essential component of any truly comprehensive on-site system management program" (Dietzmann, 2007c). They also can provide regulators with an "inventory" of septic systems in their jurisdiction.

RECOMMENDATIONS

Because surface water bodies and aquifers are vulnerable to groundwater contamination, an update is needed to OWTS regulations in the Great Lakes Basin (IJC, 1993; Mancl, 1999; Falardeau, 2006; Gorman and Halvorsen, 2006). Although many agencies have taken steps to address these challenges – such as requiring maintenance contracts for alternative systems, performing inspections when homes change ownership and communicating with homeowners more regularly – few have implemented all the program elements recommended by the U.S. EPA. As a starting point, the U.S. EPA's Voluntary National Guidelines for Management of On-site and Clustered (Decentralized) Wastewater Treatment Systems should be implemented in each jurisdiction (Gorman and Halvorsen, 2006). In relation to these guidelines improvements are needed in each of the following areas:

- **Tracking of and communication with homeowners.** Increase homeowner awareness through dissemination of information regarding the effects of septic failure (e.g., groundwater contamination) and regulatory expectations. Ideally, septic systems should be inspected as a condition for the transfer of a deed as implemented in Door County, Wisconsin, and Ingham County, Michigan.

- **Permitting of alternative technologies to be better integrated into the process.**

- **Requirement for and tracking of maintenance contracts.** For example, in British Columbia, the installer only has to provide warranty on the system based on a maintenance contract. It is the onus of the owner to keep up maintenance or risk losing the warranty.

- **Encouragement of experienced Responsible Management Entities**, who are responsible for ensuring the long-term management of decentralized on-site wastewater treatment facilities. Training in site evaluation, soil assessment and system selection is needed for these individuals, as well as more in-depth and hands-on field training to reinforce the links between site evaluation, system selection, system design and long-term performance (Mancl, 1999).

- **Funding and support from local governments and homeowners.** Regulatory codes should be backed by appropriate department budgets (Gorman and Halvorsen, 2006). The provincial and federal governments should help homeowners pay to fix faulty septic systems that contribute to poor water quality (Hill, 2006). For example, Ontario has a system for front-loading development costs for new developments to include cost of new sewage plants and infrastructure. Homeowners can be granted as much as $7,500 to upgrade septic systems (Conboy, personal communication, Syracuse Consultation).

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Threats to Groundwater Quality in the Great Lakes Basin — Leaking Underground Storage Tanks

CONTENTS

INTRODUCTION

Leaking underground storage tanks (LUSTs) are a serious concern regarding groundwater quality, and also of Great Lakes water quality in the Basin (Figure 1). The Great Lakes receive recharge not only via surface water runoff and precipitation but also through regional groundwater flow. If this groundwater is contaminated by LUSTs, significant amounts of pollution will be discharged into the Great Lakes. Although an accurate tally of total USTs in the U.S. and Canada is currently unknown, since not all underground tanks are mandated to be registered and many older tanks were installed before registrations came into effect, estimates place this number, for both countries combined, in the millions (CESD, 2002; Sierra Club, 2005).

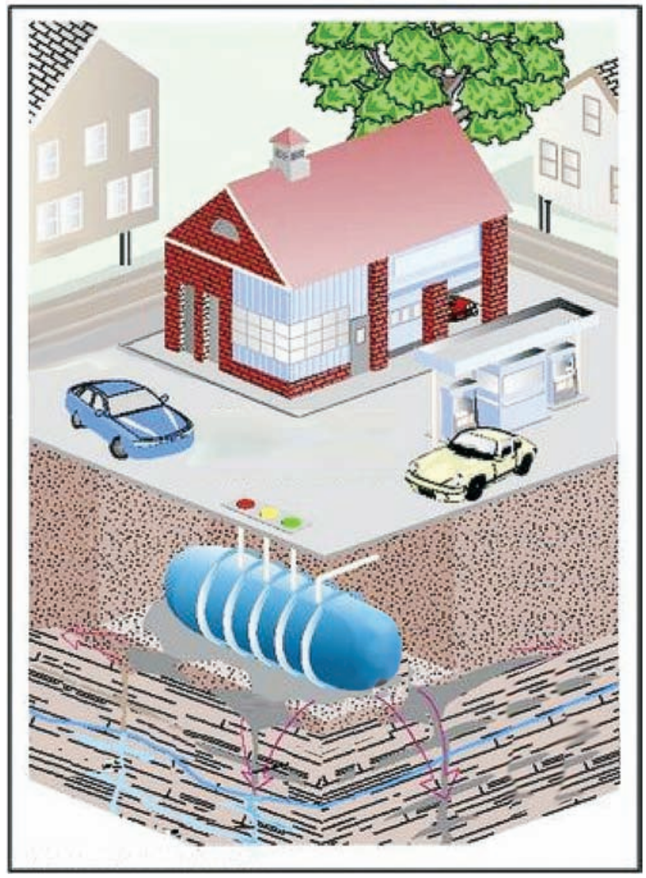

Figure 1. **Leaking underground storage tanks.** Source: U.S. EPA & USGS.

NUMBER OF UNDERGROUND STORAGE TANKS

USTs frequently contain potentially dangerous and toxic substances including, but not limited to, oil, gasoline, diesel fuel, aviation fuel, other petroleum products, radionuclides, solvents and waste/spent fluids (Sierra Club, 2005). These stored materials often contain carcinogenic compounds (e.g., benzene, toluene, ethylbenzene and xylene or BTEX). Many USTs are known to be currently leaking or have leaked at some point in their past (Figure 2). A pinhole leak can release 400 gallons (1,514 litres) in a year, having the potential to contaminate vast quantities of groundwater with a contamination ratio of one to one million (Environment Canada, 1999; Sierra Club, 2005). LUST and refinery spills like that at Exxon Mobil's property in Brooklyn, New York, with a volume of 17 to 30 million gallons (77-136 million litres) (Leising, 2007), result in extensive groundwater contamination, and adjacent surface waters are also adversely affected. Hazards arising from LUSTs include acute and chronic drinking water health issues as well as the accumulation of volatile and flammable gases, which have resulted in spectacular and often fatal sewer and basement explosions (e.g., St. John, New Brunswick, and Guadalajara, Mexico). In Utah a leak from a local gas station released 20,000 gallons of gasoline. Fumes from the gasoline caused significant damage to local homes and businesses (Fahys, 2008).

Figure 2. **Exhumed leaking underground storage tanks.** *Photo by: D.W. Alley*

In the United States, as of March 2008, 478,457 releases had been confirmed from the more than 2,302,287 registered USTs, both active and closed, which are subject to federal regulations (U.S. EPA, 2008a; U.S. EPA, 2007c). Other sources indicate that this figure, however, may be more than 551,000 (Environmental Data Resources Inc., 2008).

Although significant cleanup efforts have been made, the current national backlog is still more than 106,577 with 25,392 of these sites yet to be addressed (U.S. EPA, 2008a). Additionally, more than 7,500 new LUST sites are found each year (U.S. EPA, 2007c). The Federal Emergency Management Agency knows of at least 150 tanks storing more than 5,000 gallons of diesel fuel, which they are responsible for, that could be leaking contaminants into groundwater (Sullivan, 2008). Other sources indicate that there may be an additional 3.8 million non-federally regulated and orphaned USTs (Sierra Club, 2005) resulting in an overall total of 5 million USTs in the U.S. USTs that are exempt from federal regulations are not regulated and therefore do not undergo routine inspections or updates. These include, but are not limited to (U.S. EPA, 2002; Rothe, 2003):

- Tanks located on residential or farm properties with a capacity of less than 1,100 gallons (4,164 litres) containing petroleum products to be used as motor vehicle fuel for non-commercial purposes
- Tanks for storing heating oil for use on the premises where the tank is located
- Flow-through process tanks
- Septic tanks
- Storm water or wastewater collection systems
- Surface impoundments, pits, ponds or lagoons
- Storage tanks located in an underground area such as a basement, cellar, mine, shaft, if the tank is on or above the surface of the floor
- Emergency spill and overflow tanks which are promptly emptied
- Underground storage tank systems with a capacity of 110 gallons or less
- Underground storage tank systems that contain a *de minimis* concentration of regulated substances

Assuming that 25% of all USTs are leaking (MacRitchie, Pupp, Grove, Howard and Lapcevie, 1994; Alsip, 1993; IJC, 1993), results in a LUST count of 1,250,000, significantly higher than indicated by the tally for federally regulated USTs alone.

CONTAMINATION DANGERS

Although petroleum products and additives (e.g., methyl *tert*-butyl ether or MTBE) are generally the major concern at LUST sites, leaking solvents (e.g., TCE and PERC) are also a serious issue regarding groundwater contamination. Many of the substances stored in USTs are not only dangerous but also highly mobile in soils and aquifers. Toxic chemicals present in LUSTs include, but are not limited to, BTEX, MTBE, methylcyclopentadienyl manganese tricarbonyl (MMT), cadmium, naphthalene, lead, PCBs, 1,2-dichloroethene (DCA) and 1,2-dibromoethene (EDB) (Braves, 2003; Galloway, 2004; Falta, Bulsara, Henderson and Mayer, 2005; Sierra Club, 2005). Health effects caused by these chemicals include damage to various vital organs; damage to the immune, respiratory, reproductive, endocrine and other systems; various health effects to developing children and cancer (Sierra Club, 2005). Some efforts are being taken by refineries to help reduce toxic additives. Canada's largest refineries have voluntarily stopped using MMT even though it is still permitted by law (Galloway, 2004). However, states are not required to follow rigid guidelines when testing for all contaminants present at LUST sites as long as procedures and regulations meet U.S. EPA standards. This is causing difficulties in determining the degree of contamination of various substances (Falta et al., 2005). For example, compounds of specific concern include EDB and DCA, which were additives to leaded gasoline. Both are designated as probable carcinogens, and EDB has been found to be an exceptionally strong carcinogen in animals. They are noted as being "among the most commonly detected contaminants in U.S. public drinking water systems that rely on groundwater" (Falta et al., 2005). However, unless specified in the sampling program, they are generally not tested for in site analyses, potentially leaving thousands of contaminated sites (Falta et al., 2005). In a recent study of LUST sites 59% have groundwater contaminated with EDB (Falta et al., 2005).

METHYL *TERT*-BUTYL ETHER

MTBE is a gasoline additive used to oxygenate fuel and reduce emissions (GAO, 2007). MTBE is highly mobile and persistent in the environment, resulting in the development of large contamination plumes (Falta et al., 2005) that often contaminate groundwater (GAO, 2007). Because MTBE is water soluble, it can easily contaminate groundwater, seeping out from USTs and transmission lines (Larini, 2008). For example, as of 2005 MTBE has been found in more than 1,861 public water supply systems in the U.S., up from 1,500 in 2003 (Environmental Working Group, 2005). Even very low MTBE concentrations render groundwater unsuitable for drinking, and many municipal wells have been closed as a result. A survey by the U.S. Geological Survey found 300 out of 3,964 sampled groundwater sites to be contaminated with MTBE. 13% of contaminated samples were found in urban areas (Moran, Zogorski and Squillace, 2005). No national standard has yet been set regarding acceptable levels (GAO, 2007). Due to health concerns many states have banned MTBE including seven of the eight Great Lakes States (Bauman, 2003). In 2006 oil companies stopped using MTBE (Mouawad, 2008). However, MTBE is still being discovered at LUST sites in states with bans (Martinson, 2003) and is also being found at LUST sites that were previously closed, forcing them to be re-opened for further remediation. These re-openings will result in additional cleanup costs to states since original owners will no longer be responsible for covering additional costs (GAO, 2002).

With decreased use of MTBE, newer and less well-known fuel oxygenates are being touted as replacements (Ellis, 2001). These include TAME, DIPE, ETBE, ethanol and methanol. For many of these, there is little or no available information regarding their properties, potential to contaminate water and health effects (Ellis, 2001). One of the most common replacements is ethanol.

ETHANOL

Approximately one-third of gasoline sold in the U.S. (White, 2007) and 10% of the gasoline sold in Canada ("Ethanol A Clean," 2006) contains up to 10% ethanol. However, there are major differences between gasoline and ethanol/gasoline mixtures that affect compatibility with USTs. Issues regarding ethanol include phase separation, solvency, metal corrosion and permeation of nonmetals (English II, 2006). Ethanol can hold appreciably more water than gasoline. If there is sufficient condensate water in the tank, ethanol will undergo phase separation, causing a layer of water containing high ethanol concentrations to be overlain by a layer of gasoline with low ethanol concentrations. This bottom water layer can lead to accelerated corrosion of metal tanks (NEIWPCC, 2001). Being a solvent, ethanol acts to remove buildups on tank walls such as rust. While gasoline is generally considered to be non-corrosive and non-conductive (English II, 2006) ethanol is both (White, 2007). Low ethanol blends, E10, have shown only minimal erosive tendencies toward metals typically used in USTs and are considered compatible with aluminum, black iron, brass, bronze, carbon steel and stainless steel. They are non-compatible with galvanized steel (English II, 2006). High percentage ethanol blends, such as E85, readily corrode soft metals. E85 blends are non-compatible with brass, lead, lead solder, magnesium, lead-tin alloy or zinc (English II, 2006). Nonmetallic substances are also sensitive to deterioration by ethanol including natural rubber, polyurethane, adhesives, elastomers and polymers used in flex piping, bushings, gaskets, meters, filters and materials made of cork (Indiana Government, 2007). Leak detection equipment frequently contains metals and other materials that are not compatible with ethanol. This could result in malfunctions and undetected leaks (NEIWPCC, 2001).

Since many USTs are now fiberglass-reinforced plastics (FRP) (Figure 3), the issue of their compatibility with ethanol is of considerable concern. While recent studies indicate no storage problems with low-ethanol-content blends, more testing is still necessary, especially long-term, E85 effects on tanks that have been in service (NEIWPCC, 2001). New double-walled low-carbon cold finished steel USTs as well as new double-walled fiberglass tanks are both approved for ethanol storage. Single-walled FRP tanks installed prior to 1992 must be approved by the Underwriters Laboratories Inc. before they are used with ethanol-blended fuels (U.S. Department of Energy, 2007).

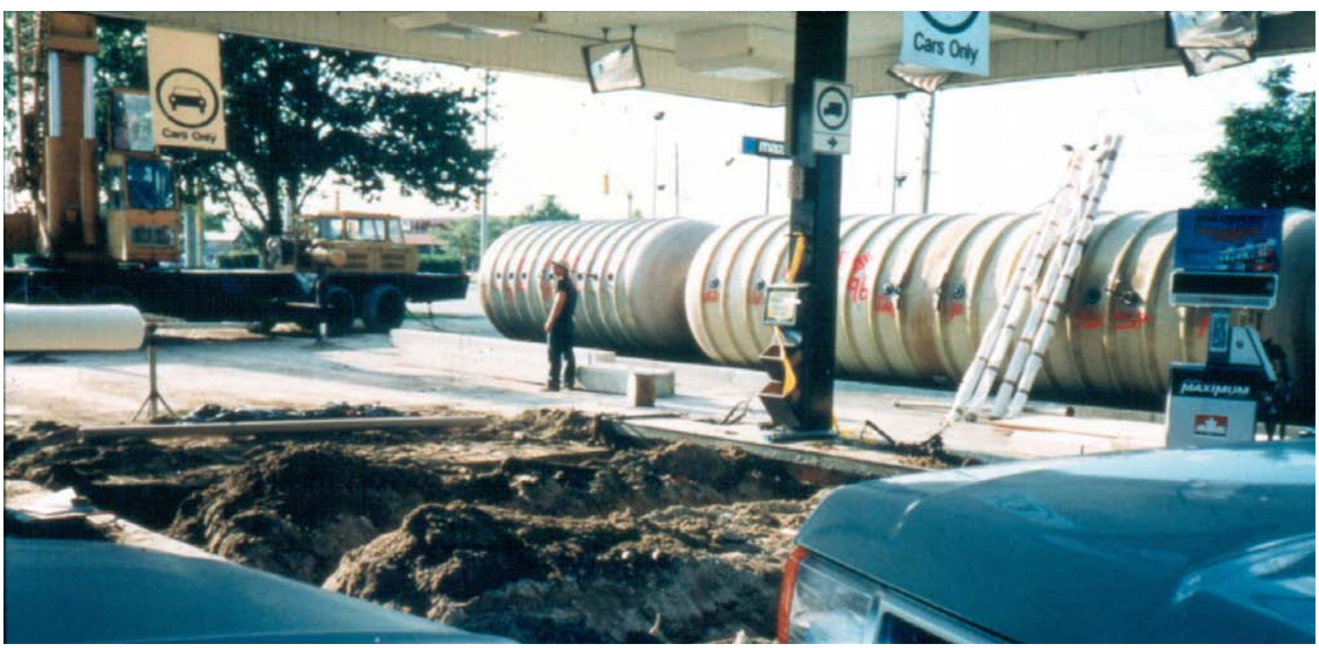

Figure 3. Replacement fiberglass-reinforced plastic tanks being installed at a gasoline station.
Photo by: D.W. Alley

UNDERGROUND STORAGE TANKS
IN THE GREAT LAKES BASIN

Great Lakes groundwater quality is being threatened as significant numbers of USTs are located within the Great Lakes Basin. More than 612,000 USTs are known in the eight Great Lake States of which over 148,000 have been identified as having confirmed releases (Table 1) (U.S. EPA, 2007c). As of September 2007, 31,628 sites are backlogged awaiting remediation, representing 29% of the U.S. total (U.S. EPA, 2007c). Seven of the eight Great Lakes states each have over 2,500 backlogs and are among the top 15 states with the largest backlog problems (Figure 4) (U.S. EPA, 2006). In Detroit, Michigan, alone there are 805 LUST sites. This problem was identified by the mayor who issued a moratorium against building new gas stations in an attempt to redevelop existing closed and abandoned sites (Wisely, 2007). BP Products North America Incorporated was fined $869,150 in 2007 for LUSTs at eight of its former stations in Michigan, some of which have contaminated groundwater. One of the eight sites located in Roseville, Michigan, was discovered in 1966; however, in 2007 clean-up still had not been completed (Lam, 2007). In 2007 more than 200 former BP gas stations were being monitored by the Michigan Department of Environmental Quality for releases from USTs. A 2006 study indicates that BP has a 60% noncompliance rate (Lam, 2007).

With more LUSTs being found annually in every jurisdiction, ranging from 109 in Wisconsin to 603 in New York through fiscal year 2007 (U.S. EPA, 2007c), the issue of reducing LUST backlogs is of key importance. Yet, the overall cleanup pace has decreased significantly, averaging 23,235 per year from 1997-2001 to only 13,862 in 2007 (Figure 5) (U.S. EPA, 1997-2007). In Michigan cleanup has decreased from 1,547 site closings in 1997 to only 277 in 2006, less than the number of new LUST sites discovered (Wisely, 2007). Furthermore, while the national cleanup average is 77%, Michigan is well below this, having cleaned up only 57% of its known releases (U.S. EPA, 2007c). Although accurate data regarding the number of LUST sites situated within the Great Lakes Basin region of each jurisdiction is unavailable, the majority of LUSTs in Ohio, Michigan, Wisconsin and Ontario are likely within the Great Lakes Basin based on population numbers.

In Canada there is a lack of comparable data on the number of USTs and potential LUST sites. Although an accurate number of USTs in Canada is currently unknown or unavailable, estimates place the number in service at around 200,000 (Alsip, 1993; Rush and Metzger, 1991; WCELRF, 1991). In 1994, Environment Canada estimated there are approximately 40,000 LUST sites across Canada (Lalonde, 1995). As of 2006 the number of storage tanks on federal land, both above and below ground, was recorded to be 8,449. Of these more than 3,000 are believed to be leaking (Canada Gazette, 2007). Recent estimates indicate that approximately 34% of these tanks are USTs (CESD, 2002).

There is also a lack of data regarding USTs located within Ontario. A recent count of gasoline stations in Ontario indicated more than 3,800 (Misener, 2007), each having 3 to 4 USTs (Howard and Livingston, 1997; U.S. EPA, 1986). Estimates of USTs in Ontario vary, suggesting more than 10,000 are located on federally

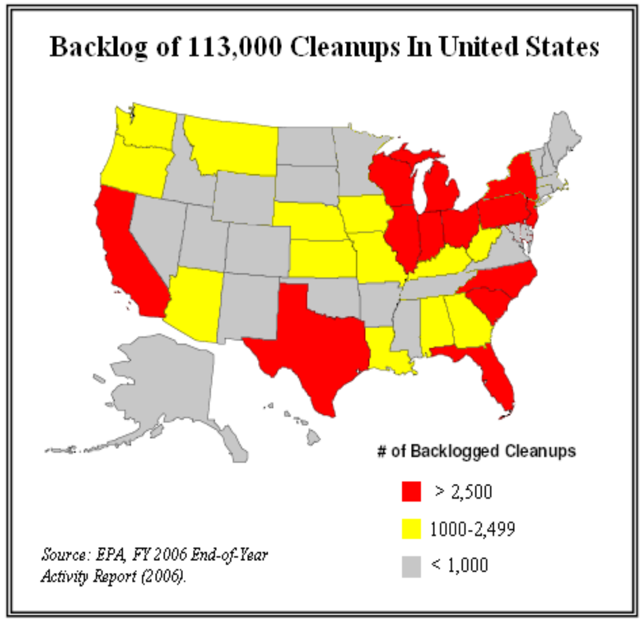

Figure 4. Backlogged clean-ups in U.S.

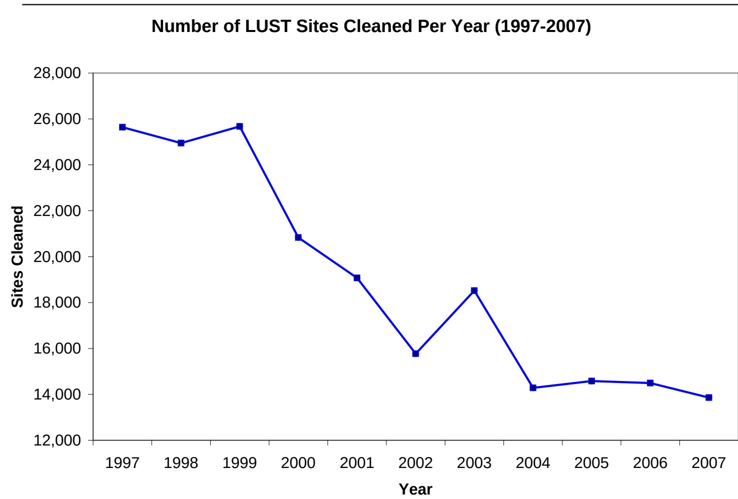

Figure 5. Decrease in U.S. LUST site clean-ups
Note: There is a slight discrepancy between reported and calculated figures Source: U.S. EPA, 1997-2007

Table 1. USTs in Great Lakes States

State	Number of Active Tanks	Number of Closed Tanks	Confirmed Releases (Cumulative)	Cleanups Initiated	Cleanups Completed (Cumulative)	Cleanup Backlog
IL	22,574	63,619	23,396	22,022	16,209	7,187
IN	13,840	36,240	8,637	8,109	6,028	2,609
MI	20,155	66,719	21,371	20,949	12,294	9,077
MN	14,532	28,070	10,020	9,894	9,090	930
OH	23,998	41,691	26,198	25,640	23,277	2,921
WI	13,725	65,775	18,578	18,241	15,970	2,608
NY	28,897	86,261	25,591	25,562	22,904	2,687
PA	24,677	61,356	14,420	13,837	10,811	3,609
Total	**162,398**	**449,731**	**148,211**	**144,254**	**116,583**	**31,628**

Source: U.S. EPA, 2007c

Table 2. Frequency of Financial Coverage Checks for UST Owners in the Great Lakes States

State	At Least Annually	1 to 2 Years	3 Years or Longer	Do Not Check	Other**
IL					✖
IN				✖	
MI	✖				
MN*					✖
OH			✖		
WI	✖				
NY				✖	
PA	✖				

* Does not check whether financial responsibility coverage is current as financial assurance funds provide sufficient coverage for all tanks in the state.

** Includes "as events warrant," and "annual permit applications contain financial responsibility information that may be checked," among other responses.

Source: GAO, 2007

owned or leased facilities (Braves, 2003) with totals of 30,000 to 60,000 across the province (Alsip, 1993). A 1997 study found there are approximately 21,000 USTs in the Greater Toronto Area (GTA) (Howard and Livingston, 1997). Estimating a minimal GTA population growth of 20% in the last ten years this number is now likely close to 26,000 USTs. One reference suggests there are between 6,000 and 12,000 LUSTs in Ontario (Alsip, 1993).

ABOVEGROUND STORAGE TANKS

Groundwater contamination also is occurring from aboveground storage tanks (AST). For example as previously noted by the IJC in its 1993 report on Groundwater Contamination in the Great Lakes Basin, petroleum refineries are a significant source of groundwater contamination. At the Amoco Refinery in Whiting, Indiana (in the Grand Calumet Area of

Concern), 17 million gallons (64 million litres) of petroleum are floating on the water table (IWRA, 1993), an amount which greatly exceeds the volume of the Exxon Valdez spill. Between 30 to 50 million gallons (115 to 190 million litres) are estimated to pollute groundwater across the entire Area of Concern (Tolpa, 1992).

Many homes and cottages have ASTs containing heating oil, which are rarely inspected and minor leaks often go unrepaired. Over time, these leaked fluids percolate through the soil and eventually reach the water table. A significant issue regarding ASTs is the diurnal expansion and contraction of fuel within the tank due to atmospheric temperature variation and full-sun/shade cycles. In ASTs, variation in pressure is alleviated by venting to prevent flexing of joints and weakening of the tank seams. However, vents do become clogged. Additionally, they also allow water to enter the tank as the fuel contracts and draws in humid air. Over time, water accumulates in the base of the tank causing it to rust and leak (Friedman, 2007).

FUNDING

To aid with the cleanup and remediation of LUSTs, many states as well as the U.S. government have set up funding programs. Financial assurance funds by individual states accumulate assets through state-specific gasoline taxes and tank registration fees. Approximately 40 states have UST cleanup funds, separate from the federal LUST Trust Fund (U.S. EPA, 2008c). In Michigan, owners/operators have to submit a registration form to the Waste and Hazardous Materials Division (WHMD) along with a $100 annual registration fee per UST (Rothe, 2003). These funds are used to help owners clean up sites as well as for cleaning up orphaned sites that have no known owner or the owner is unable or unwilling to remediate the area (GAO, 2007). One such fund, the Refined Petroleum Fund Temporary Reimbursement Program, was established in Michigan to provide $45 million for UST owners and operators who met specific requirements (Michigan DEQ, 2007).

The U.S. federal LUST Trust Fund, was established in 1986 to provide subsidy for "overseeing and enforcing clean-up actions taken by a tank owner or operator and cleaning up leaks at tank sites, including those without a viable owner, or at sites that require emergency action" (GAO, 2007). The LUST Trust Fund is financed through a 0.1 cent per gallon tax placed on the sale of motor fuel (U.S. EPA, 2006) and currently has assets in excess of $2.6 billion and expected to reach over $3 billion at the end of the 2008 fiscal year ("Clean up," 2007). Although total revenue to the LUST fund in 2005 was $269 million (GAO, 2007), only $73 million was designated to be allocated in 2006. Of this, only $59 million was distributed among the 50 states and the District of Columbia. The remainder was divided between cleaning up sites on tribal lands and program responsibilities for the U.S. EPA (Henry, 2006).

The U.S. EPA determines the amount allocated to each state from the LUST fund based on whether the state has a U.S. EPA-approved LUST financial assistance program, the state's needs, cumulative confirmed releases, percent of the population reliant on groundwater for drinking purposes and past cleanup performance (GAO, 2005, 2007). Although a large portion of these funds are utilized for cleaning up orphaned sites, the number of such sites per state is currently not considered by the U.S. EPA when distributing funds (GAO, 2007). Estimates place the number of orphaned sites in Michigan around 4,200 and the number of abandoned tanks at approximately 9,000 (Pollack, 2007; Michigan DEQ, 2006). These sites are causing significant financial pressure to be placed on the state as an estimated $1.5 billion will be needed to clean up the orphaned sites (Michigan DEQ, 2006). Nevertheless, $76 million has already been diverted from the UST cleanup program, and in 2007 the Legislature decided to take the remaining $70 million to balance the budget ("Clean up," 2007; Lam, 2007; Pollack, 2007).

As designated by the Resource Conservation and Recovery Act (RCRA), adequate insurance coverage must be maintained by tank owners. Yet, in 25 states proof of this coverage is checked infrequently and in some cases not at all. In the Great Lakes states, checking is variable (Table 2) (GAO, 2007). This can result in owners lapsing their leak insurance coverage, forcing the state to utilize public funding (GAO, 2007) for clean-ups. States are slow to apply penalties on companies who are in violation. More than eight years after a leak was detected in Pierson under a Mobil Station fines have yet to be handed out ("Clean up," 2007).

CLEANUP COSTS

Average clean-up cost per LUST site is estimated by the U.S. EPA to be $125,000 (Figure 6). However, several experts believe this number to be much closer to $400,000 (Wisely, 2007). Depending on the extent of contamination this figure may easily exceed $1 million, especially if there has been groundwater contamination. Clean-up at one site in Utica, New York, cost $2 million, which was equivalent to the total received by that state for its LUST program from the LUST Trust Fund in 2006 (Brazell, 2006). Furthermore, this estimate does not take into account all costs of site

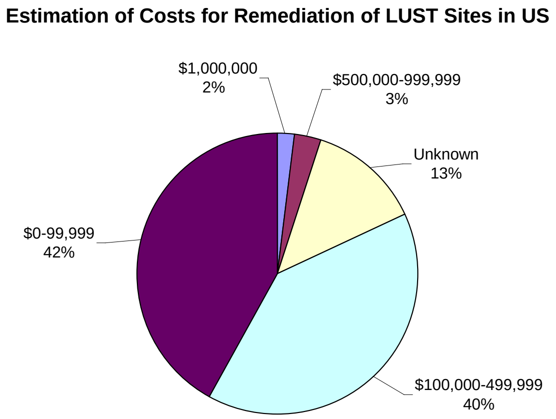

Figure 6. Estimation of costs for remediation of LUST sites in U.S. Source: GAO, 2007

cleanup since it only includes treatment of contaminated soil and groundwater, site surveying costs and feasibility studies, while ignoring the additional costs resulting from excavation and disposal/repair of tanks and pipes (U.S. EPA, 1986). For 2005 the GAO received information from the states indicating that 54,000 of the then remaining 117,000 federally regulated LUST sites across the United States would require approximately $12 billion in public funding. The other 63,000 LUST sites were to be cleaned up by funding supplied by the tank owners (GAO, 2007). However, the states also reported that over the next five years they expect more than 16,700 new sites to be found, which will require additional public funding (GAO, 2007). Funding provided by the federal LUST fund is only a minor contributor to the total that states spend on LUST sites. In comparison, combined state LUST funds raise around $1 billion per year (U.S. EPA, 2007a).

In Canada, the average clean-up costs for LUST sites on federal lands in 1994 was estimated to be $147,000 per site, giving a national estimate for the total 40,000 LUST sites across Canada to be upward of $5.9 billion (Lalonde, 1995). However, this figure may be misleading since an accurate number of LUST sites is unknown and there is a lack of assessments of the contaminated sites (Lalonde, 1995).

In the Great Lake states, estimates of necessary funding for backlogged LUST sites is more than $3.3 billion; and four of the eight states have funding deficits (Sierra Club, 2005; U.S. EPA, 2006). For example, Michigan had a reported deficit of over $1.7 billion (Sierra Club, 2005).

Estimates of clean-up costs of LUST sites in Ontario are between $882 million and $1.7 billion (Lalonde, 1995; Alsip, 1993). The total cost for remediation of identified LUST sites in the Great Lakes states and Ontario is therefore over $4.5 billion (Table 3). Due to high costs of remediation and a lack of adequate funding, many states do not have sufficient human and financial resources to adequately monitor all USTs in their jurisdiction, to enforce regulations or to guarantee timely LUST cleanups. In 2002 only 19 states reported to the GAO that they were meeting conditions that the U.S. EPA deems necessary and were physically inspecting all USTs at least once every three years (Table 2) (GAO, 2002).

REGULATIONS

Before 1980, most tanks were constructed from steel and are highly susceptible to corrosion. Unless properly maintained, 50% of these steel tanks may have been leaking by the time they were 15 years old (Environment Canada, 1999). Due to high leak potential, USTs in Ontario older than 20 years must be removed and owners do not have the option of upgrading (Braves, 2003). The owner is responsible for removal costs. USTs with a capacity of 5,000 litres or more must be tested annually for leaks (Carter, 2006). Tanks that do not pass inspection are given a time frame for repair after which fuel will no longer be supplied to that tank (Braves, 2003). If there has been a leak, the Spills Action Centre of the Ontario Ministry of Environment and Energy must be informed (Carter, 2006). USTs no longer in use must be removed within two years of decommissioning, and an assessment of the area is required. If contamination is found, it must be cleaned up immediately; costs are the responsibility of the owner (Braves, 2003; Carter, 2006).

Both Canada and the U.S. have established new standards for USTs. In Ontario, regulations have been implemented by the Technical Standards and Safety Authority (TSSA) requiring all USTs to be registered and either removed or upgraded to meet new leak and spill protection equipment regulations within a given time, dependent upon the age of the UST (Table 4) (Carter, 2006). Canada has also taken steps by implementing the Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations, under the Canadian Environmental Protection Act 1999, to protect soil and groundwater from contamination by USTs on federal and aboriginal lands (Environment Canada, 2008).

U.S. regulations regarding USTs were issued by the U.S. EPA in 1988. These generally require tanks to be inspected by owners/operators every 30 days and any leaks found to be reported within 24 hours (GAO, 2005). However, all too frequently owners/operators do not perform adequate leak checks or intentionally disconnect equipment that would signal a leak. In 2002, fifteen states reported to the GAO that leak detection equipment was frequently turned off or was not maintained (GAO, 2002). The issue of enforcement is of key importance. Lack of monitoring of non-federally regulated USTs is likely allowing significant numbers of leaks to go undetected for extended periods of time. The longer sites are backlogged the greater the subsurface area and volume of groundwater that becomes contaminated, resulting in increased difficulties and costs associated with site remediation. Depending on the location and nature of the chemicals released, remediation of the site may become impossible, financially and/or technically. Environment Canada stated that contamination of surface water by polluted groundwater is likely just as serious as the contamination of groundwater itself (United States Geological Survey, 2004).

The U.S. Energy Policy Act of 2005 was developed in an effort to help reduce leaks. The policy requires tanks to be inspected once every three years (GAO, 2007) and, starting in 2007, tanks that do not meet regulations will be denied shipments (GAO, 2005). A number of Great Lakes states have implemented delivery prohibition programs (Table 5). Frequently this involves red and green tags attached to tanks. For example red tags identify tanks ineligible to receive product (U.S. EPA, 2008b). Regulations require that all newly installed tanks meet leak detection and prevention standards. Existing tank owners had until 1993 to install leak detection equipment and 1998 to install leak prevention methods (GAO, 2003). However, not all tanks have been inspected and some owners have still not met this deadline. In addition new tanks are frequently not properly installed, operated or maintained. In 2007 according to the U.S. EPA, only 63% of U.S. tanks were in "significant operational compliance" with both

Table 3. Cost of LUST Cleanup in Great Lakes States and Provinces

State / Province	Number of Backlogs	Estimated Average cost of Cleanup	Estimated Total Cost (million)
Wisconsin	2,956	$133,581	$394.9
Illinois	7,513	$75,000	$563.5
Indiana	2,920	$135,000	$394.2
Michigan	9,069	$87,169	$790.5
Minnesota	984	$125,000*	$123
Ohio	2,706	$58,587	$158.5
New York	2,972	$125,000*	$371.5
Pennsylvania	3,842	$121,060	$465.1
Ontario	9000**	$147,000***	$1,323
Total	**34,962**		**$4,584.2**

* Average cost of cleanup for state unavailable, utilized U.S. EPA estimation of $125,000

** Average of estimated 6,000-12,000 LUST sites in Ontario

*** Average cost of cleanup for province unavailable, utilized estimation of $147,000 (average cleanup for nation's federal sites)

Source: U.S. EPA, 2006; Sierra Club, 2005; Lalonde, 1995; Alsip, 1993

Table 4. Deadlines for Removal and Upgrading of USTs in Ontario

Age of UST (years from installation)	Deadline for Removal or Upgrade
≥ 25 (or unknown)	October 1st 2006
20-24	October 1st 2007
10-19	October 1st 2008
0-9	October 1st 2009

Source: Carter, 2006

Table 5. States with Red and Green Tag Programs

State	Red Tag	Green Tag	Neither
NY			✖
PA			✖
IL	✖	✖	
IN			✖
MI	✖		
MN	✖		
OH			✖
WI	✖		

Source: U.S. EPA, 2008b

Table 6. Operational Compliance of Great Lakes States in 2007

State	% in Significant Operational Compliance with Release Prevention Regulations	% in Significant Compliance with Release Detection Regulations	% of UST Facilities in SOC with UST Release Detection and Release Prevention
NY	74%	68%	57%
PA	85%	79%	69%
IL	61%	56%	44%
IN	76%	84%	79%
MI	74%	45%	38%
MN	57%	65%	49%
OH	80%	69%	66%
WI	81%	80%	68%
Total	**74%**	**68%**	**59%**

Source: U.S. EPA, 2007c

release prevention and leak detection requirements and only 59% of those in the Great Lake states (Table 6) (U.S. EPA, 2007c). The U.S. EPA's June 2008 report indicated that significant operational compliance had increased slightly to 65% (U.S. EPA, 2008a). As of February 2007, states that receive federal funds must require additional/secondary structures for USTs that are near sources of drinking water or evidence of financial responsibility from tank manufacturers and installers (GAO, 2007). Additionally, the U.S. EPA is required to prepare and publish training requirements for tank operators and maintenance personnel as well as award up to $200,000 to states that develop and implement these training programs (GAO, 2005). The policy act also extended the 0.1 cent LUST Trust Fund tax on petroleum products until 2011 (GAO, 2007).

In 1990 Florida passed a state law requiring that all USTs have a double-walled system. The deadline for the update is December 31, 2009 and 11,168 out of 25,529 tanks are still out of compliance (Torres, 2008).

REMEDIATION AND PREVENTION

In order to protect groundwater quality and both human and ecosystem health, measures need to be taken in order to achieve a comprehensive count of USTs and LUSTs present in Canada and the U.S. This will allow for a better estimate of potential contamination as well of the cost of remediation. Suggestions have previously been made by various sources as to appropriate measures which should be taken regarding USTs. The GAO (2007) has recommended that U.S. EPA take steps to:

- Ensure that states verify tank owners' financial responsibility coverage on a regular basis.
- Improve the agency's oversight of the solvency of state assurance funds.
- Assess the relative effectiveness of options for financial responsibility coverage.
- Better focus how U.S. EPA distributes LUST Trust Fund money to the states.

The GAO (2003) has suggested that Congress:

- Provide the states more funds from the LUST Trust Fund so they can improve training, inspection and enforcement efforts.
- Provide U.S. EPA and the states additional enforcement authorities.

The Sierra Club (2005) has recommended that the following measures be implemented:

- Fund more cleanups, prevention and enforcement activities.
- Require secondary containment, leak detection and biannual inspections.
- Enforce protections in states that fail to safeguard communities.
- Make polluters pay to clean up LUST contamination.
- Ensure that people know about LUSTs in their communities.

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GLOSSARY

AST – above ground storage tank

Backlog – total number of LUST sites that are in the process of being remediated as well as those that have not yet begun to be remediated.

BTEX – the volatile organic compounds benzene, toluene, ethylbenzene and xylenes found in gasoline

DCA - 1,2-dichloroethene. Occurs in two forms known as cis and trans which have similar properties. It is a highly flammable, colorless liquid with a sharp, harsh odor. It is a synthetic chemical used in chemical mixtures as well as to manufacture solvents.

De Minimus Concentration – There are two requirements, both which must be satisfied. First – the concentration of a regulated substance in a UST system, when mixed with a non-regulated substance, is less than 110 gallons of regulated substance when the storage tank is full. Second – the UST system, of any size or capacity, contains less than the reportable quantity of hazardous substance or substances in the product stored, as identified in the United States Environmental Protection Agency Table 302.4 list of hazardous substances and reportable quantities, when the storage tank is full.

DIPE – diisopropyl ether. Having the chemical formula $C_6H_{14}O$, it is a colourless liquid that is slightly soluble in water. Commonly used as an oxygenate for gasoline.

E10 – fuel blends of 10% ethanol and 90% gasoline.

E85 – fuel blends of 85% ethanol and 15% gasoline.

EDB – ethylene dibromide, also known as 1,2-dibromoethene. Having the chemical formula $BrCH_2CH_2Br$, it is a colorless liquid with a mild, sweaty odor and is mainly synthetic.

ETBE – Ethyl tertiary butyl ether. Having the chemical formula $(CH_3)_3COC_2H_5$, it is a colourless, flammable, oxygenated hydrocarbon. It has low volatility and low water solubility. It has a high octane value and is commonly used as an oxygenate in gasoline.

Ethanol – Ethanol fuel is a biofuel alternative to gasoline. It is a liquid alcohol produced from the fermentation of sugar or converted starch, which is then distilled and dehydrated to create a high-octane, water-free alcohol. It is used as an oxygenate additive for gasoline. It can be combined with gasoline in any concentration up to pure ethanol (E100) in an attempt to reduce the use of petroleum fuels and air pollution.

Ethylbenzene – is an organic chemical compound having the chemical formula C_8H_{10}. It is an aromatic hydrocarbon, colorless, flammable liquid and smells like gasoline.

LUST – leaking underground storage tank.

Methanol – also known as methyl alcohol, methyl hydrate, carbinol or wood alcohol. Having the chemical formula CH_3OH, it is a clear, colorless liquid with a faint odor like alcohol. Can be used as an additive to gasoline.

MTBE – methyl *tert*-butyl ether is a fuel oxygenate that is used in gasoline to reduce the atmospheric pollution associated with automobile emissions.

Naphthalene – is a crystalline, aromatic, white, solid hydrocarbon having the chemical formula $C_{10}H_8$. It is volatile and occurs naturally in fossil fuels.

Orphaned Site – underground storage tanks that have been abandoned and no financially viable responsible party can be found.

Oxygenate – compound containing oxygen that is added to gasoline in order to reduce emission.

PCB – polychlorinated biphenyls having the general chemical formula $C_{12}H_{10-x}Cl_x$. There are no known natural sources of PCBs. PCBs are oily liquids or solids that are colorless to light yellow. PCBs have no known smell or taste.

PERC – perchloroethylene, also known as tetrachloroethylene or tetrachloroethene. Having the chemical formula $Cl_2C=CCl_2$, it is a nonflammable liquid at room temperature, evaporates easily and has a sharp, sweet odor. It is a synthetic liquid that is widely used for dry cleaning and removing grease from metal.

TAME – *tert*-amyl methyl ether. Having the chemical formula $C_2H_5C(CH_3)_2OCH_3$, it is a volatile, low viscosity clear liquid at room temperature which is highly flammable and slightly soluble in water. Commonly used as an oxygenate for gasoline.

TCE – Trichloroethylene is a colorless liquid commonly used as an industrial solvent. Having the chemical formula $ClCH=CCl_2$, it is a nonflammable, colorless liquid with a somewhat sweet odor and a sweet, burning taste.

UST – underground storage tank.

Underground Storage Tank System – a tank or combination of tanks, including underground pipes connected to the tank or tanks, which is, was, or may have been used to contain an accumulation of regulated substances, and the volume of which, including the volume of the underground pipes connected to the tank or tanks, is 10% or more beneath the surface of the ground.

Threats to Groundwater Quality in the Great Lakes Basin — Hazardous Waste Sites

CONTENTS

INTRODUCTION

Hazardous wastes are generally defined as materials, including liquids, solids and gases, that are dangerous or potentially dangerous to environmental or human health. Hazardous wastes are identified as having one or more of the following properties: ignitability, corrosivity, reactivity or toxicity (U.S. EPA, 2006a). The U.S. Environmental Protection Agency (EPA) has compiled a list containing more than 500 hazardous wastes (U.S. EPA, 2006c). According to the U.S. EPA (2006c) more than 40 million tons of hazardous wastes are produced in the U.S. every year. However, other sources indicate that this figure might be as high as six billion tons (Natural Resource Council on Environmental Epidemiology, 1991). Canada produces more than six million tons of hazardous waste per year (Environment Canada, 2003). Hazardous waste sites are deemed potentially dangerous if not properly maintained because they hold the potential to release irritant gases, metals, solvents, pesticides and many other harmful substances. These substances can easily migrate away from the site contaminating the surrounding air, soil and water (both above and below ground). Many examples of groundwater contamination resulting from hazardous waste dumps can be found in the literature, including many in the Great Lakes region, especially in the Niagara Falls area (Love Canal, Hyde Park, etc.) (Fletcher, 2002).

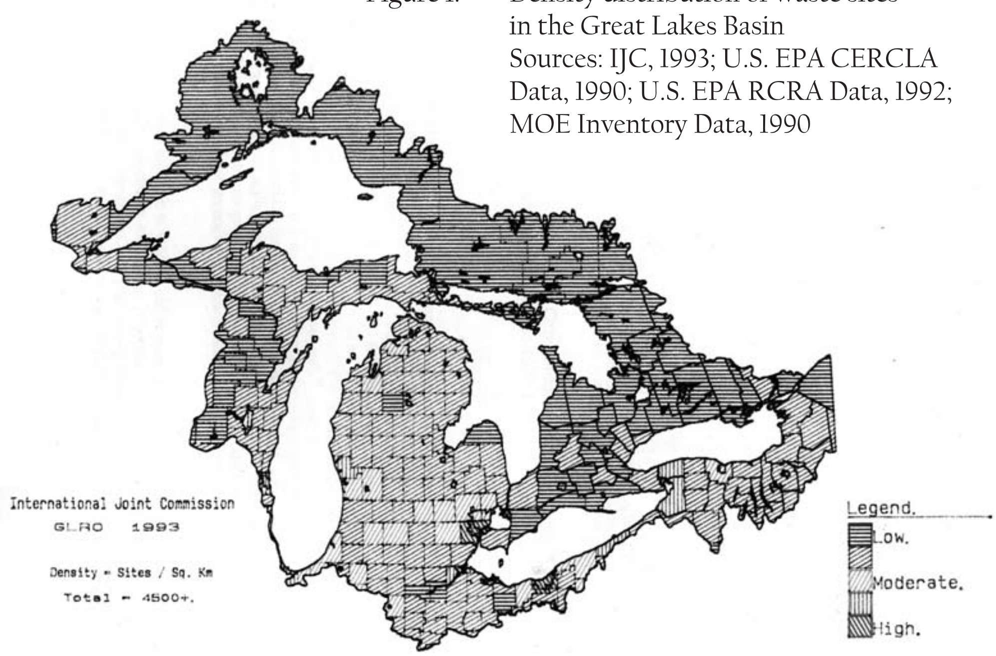
Hazardous waste production began to increase in the 1940s along with industrial expansion and the chemical revolution (Government of Canada, 2002). During the 1940s and 1950s land disposal of hazardous waste in unlined landfills and lagoons was common industrial practice. In many cases, these practices continued into the 1980s. As a result there are currently more than 4,500 known hazardous waste sites in the Great Lakes Basin. Of the known sites, 98% are in the United States and 2% in Canada (Fletcher, 2003). Of the previously estimated total, only 6% are still open and accepting waste (Fletcher, 2003). Currently there is only one operating commercial hazardous waste landfill in Ontario, located near Sarnia (Fletcher, 2003).

GROUNDWATER CONTAMINATION

The density distribution of hazardous waste sites varies considerably across the basin (Figure 1). Some of the highest densities are located in the Detroit, Michigan, and Niagara Falls, New York, areas where there is more than 1 site per 13 square kilometers (Fletcher, 2003). In contrast, in the adjoining Canadian areas, the densities are much lower with less than 1 site per 52 square kilometers in Lambton County, Ontario, and less than 1 site per 259 square kilometers in Niagara Falls, Ontario (Fletcher, 2003).

Hazardous waste sites are a significant concern to water quality of the Great Lakes. Precipitation that has come in contact with hazardous waste percolates down through the earth, contaminating groundwater supplies that serve to recharge the lakes. Significant groundwater contamination has occurred at the FMC Corporation Dublin Road Site, an inactive waste site located in Orleans County of northwestern New York. From 1933 to 1968, debris, including laboratory wastes, pesticides and chemical residues, was disposed leading to water and soil contamination. Lead, mercury, arsenic and pesticides have been identified resulting in the construction of a groundwater extraction treatment system and an on-site water treatment facility. Over the next 20 to 30 years approximately 126 million gallons of groundwater will need to be treated (U.S. EPA, 2006d).

Figure 1. Density distribution of waste sites in the Great Lakes Basin
Sources: IJC, 1993; U.S. EPA CERCLA Data, 1990; U.S. EPA RCRA Data, 1992; MOE Inventory Data, 1990



While hazardous waste sites are a known threat to groundwater quality, the full extent of the threat is still unknown since additional sites are still being discovered. Furthermore the nature and quantity of contaminants at most waste sites has still not been determined (IJC, 1993). Enormous potential exists for surface water contamination by groundwater-borne contaminants emanating from hazardous waste sites. For example, the Mill Creek Dump in Erie County, Pennsylvania, was a freshwater wetland located two miles west of Erie. Used as a dump for foundry sands, solvents and oils, groundwater, soils and sediments, respectively, became contaminated with volatile organic compounds (VOCs) and polynuclear aromatic hydrocarbons (PAHs), PCBs and heavy metals (Figure 2). Contaminated groundwater and surface water drain into Lake Erie (U.S. EPA, 2007a).

Figure 2. Mill Creek Dump before clean-up
Source: U.S. EPA, 2007a

Another study for the U.S. EPA, by E.S. Morton and P. Miller of PRC Environmental Management Inc. (1992), estimated a worst-case scenario for toxic chemical loadings to Lake Michigan from Resource Conservation and Recovery Act (RCRA, 1992) and Superfund disposal sites. The report concluded that there is potential for more than 40,000 tonnes (44,000 tons) of 28 toxic chemicals to migrate with groundwater to Lake Michigan each year.

The recently published ATSDR (2008) report on Chemical Releases in the Great Lakes Region documents a troubling litany of groundwater contamination locations from around the basin including several requiring additional assessment, ongoing monitoring and perpetual 'pump and treat' remediation augmented, in some cases, by air sparging and in-situ chemical oxidation.

HUMAN HEALTH EFFECTS

Over the years numerous studies have been conducted in order to try to determine a connection between various health effects and proximity to hazardous waste sites. Specifically, studies have focused on a relationship to fetal deaths, birth defects, low birth weight and increased risk of cancer. Goldberg, Al-Homsi, Goulet and Riberdy. (1995) examined a population near the Miron Quarry in Montreal, Quebec. They found the primary means of exposure to the population to be through biogas which contained methane, carbon dioxide, sulfur compounds and VOCs (including suspected carcinogens). Traces of benzene, tetrachloroethane and chloroform, known embryotoxins, also were found. Their study found people in close proximity to the site have moderately increased risks of stomach cancer as well as cervi uteri and liver cancer.

Berry and Bowe (1997) examined more than 11,000 births near the Lipari Landfill. They found an increased risk of low birth weight and of babies being born preterm for mothers living near the waste site. Another study by Croen, Shaw, Sanbonmatsu, Selvin and Buffler (1997) examined birth defects in babies near hazardous waste sites. They found that babies of women who lived within ¼ mile of a Superfund site were four times more likely to acquire heart defects and two times more likely to acquire neural tube defects.

SITE ASSESSMENT

While hazardous waste sites are known to pose possible health problems to the public, each site possesses its own set of unique characteristics and must undergo examination. These examinations consider the extent of environmental contamination and possible contact with human populations, the substances which are present and their unique and synergistic toxic properties, and the characteristics of the affected population including age and gender (Johnson and DeRosa, 1997).

Recently, there has been a proposal on deep storage of spent radioactive uranium fuel and other waste in Southern Ontario's sedimentary rocks. Originally the waste was being considered for storage in the Canadian Shield, crystalline rocks that have been stable for over 2 billion years. However, transportation and drilling into the dense rock result in this being a costly operation. The Nuclear Waste Management Organization released a report stating that Southern Ontario's sedimentary rocks would be a viable alternative. This has worried local environmentalists as Southern Ontario's sedimentary rocks are fractured and prone to geological activity. Aquifers may be negatively affected should they come into contact with radioactive storage containers (Burman, 2007).

The town of Kincardine, Ontario, has agreed to Ontario Power Generation's (OPG) proposal to construct a deep geologic repository, 660 meters below surface, in nearby sedimentary rocks. This facility will house low- and intermediate-level hazardous wastes. Construction is scheduled to begin in 2012 and operation in 2017 pending appropriate approvals and licensing (OPG, 2008).

THE NIAGARA RIVER AREA OF CONCERN

One of the major areas of concern in the Great Lakes Basin with regard to hazardous waste sites is the Niagara River, a major toxic pollution "hot spot." There are 215 known hazardous waste sites within Niagara and Erie counties of New York, 164 of which are located within 3.1 miles (5 kilometers) of the Niagara River (Philbert, 1991). These include sites such as Hyde Park, S-Area, Love Canal (Figure 3) and 102nd Street landfill sites (Cohen, Rabold, Faust, Rumbaugh and Bridge, 1987). An example of the amount of waste at these sites can be portrayed through Hyde Park where more than 80,000 tons of dense non-aqueous phase liquid (DNAPL) was disposed between 1953 and 1975. "Pump and treat" groundwater remediation efforts have recovered more than 300,000 gallons of non-aqueous phase liquid from the site (Becker, 2006).

The Niagara River flows 38 miles from Lake Erie to Lake Ontario, forming the border between western New York and Ontario (U.S. EPA, 2008b). In 1973, the IJC designated the Niagara River as an Area of Concern because of concerns about toxic contamination of the river and Lake Ontario and the effects on human health and the ecosystem (EC, 1996). Chemicals are entering the Niagara River through groundwater discharges into the river, the urban drainage network and from the Niagara Wastewater Treatment Facility (EC, 1996).

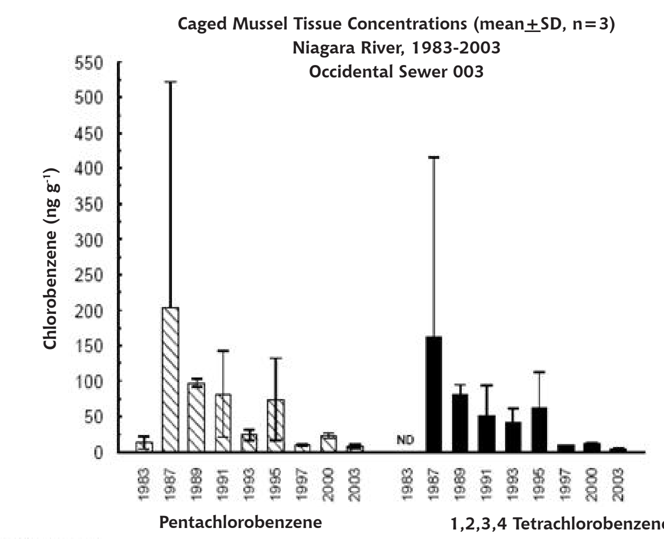
Figure 3. Sign posted at Love Canal area
Source: CNN, 1998

Annex 16 on contaminated groundwater affecting the Great Lakes was added to the GLWQA as a result of these Niagara River contamination issues. In 1998 New York included the river on its 303(d) list of impaired waters for priority organics. Since then, significant remediation efforts at many sites have improved water quality (U.S. EPA, 2008b).

Work to reduce toxic loadings to the Niagara River began in the 1960s and was intensified during the 1980s and 1990s. According to New York estimates, there has been an 80% reduction in priority pollutants discharged from all New York point sources. Nevertheless, point sources alone discharge 248 kg (546 lb.) a day of U.S. EPA priority pollutants to the Niagara River (Colborne et al., 1990). This does not include toxic substances discharged from non-point sources, notably from at least 38 hazardous waste disposal sites known to contribute contaminants to the river via groundwater flow. It is estimated that 341 kg (750 lb.) of contaminants enter the river by groundwater discharge every day.

Since 1975 the Ontario Ministry of the Environment (MOE) has been using biomonitors to monitor contaminants in the Niagara River. Biomonitoring indicates the presence of contaminants in the water column when concentrations in the water are below the method detection limits (Richman, 2006). Caged mussels have been used in various reaches of the Niagara River since 1980 to identify the presence or absence of contaminants, sources and to assess the success of remedial activities (Richman, 2006). The collected data indicate that remedial activities have been successful in reducing the bioavailability of contaminants. See Figure 4 for an example of data collected from Occidental

Figure 4. Data for caged mussels at Occidental Sewer, Niagara River
Source: Richman, 2006



Sewer, Niagara River. However, the data also show that there are still sources of organic chemical contaminants along the Niagara River (Richman, 2006).

New York included the entire length of the Niagara River on its 1998, 2002, 2004 and 2006 303(d) lists for not meeting beneficial uses of aquatic life and fish consumption due to priority organics (U.S. EPA, 2008b). These priority organics are identified as originating from contaminated sediments and from hazardous waste sites (U.S. EPA, 2008b). The Niagara River Toxics Management Plan (NRTMP) process has identified hazardous waste sites as the most significant nonpoint sources of priority toxics loading to the river (U.S. EPA, 2008b). Total priority toxic loads to the river have decreased more than 90%, from approximately 700 lbs/day to less than 50 lbs/day under the NRTMP process (U.S. EPA, 2008b).

The sedimentary bedrock of the Niagara Frontier and the western Lake Ontario basin contains a complex intersecting network of fractures, tectonic faults and karstic terrain, and the basin is also a region of intermittent earthquake activity. Groundwater-borne toxic contaminants emanating from hazardous waste repositories have infiltrated this network and are entering Lake Ontario via discharge to the Niagara River and possibly also directly via upwelling through littoral lake and river bottom sediment. Past usage, former waste disposal practices and the continued presence of these wastes *in situ* will continue to pollute the water. It is not certain what effects these compounds will have on the equilibrium of this large natural system.

In 1984, the Buffalo Avenue wastewater treatment plant serving Niagara Falls, New York, had been described in a joint U.S. and Canadian government report as "the largest toxic polluter of the Niagara River" (Lisk, 1995). They claimed that the plant was by-passing as much as two million gallons of contaminated wastewater a day into the river, and that this discharge frequently contained 700-800 pounds of priority pollutants (Lisk, 1995). To address contaminated effluent issues from the facility it was re-designed to use granular activated carbon (GAC) to absorb the relatively small quantities of soluble organics and inorganic compounds remaining in the wastewater following biological or physical-chemical treatment (U.S. EPA, 2000). Absorption occurs when molecules adhere to the internal walls of pores in carbon particles produced by thermal activation (U.S. EPA, 2000). Typically, GAC absorption is utilized in wastewater treatment as a tertiary process following conventional secondary treatment and for wastewater flows which contain a significant quantity of industrial flow (U.S. EPA, 2000). GAC absorption is a proven, reliable technology to remove dissolved organics (U.S. EPA, 2000).

However, spent carbon, if not regenerated, may present a land disposal problem, and wet GAC is highly corrosive and abrasive (U.S. EPA, 2000). Variations in pH, temperature and flow rate may adversely affect GAC absorption and air emissions from the regeneration furnace contain volatiles stripped from the carbon (U.S. EPA, 2000). Therefore, afterburners and scrubbers are usually needed to treat exhaust gases (U.S. EPA, 2000). The plant requires an inventory of more than five million pounds of GAC (Lisk, 1995).

Current flow averages about 35 mgd, but the plant was designated to handle up to 48 mgd. The flow carried under the city to an outfall over a mile away in the gorge down river from the falls. "Pumped and treated" groundwater forms part of this flow. $110 million had been spent during the GAC upgrade-twice the original cost of the facility (Lisk, 1995). On a daily basis, the facility receives approximately 800 pounds of influent pollutants which are reduced by the treatment process to 12 pounds in the effluent to the Niagara River (U.S. EPA, 2000). Only 13 wastewater plants using the GAC filtration/absorption technology are believed to have been built in the United States, and Niagara Falls is the largest of them (Lisk, 1995).

Currently however, the Niagara Falls, Buffalo Avenue Waste Water plant has been out of compliance and has not been meeting the requirements of its complicated discharge permit for the last three years (U.S. EPA, 2008a).

In November 2000, the Science Advisory Board (SAB) of the IJC hosted technical presentations from representatives of the government agencies cooperating under the NRTMP, conducted a tour of hazardous waste sites on the U.S. side and held a public meeting involving invited scientific presentations and interested citizens (IJC, 2003). The following comments and conclusions were reached by the SAB and submitted to the Commission (IJC, 2003).

- Chemicals, such as PCBs, Mirex and dioxins from the Niagara region not only can influence all of Lake Ontario and the St. Lawrence River but also can impinge on the Gulf of St. Lawrence and the Atlantic Ocean. See, for example, Figure 5.
- Serious efforts are underway at each individual waste site to contain movement of chemicals from the sites, but the larger reality of the immense geographical and temporal scale of the problem needs to be recognized and acknowledged. For example, approximately 80,000 tons of waste, some of which is hazardous material, is contained at the Hyde Park dump. By pumping and treating water infiltrating the site, about eight pounds of chemicals are removed and treated daily.

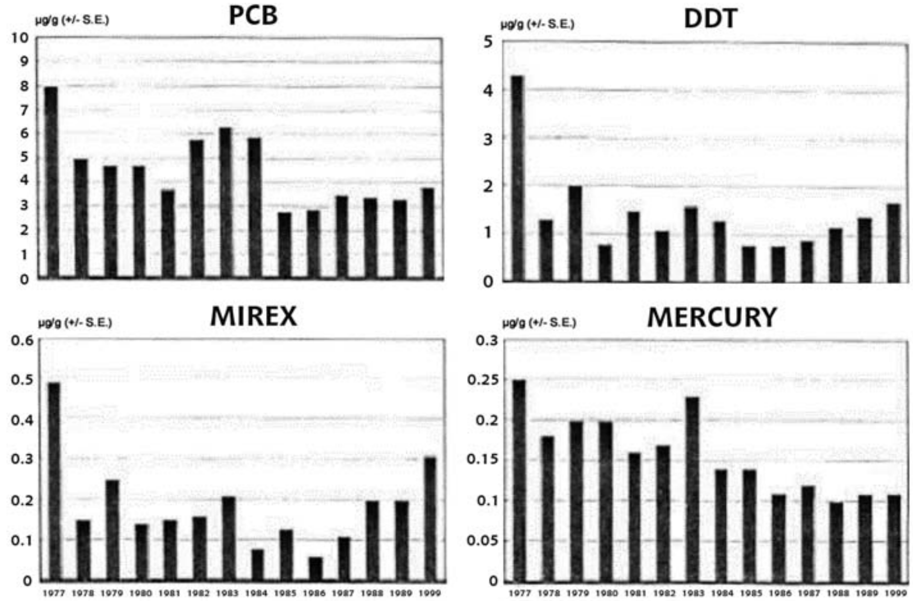


Figure 5. Lake Ontario trout (Aged 4+) - Whole fish contaminant levels
Source: Department of Fisheries and Oceans (Unpublished Data)

- The monitoring and surveillance programs under the NRTMP are models for binational cooperation and success. While these actions appear to have been successful, there was apprehension expressed whether this commitment would be sustained in the face of high cumulative costs of containment and the absence of immediately affected citizens to demand action.
- The importance of dense non-aqueous phase liquids (DNAPL) in fractured rock aquifers is well understood scientifically; however, it is difficult to locate the DNAPL in fractures and access is even more difficult. Pump-and-treat technology is not very effective for DNAPL removal. DNAPL could therefore become increasingly significant as an ongoing source requiring treatment as more soluble wastes within the site are removed.
- There appears to be very limited applied research into alternatives to pump-and-treat technologies in the Niagara region involving local hydrogeological expertise at nearby universities or involving institutions such as the U.S. Geological Survey.
- For short term, the crisis of hazardous waste management appears to be manageable through containment at individual priority waste sites. But issues related to other sources to the Niagara River including, for example, non-priority waste sites, contaminated sediments and other nonpoint sources, continue to have an impact on beneficial uses and will necessitate ongoing fish consumption advisories for the foreseeable future. For example, there are more advisories, and the advisories are more restrictive in the Lower Niagara River than in the Upper Niagara River (MOE, 2007).
- The waste management approach through containment has resulted in extensive areas of restricted, grassed, open space that may exist within the city for decades, even for centuries. From a land-use perspective, such areas will continue to have a severe economic and social impact on the city as long as they are unusable.

The SAB will conduct another Niagara hazardous waste site tour and public meeting in 2009 and assess progress achieved since 2000. Both Crittenden (1997) and Besecker (2008) express little optimism that the contamination issues in the Niagara region can, or will be, solved anytime soon and the area will remain a significant threat to public health and the environment.

The next NRTMP report is due in 2009 and will include a retrospective analysis and assessment of 20 years of effort in the region.

LEGISLATION

Brought about by the Love Canal incident to address health hazards associated with exposure to hazardous waste sites, the U.S. Congress in 1980 enacted the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly known as the Superfund Act (Natural Resource Council on Environmental Epidemiology, 1991). Superfund is the U.S. federal government's program to clean up the nation's uncontrolled hazardous waste sites (U.S. EPA, 2007b). Originally Superfund was created with the "polluter pays" focus. Polluters are responsible for the cleanup of contaminated sites. According to the Center for Public Integrity (2007c) there are 1,623 Superfund sites located across the United States, 540 of which are located within the Great Lakes states. It is estimated that approximately

100 companies are connected to more than 40% of America's most dangerous contaminated waste sites (Center for Public Integrity, 2007b). However, companies undergo corporate maneuvering in order to blur and avoid financial responsibility (Sapien and Knott, 2007). If a polluter cannot be associated with the site, if polluters refuse to undertake cleanup actions or where polluters do not have financial resources to conduct a cleanup, a trust fund, supplied mainly by an industry tax, ensured that U.S. EPA could clean up the site (Sierra Club, 2004). However, that tax measure expired in 1995 and was not reinstated. When the tax expired, only 18% of Superfund's funding came from taxpayers. In 2004 Superfund's trust fund was bankrupt and now 100% of the bill is footed by taxpayers (Sierra Club, 2004). Furthermore the Superfund program has been underfunded by 1.6 to 2.6 billion dollars from 2001 to 2004 (Table 1). As a result of insufficient funds, the U.S. EPA's cleanup of Superfund sites decreased by 50% from 87 sites in 1997-2000 to 43 sites in 2001-2003 (Sierra Club, 2004).

With insufficient funding hundreds of sites remain uncontrolled (Table 2). In 2007 there were 224 sites on the National Priorities List where contaminated groundwater was not under control and 114 Superfund sites with no control over human exposure to possible carcinogenic substances (Shaw, 2007). According to 2000 U.S. Census data there are more than 25 million people living within 10 miles of these 114 Superfund sites.

Table 1. Under-Funding of Superfund Program, 2001-2004

Year	Superfund Budget	Low-end Estimate of Superfund Program Needs	Difference between Superfund Budget and Low-end Estimate	High-end Estimate of Superfund Program Needs	Difference between Superfund Budget and High-end Estimate
2001	$1,336,000,000	$1,632,000,000	-$296,000,000	$1,740,000,000	-$404,000,000
2002	$1,340,000,000	$1,759,000,000	-$419,000,000	$1,988,000,000	-$648,000,000
2003	$1,265,000,000	$1,760,000,000	-$495,000,000	$2,130,000,000	-$865,000,000
2004	$1,257,000,000	$1,605,000,000	-$348,000,000	$1,921,000,000	-$664,000,000
Total Underfunding			-$1,558,000,000		-$2,581,000,000

Source: Sierra Club, 2004

Table 2. Superfund Sites Not Under Control.

State	Superfund Sites	Sites With Contaminated Groundwater Mitigation Not Under Control	Sites With Human Exposure Not Under Control
Pennsylvania	122	23	7
New York	110	9	7
Michigan	84	11	2
Illinois	51	6	4
Minnesota	46	1	4
Wisconsin	44	1	3
Ohio	44	3	0
Indiana	39	6	6
Total	540	60	30

Source: Center for Public Integrity, 2007c.

However, the U.S. EPA has been reluctant to release information including a cleanup timeline, funding needed and whether they are investigating an additional 181 sites that may pose health risks (Sapien, 2007a). The Forest Waste Products site located in Otisville, Michigan, is currently an active Superfund site. With 36 identified contaminants, of which at least one is ranked within the top five most hazardous chemicals, contaminated groundwater migrating from the site is currently not under control (Center for Public Integrity, 2007a). Bound Brook in New Jersey runs alongside the Cornell Dubilier Electronics Superfund Site. The U.S. EPA has declared that the brook is safe for recreational use; however, electrical capacitors leaking PCBs have been discovered along the banks (Sapien, 2007b). The U.S. EPA did not undertake any soil or water sampling tests after the capacitors were found nor did they warn the community that more contaminants had been discovered (Sapien, 2007b). However, Superfund sites likely contain only a small portion of contamination with thousands of old commercial and industrial sites leaching contaminants into the surrounding ground and surface water supplies (Shaw, 2007).

A proposed bill for limiting the siting of hazardous waste facilities in New York was vetoed by Governor Spitzer. The proposed legislation would have prohibited the siting of a hazardous waste landfill in an area with potential to discharge into the Great Lakes system. The bill,also would have curtailed the planned expansion of CWM Chemical Services in Porter, the state's only active hazardous waste landfill (Besecker, 2007).

HAZARDOUS WASTE INJECTION WELLS

In March 2004 the U.S. government gave the go ahead for the production of two 4,500-foot wells in Romulus, Michigan, licensed to accept 460,000 gallons of toxins a day ("Where did," 2006; Warikoo, 2004). In October 2006, less than a year after the site was opened, the site was shut down by the Michigan Department of Environmental Quality when they discovered that one of the wells was leaking, the other giving off an acidic gas and the company responsible was not to be found ("Where did," 2006; Warikoo 2004). Against much skepticism the wells were sold to Environmental Geo-Technologies, an investment company ("Greektown mogul," 2007).

BASINWIDE REMEDIATION AND PREVENTION

Remediation of groundwater emanating from hazardous waste sites is a complex undertaking that may prove to be neither technically nor financially feasible. The U.S. EPA estimated that remediation of each hazardous site carries an average price tag of $US 27 million (Elder, Proctor and Hites, 1981). Therefore, the estimated cost to remediate the 4,500 known sites in the basin will require $US 112.5 billion and several decades of effort. The virtual elimination strategy of the Parties to the Agreement will continue to be compromised or confounded.

Proper monitoring systems need to be in place in order to accurately keep track of hazardous waste produced and its storage. Ontario needs to put serious effort into improving its hazardous waste tracking system. The system is deficient, leaving the government without accurate figures of how much hazardous waste is moving around the province. It is estimated that $100 million would be needed over the next 10 years to implement a proper monitoring system (Mittelstaedt, 2008).

The most effective method to help reduce the effects of hazardous waste sites is to minimize the amount of hazardous waste produced. Treatments including chemical, physical, biological and thermal can be utilized to reduce volume and render wastes less toxic (Government of Canada, 2002). Also many industries and individuals have begun implementing the "four-R's" – reduce, recover, reuse recycle. Educational programs need to be implemented to help reduce hazardous waste produced. Canadians improperly dispose of 27,000 tonnes of household hazardous wastes each year ("Hazardous waste," 2006). The process of reducing hazardous wastes can be achieved simply if industries implement more efficient manufacturing processes, use alternative compounds and use or reprocess waste (Government of Canada, 2002).

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GLOSSARY

Bioavailability – A measure of the physicochemical access that a toxicant has to the biological processes of an organism. The less the bioavailability of a toxicant, the less its toxic effect on an organism (U.S. EPA, 2006e).

Biomonitoring – (1) The use of living organisms to test the suitability of effluents for discharge into receiving waters and to test the quality of such waters downstream from the discharge; (2) analysis of blood, urine, tissues etc. to measure chemical exposure in humans (U.S. EPA, 2006e).

Chlordane – A chemical pesticide used in the United States from 1948 to 1988. Technical chlordane is not a single chemical, but a mixture of pure chlordane with many related chemicals. It does not occur naturally. It is a thick liquid whose color ranges from colorless to amber. Chlordane has a mild, irritating smell (ATSDR, 1995c).

Detection Limit – A measure of the capability of an analytical method to distinguish samples that do not contain a specific analyte from samples that contain low concentrations of the analyte; the lowest concentration or amount of the target analyte that can be determined to be different from zero by a single measurement at a stated level of probability. Detection limits are analyte- and matrix-specific and may be laboratory-dependent (U.S. EPA, 2006e).

DDT (dichlorodiphenyltrichloroethane) – A persistent organochlorine insecticide introduced in the 1940s and used widely because of its persistence (meaning repeated applications were unnecessary), its low toxicity to mammals and its simplicity and cheapness of manufacture. It became dispersed worldwide and, with other organochlorines, had a disruptive effect on species high in food chains, especially on the breeding success of certain predatory birds. DDT is very stable, relatively insoluble in water but highly soluble in fats. Health effects on humans are not clear, but it is less toxic than related compounds. It is poisonous to other vertebrates, especially fish, and is stored in the fatty tissue of animals as sublethal amounts of the less toxic DDE. Because of its effects on wildlife its use in most countries is now forbidden or strictly limited (U.S. EPA, 2006e).

Dieldrin – The pure form is a white powder, the technical grade a tan powder. Slowly evaporates into the air and has a mild chemical odor. Was once used as an insecticide and does not occur naturally (ATSDR, 2002).

Hazardous Waste – A waste with properties that make it dangerous, or capable of having a harmful effect on human health and the environment. Under the RCRA program, hazardous wastes are specifically defined as wastes that meet a particular listing description or that exhibit a characteristic of hazardous waste (U.S. EPA, 2006e).

Heavy Metal – (1) A common hazardous waste; can damage organisms at low concentrations and tends to bioaccumulate; (2) a metal whose specific gravity is approximately 5.0 or higher (U.S. EPA, 2006e).

In situ – In its original place, unmoved, unexcavated, remaining at the site or in the subsurface (U.S. EPA, 2006e).

Karstic Terrain – A type of topography that is formed on limestone, gypsum and other rocks by dissolution. It is characterized by sinkholes, caves and underground drainage (U.S. EPA, 2006e).

Littoral – (1) Of, relating to or existing on a shore; (2) the intertidal zone of the seashore (U.S. EPA, 2006e).

Love Canal – Community in Niagara Falls, New York.

Mirex – An odorless, snow-white crystalline solid used as a pesticide to control fire ants mostly in the southeastern United States. It also was used extensively as a flame retardant additive (under the trade name Dechlorane) in plastics, rubber, paint, paper and electrical goods from 1959 to 1972 because it does not burn easily (ATSDR, 1995a).

Non-point source – Source of pollution in which wastes are not released at one specific, identifiable point but from a number of points that are spread out and difficult to identify and control (U.S. EPA, 2006e).

PAHs – Polycyclic aromatic hydrocarbons are a group of chemicals formed during the incomplete burning of coal, oil, gas, wood, garbage or other organic substances, such as tobacco and charbroiled meat. There are more than 100 different PAHs. PAHs generally occur as complexes, not as single compounds. PAHs usually occur naturally, but they can be manufactured as individual compounds for research purposes, however, not as the mixtures found in combustion products. As pure chemicals, PAHs generally exist as colorless, white or pale yellow-green solids. They can have a faint, pleasant odor (ATSDR, 1995b).

PCB – (1) Polychlorinated biphenyls, a group of organic compounds used in the manufacture of plastics. In the environment, PCBs exhibit many of the same characteristics as DDT and may, therefore, be confused with that pesticide. PCBs are highly toxic to aquatic life, persist in the environment for long periods of time and are biologically accumulative; (2) any chemical substance that is limited to the biphenyl molecule that has been chlorinated to varying degrees or any combination of substances which contains such substances (U.S. EPA, 2006e).

Point Source – A stationary facility from which pollutants are discharged or emitted. Also, any single identifiable source of pollution (e.g., a pipe, ditch, ship, ore pit, factory smokestack) (U.S. EPA, 2006e).

Superfund – (1) The program operated under the legislative authority of CERCLA and SARA that funds and carries out U.S. EPA solid waste emergency and long-term removal and remedial activities. These activities include establishing the National Priorities List, investigating sites for inclusion on the list, determining their priority and conducting and/or supervising cleanup and other remedial actions; (2) a fund set up under CERCLA to help pay for cleanup of hazardous waste sites and to take legal action to force those responsible for the sites to clean them up. The Superfund consists of funds from taxes imposed upon the petroleum and chemical industries, an environmental tax on corporations, and from general tax revenues (also known as Trust Fund and Hazardous Waste Superfund) (U.S. EPA, 2006e).

APPENDIX G

Threats to Groundwater Quality in the Great Lakes Basin — Abandoned Wells

CONTENTS

INTRODUCTION

An abandoned well is defined as a well that is no longer in use, is not intended for future use, has not properly been decommissioned or is in a state of extreme disrepair (Michigan Department of Environmental Quality (DEQ), 1998; Lowey, 2004; AgrGC, 2003). Best estimates indicate the number of household wells varies considerably around the Great Lakes with fewer than five wells per square mile in Ontario to more than 20 per square mile in Michigan and Pennsylvania (see Figure 1). Abandoned wells in the Great Lakes Basin range from shallow, small-diameter geotechnical bore-holes to oil and gas exploration and production wells thousands of metres deep. Some of the largest abandoned wells are the Atlas F intercontinental ballistic missile (ICBM) silos, approximately 174 feet deep and 54 feet wide (Figure 2). One such abandoned ICBM silo cluster is located near Plattsburgh, New York, and contains 12 missile silos (Strategic Air Command, no date).

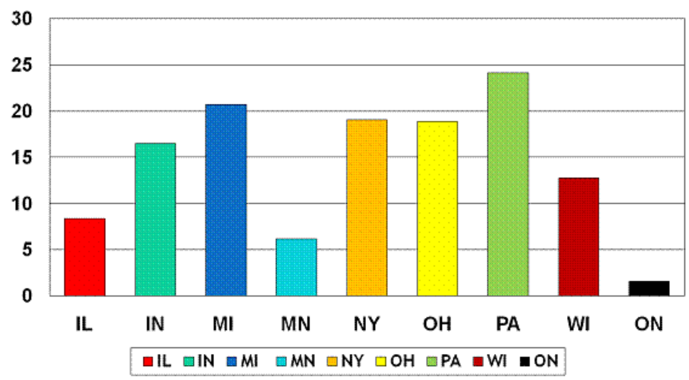

Figure 1. Individual household well density per rural square mile
Source: McCray, 2007. Extrapolated from U.S. Bureau of the Census, 1990 and 2000 rural square miles; Ontario Ministry of the Environment and Statistics Canada data.

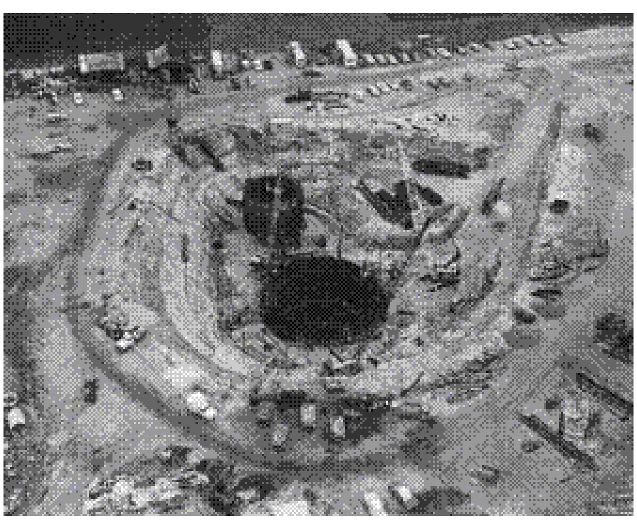

Figure 2. Construction of Atlas F missile silo at Plattsburgh, New York, July 18, 1961
Source: SiloWorld, n.d.

SAFETY HAZARDS

Abandoned wells can be extremely dangerous, posing various health, safety and environmental hazards. Large-diameter abandoned water wells are frequently covered with ill-fitting and poorly maintained wooden covers (Figure 3). Every year, people (mostly children) and animals (both wild and domestic) tumble into abandoned wells, resulting in injuries and frequently ending in fatalities (Michigan DEQ, 2005; Glanville, 1994). The dangers associated with abandoned wells are constantly portrayed to society. From an episode of the animated show *The Simpsons*, where Bart falls down an abandoned well, to the ever-famous Lassie expression "What's wrong girl? Timmy's in the well?" the notion of abandoned wells has been in the media for generations.

Well accidents are much more common than most people realize. Only the most extreme cases are extensively publicized. Examples include the following:

- In Midland, Texas, in 1987, at the age of 18 months, Baby Jessica fell into a well. Her famous story was subsequently made into a movie (Celizic, 2007; Misra, 2006).
- In Chicago, January 1991, a 10-year-old girl fell into an unsecured well located a mere 60 feet from a playground. Despite rescue efforts the young girl died (King, 1994).
- In Midland, Michigan, December 1998, a four-year-old girl fell into an abandoned well through a rotting cover (Michigan DEQ, 2002a).

Figure 3. Improperly covered well
Source: Jones, 2006

- In Perris, North Carolina, October 2000, a 73-year-old woman fell down a 20-foot well when a rotting wood cover disintegrated beneath her feet (Wellwise, 2007).
- In Alabama, in 2004, a 22-month-old toddler was rescued 13 hours after having falling into a 14-foot abandoned well hidden by grass ("TODDLER RESCUED," News, 2004).
- In 2006, the Indian boy known as Prince was trapped 18 metres down a well in India for over 50 hours (Usborne, 2006).
- In Ontario, August 2006, a 41-year-old man fell into a 25-foot abandoned well when rotting boards covering the opening gave way (Wellwise, 2007).
- In Bangalore, Karnataka, on April 26, 2007, a nine-year-old boy was found dead in a 60-foot deep bore-well after having been trapped for two days (Nerve News of India, 2007).
- A tragic occurrence transpired on June 27, 2007, when a 37-year-old police constable who was chasing a felon fell into an open 80-foot well to his death ("Policeman falls," 2007).
- In South Carolina, July 20, 2007, 15-year-old Jeffrey Johnson fell 80 feet into an abandoned well. Fortunately he was rescued with only minor injuries ("Teen survives," 2007).
- In Cayuga, Ontario, on February 18, 2008, an eight-year-old girl fell over 59 feet into freezing water when the cover over a well crumbled. Luckily the girl was rescued (Globe and Mail, 2008).
- The bodies of two young boys were found in an abandoned well in southern Italy, ending an 18-month search. The bodies were found when another 13-year-old child fell down the well. The 13-year-old was rescued but suffered fractures to both legs (Pisa, 2008).
- Canadian army captain Jonathan Snyder died in June 2008 when he fell approximately 6 stories down an abandoned well while on night patrol in Afghanistan (Schmidt, 2008).

Depending on the size of the opening anything from a small squirrel to a large cow may fall into a well (Richard, 2007). For example, in Boston in 2007 a pony fell into an abandoned well and was most fortunate as rescuers were able to secure her to a tow truck and pull her out (Killingworth, 2007). Many of the wild animals that fall into wells perish as no one reports their disappearance. Yet, even with all of the attention these stories brought, abandoned wells continue to be left improperly closed, allowing for horrific accidents to continue. Millions of abandoned wells of all types remain unplugged in the Great Lakes Basin (Figures 4 and 5).

CONTAMINATION DANGERS

Improperly decommissioned and abandoned wells provide direct routes by which contaminants can quickly reach groundwater. They allow contaminants to bypass natural filtration (Jeter, 2005). Wells with broken or missing caps or that have casings cut off nearly flush with, or below, the ground surface (a common practice) often allow contaminated runoff

Figure 4. **Abandoned well**
Photo by: D.W. Alley, 2007

Figure 5. **Abandoned water well in corn field; note adjacent livestock watering trough**
Photo by: D.W. Alley, 2007

Figure 6: **Leaking oil well**
Source: Texas Land and Mineral Owners Association, 2005

to enter the well. Also, the caving material around old or abandoned wells is frequently more permeable, providing low-resistance pathways. Cracks and holes along corroded well casings provide yet another channel through which contaminants can enter groundwater (Wisconsin Department of Natural Resources (DNR), 2006). These conduits allow water to bypass natural filtration and degradation processes that typically occur as surface water percolates through the soil. This allows for various contaminants including fertilizers, pesticides, animal wastes, solvents, fuel, sewage, pathogens, viruses and sediments to pollute groundwater (Wisconsin DNR, 2006; King, 1994). Once in groundwater, these pollutants move with natural groundwater flow leading to health problems as nearby wells are contaminated (Miller, 2008).

Abandoned oil and gas wells introduce the potential of aquifer cross contamination with hydrocarbons as well as brine, which occurred in Romney Township, Ontario. Oil and deep-water wells provide pathways along which brines can migrate upward, contaminating fresh-groundwater aquifers and surface waters (Texas Environmental Profiles, 2004). This commonly occurs in oil wells as both hydrocarbons and brines are usually encountered in sedimentary rocks.

Contaminants from runoff can enter wells and also pollute groundwater, which eventually discharges to tributaries and the Great Lakes themselves. Abandoned oil and gas wells may still contain petroleum products even after the well is deemed no longer economically viable. If present, oil and gas hydrocarbons accumulate in the well, emerging at the surface (Figure 6) (Mayorga, 2005), which can result in contaminated surface water. Because the materials in abandoned oil and gas wells are frequently flammable, pressure build-up in the well may result in spectacular and extremely dangerous fiery eruptions and well explosions which can cause significant property and personal damage.

Unknown abandoned wells can result in devastating consequences. For example, in Wisconsin an abandoned well was located in the basement of a house that caught on fire. Debris from the fire was able to enter local groundwater supplies, contaminating drinking water in the area (Wisconsin DNR, 2006). A similar incident occurred in South Glengarry, Ontario, where an uncapped well was located flush to the basement floor of

Figure 7. **Brine well and storage tanks with secondary containment, Kent Co., Ontario**
Photo By: D.W. Alley, 2007

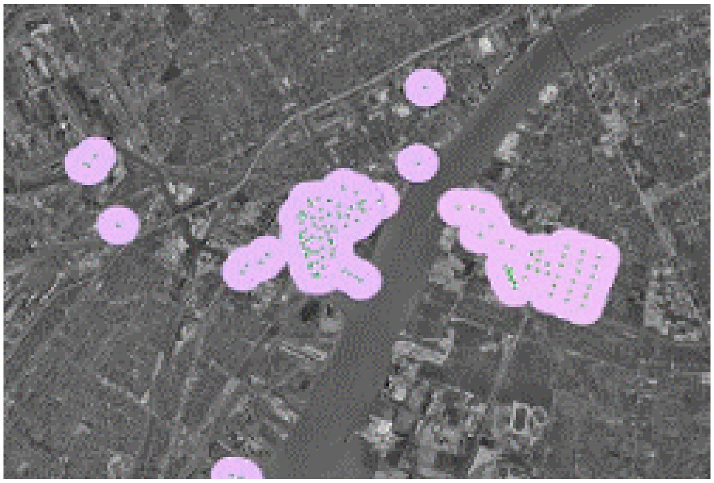

Figure 8. Brine wells in Windsor, Ontario, and Detroit, Michigan, 2007
Source: URS, 2007

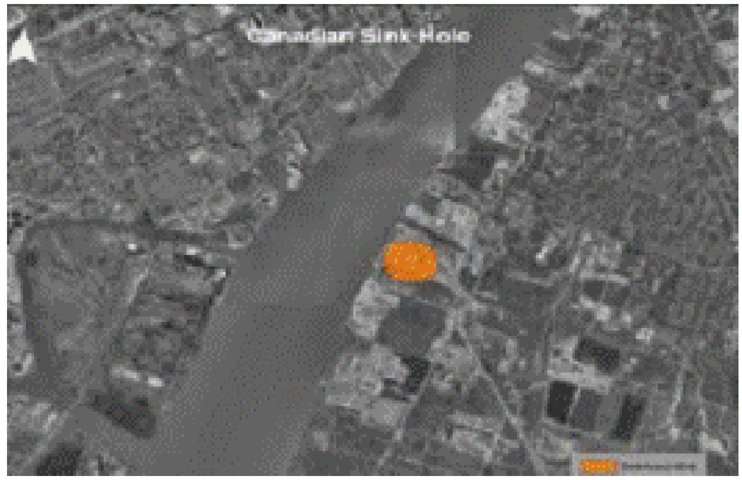

Figure 9. Location of 1954 sinkhole Windsor, Ontario
Source: URS, 2006

a house that caught fire. Contaminated water and foam used to fight the fire entered the open well and contaminated local wells up to 400 m away (St. Marseille, 2006). Remediation costs exceeded one million dollars.

Abandoned brine wells are a potential source for groundwater contamination as deep boreholes and large cavities provide excellent pathways for pollutants (Figure 7). Brine wells are bored into a large salt formation. Fresh water is injected into the well, dissolving the sodium chloride into a brine solution, which is then pumped back to the surface (RRC, 2006; Detroit River International Crossing, 2006).

Due to large salt deposits, about 400 metres below the surface, many brine wells were constructed in the Detroit, Michigan, and Windsor, Ontario, area (Figure 8). If not properly managed, these hold the potential of becoming large sinkholes. In Windsor, a 200-ft.-wide by 25-ft.-deep sinkhole developed in 1954 (URS Corporation, 2006) (Figure 9). In Hutchinson, Kansas, in 2001, abandoned brine wells served as conduits for natural gas. Multiple explosions resulted in two deaths and extensive damage (The Associated Press, 2002).

HEALTH HAZARDS

Deep aquifers are generally believed to be clean and free of pollutants, bacteria and viruses. However, viruses have been discovered in deep wells in Madison, Wisconsin. Since viruses are thought to only live up to two years in subsurface conditions, penetration and travel to the aquifer must be relatively rapid (Bradbury, Borchardt, Gotkowitz, Cherry and Parker, 2007).

In 2000, the well known outbreak of *E. coli* in Walkerton, Ontario, occurred resulting in seven deaths and more than 2,000 illnesses. The source of *E. coli* was identified as a nearby cattle farm. Two nearby abandoned wells, installed in 1949 and 1952, are believed to have aided in the transport of *E. coli* into groundwater (Howard, 2004). Even after this deadly outbreak many people do not have their wells regularly inspected and well water tested for bacteria and pathogens. In Ontario, 88% of well owners perform no extra testing beyond the complimentary bacterial test provided by the Ministry of Health, which tests solely for *E. coli* and total coliform bacteria (Ministry of Health and Long-Term Care, 2007).

The dangers of bacterial contamination are starting to be noticed. For example, in Green Bay, Wisconsin, bacterially contaminated wells now qualify for state aid. The amount provided is partially decided by household income. Owners with total incomes less than $65,000 may receive up to $9,000 toward construction of a new well ("People with," *News Online*, 2006).

Nitrates are a common groundwater pollutant found in well water. Among the sources are fertilizers and animal manure applied to farm fields. High nitrogen levels in drinking water can be deadly, especially to young infants where it has been found to cause methemoglobinemia, better known as blue baby syndrome (Richmond, 2007). On May 29, 2007, residents in Mt. Brydges (population approximately 3,000 (Industry Canada, 2006)), just outside London, Ontario, were notified of high nitrogen levels in the municipal water supply (from community wells) and advised to give only bottled water to infants under six months of age (Martin, 2007).

CONTAMINANT SOURCES

During any type of drilling multiple aquifers are often penetrated. Improper well construction, as well as ongoing maintenance and inspection issues, allow pollutants to be transmitted between aquifers that would otherwise have been separated by continuous aquitards (Lacombe, Sudicky, Frape and Unger, 1995). Frequently, toxins and other wastes are present in the vicinity of abandoned boreholes via spills, waste disposal, storage sites and unlocated holes. Contaminants can quickly migrate downward, creating extensive plumes in lower aquifers (Lacombe et al., 1995). Deep wells also may penetrate both saline and fresh water aquifers. This allows salt water to migrate into fresh water aquifers, ruining potable water supplies. Dead, decomposing animals in abandoned wells often contain parasites, viruses and pathogens that can enter and contaminate groundwater.

Figure 10. Uncovered abandoned well containing garbage
Source: CLOCA, 2005

Abandoned wells are often viewed as convenient garbage dumps, and pollutants are often introduced to groundwater by intentional disposal of wastes (Figure 10). In 1992, disposed petroleum products were found in an abandoned production well at a Wayne County oil refinery that was no longer in use. Groundwater samples taken from the area were later found to contain 855 ppb benzene (Davis, 2004). Another incident occurred in Ann Arbor in 1987, where the property owner was using an abandoned water well to dispose of trash and oil. Tests run on groundwater pumped from a nearby operating water well were found to be contaminated with benzene, toluene, xylene and other hydrocarbons (Davis, 2004).

NUMBERS OF ABANDONED AND FUNCTIONAL WELLS

Exact numbers of abandoned and functional wells in Canada and the U.S. are currently unknown. There are approximately 750,000 registered operational private wells in Ontario and an estimated additional 1.5 million unregistered (Conboy and Smith, 2005; Eco-News, 2006). A survey done by Ontario's Well Aware program found that 89% of wells in Ontario are in need of repair (Conboy, 2006b; Conboy and Smith, 2005). In addition to operational wells, there are an estimated 500,000 abandoned private water wells in Ontario (Conboy and Smith, 2005). However, not all have been registered with the Ministry of the Environment (MOE), so the exact figure is unknown. The number of abandoned wells is constantly growing. 20% of non-farm well owners have an additional well that is in need of decommissioning (Novakowski, Beatty, Conboy and Lebedin, 2006). Approximately 20,000 new water wells are constructed each year and often the old wells are left unplugged (Conboy and Smith, 2005). That number is also increasing as rural residents become connected to community water supplies (King, 1994). On most rural properties older than 50 years there is at least one abandoned well (Conboy and Smith, 2005). As well, urban sprawl has incorporated former agricultural areas, but these "estate lots" often contain several never-identified or decommissioned former farm water wells, especially if the area was a former dairy or livestock farm.

In addition to water wells, there are estimated to be 50,000 abandoned oil and gas wells in Ontario (Office of the Auditor General of Ontario, 2006). Unfortunately, of this total, only 20,000 have available records. Many of these wells are located around Petrolia and along the north shore of Lake Erie (Shortt, 2004). In 1858 the world's first registered oil well was constructed by James Williams in Oil Springs, near Petrolia. Still in operation today, Oil Springs is the world's oldest commercial oil field, and during the late 19^{th} century Petrolia was the oil capital of Canada (Whipp, 2008). The density of wildcat wells, shown in Figure 11, is similar to densities in other areas in U.S. Great Lakes states such as northwest Ohio where about 75,000 oil and gas wells were drilled in the Lima, Indiana, field at the turn of the twentieth century (Figure 12). As these abandoned and improperly-plugged wells are discovered, the DMRM spends monies from the State's Idle and Orphan Well Account to have them plugged in accordance with current standards.

Case Study: Cady Road, Cuyahoga County, Ohio
Source: ASTDR, 2008 (pg. 97).

Twenty-five households in this neighbourhood rely on private wells for their potable water supply. In the mid-1950s several 3,000-foot-deep oil and gas wells were drilled along Cady Road. “Thereafter the residents complained of gases and odors in the water, the water’s oily appearance and taste, of explosions at the wellheads and of gas bubbling up through the ground.” During ATSDR’s 2002 health consultation, the area still included 13 oil and gas production wells and a saltwater injection well was also close to the private water wells. “Many of these wells had a history of violations for maintenance and accidents.” Whether contamination of the water wells was due to the adjacent oil and gas extraction wells and/or saltwater injection well or a subsurface fault in the shale that underlies the drinking water aquifer remains unclear. Either scenario could have allowed the upward migration of oil and gas into the overlying fresh water aquifer.

As a result of the ATSDR health consultation, it was concluded that dissolved gases found in the well water (e.g., methane) were consistent with an oil and gas deposit origin and that the well water presented an *Urgent Public Health Hazard* (Category 1). Further, concentrations of combustibles gases in two of the home’s basements were near the explosive level. “In addition, hydrogen sulfide in the private well water posed a public health hazard because inhalation exposure from the resulting indoor air concentrations might have caused adverse health effects. Moreover, ingestion of sodium at the levels found in the well water could have been harmful to residents who had high blood pressure or who were on low-sodium diets.”

Currently, Cady Road, Cuyahoga County, Ohio, is an ATSDR petition site. “It does not appear in the CERCLIS database, and no regulatory action has been taken.”

Figure 11. Oil Springs, Ontario, 1866
Source: Dillon, http://www.petroliaheritage.com/oilSprings.htm

Figure 12. Map showing principal mineral resource areas
Source: Adapted from *Great Lakes Atlas*, 1995.

Nearly 16 million operational water wells (Wellowner.org, 2005), more than 520,000 operational oil wells and more than 393,000 gas wells are estimated to be spread across the United States (Interstate Oil and Gas Compact Commission, 2005). There are an estimated 23,000 active oil wells in Pennsylvania (Polczer, 2008). In addition to these wells approximately 800,000 boreholes are drilled each year and more than 90,000 new drinking wells are constructed (Wellowner.org, 2005). Exact numbers of abandoned wells (Figure 13) across the U.S. are unknown or unavailable. However, the number is estimated to be in the tens of millions, and many of these are located within the Great Lakes states. Michigan DEQ estimates that Michigan may have as many as two million abandoned wells (Monroe Conservation District, 2004). Minnesota has between 700,000 to 1.2 million abandoned wells of which more than 350,000 are currently believed to have the potential to contaminate groundwater (Perham Wellhead Protection Program, 2004). In addition to 400,000 to 500,000 active water wells in Illinois, there are also an estimated 55,000 to 155,000 abandoned wells in the state (Illinois Department of Public Health, 2006; Illinois Government News Network, 1999; King, 1994).

Figure 13. Old abandoned well pump
Photo By: D.W. Alley, 2007

WELL CLOSURE AND DECOMMISSIONING

In Michigan the following conditions require that an abandoned well be plugged: The well is not operational, the well has been disconnected and taken out of service when connection to a municipal water system was made and inoperable and abandoned wells that are not properly sealed that pose safety and environmental hazards (Michigan DEQ, 2005). In Ontario it is the sole legal responsibility of the well owner to plug abandoned wells (Office of Legislative Counsel, 2003). In the U.S. it is also the legal responsibility of the well owner to properly plug abandoned wells; however, a number of states have implemented cost-share programs in order to assist owners (Monroe Conservation District, 2004). Today an unsuccessful water well, known as a "dry hole," is normally plugged by the well drilling contractor but this was not always the case (Michigan DEQ, 2005).

The enforcement of proper well decommissioning is extremely important. Under state and provincial laws, abandoned wells are required to be properly closed within a designated time frame. For example, in Illinois water, monitoring and geotechnical boring wells must be properly sealed within 30 days. However, this law is resource intensive, difficult to enforce and significant numbers of wells are therefore never properly closed. The status of water wells in Pennsylvania is of considerable concern since there no guidelines on the location, construction or maintenance of private wells. Currently, more than one million private water wells exist in Pennsylvania, with an additional 20,000 new wells constructed per year (Pennsylvania State University, 2007).

In Ontario, standards for water well construction, disinfection and abandonment are specified under Regulation 903, which is enforced by Ontario MOE. This regulation states that it is the responsibility of the well owner to make sure that abandoned wells are properly plugged and sealed (Green Communities Canada, 2006). However, MOE does not consistently have staff dedicated to the investigation of private drinking water well construction, repair or abandonment (ECO, 2007). Currently there are only nine staff members in the MOE Water Well Business Unit. Lack of staff results in the unit being unable to carry out surprise visits to well drilling or abandonment operations of private well drillers (ECO, 2007).

The cost of plugging abandoned water wells is largely dependent on the geology of the area, the type of well and if there has been any contamination (Michigan DEQ, 2005). If the proper steps for plugging wells are taken before contamination occurs, the costs can be significantly reduced. The cost of plugging a typical residential abandoned well generally ranges from $300 to $700. The cost is significantly higher for plugging public water supply wells, ranging from $2,000 to $10,000 (McEwan, 2006). A number of programs have been established to provide financial aid to owners in order to properly close abandoned wells. For example, the Clean Michigan Initiative awarded over $3 million in grants to 64 communities in 2005 (McEwan, 2006).

Significant numbers of abandoned wells have been deemed "orphan wells." These wells do not have a viable owner or an owner who does not have sufficient funds to pay for the proper decommissioning and reclamation of the site (Turcza, 2004). These sites result in significant expenses being placed on the government and states. In the United States there are more than 57,000 orphan oil and gas wells (Turcza, 2004). With an average closing cost of $5,400, it is estimated that over $560 million will be needed to properly plug these known wells (Turcza, 2004). The number of orphan wells in Canada is unknown but Environment Canada estimates it to be in the thousands (Environment Canada, 2004). In Pennsylvania there are estimated to be 7,500 orphan wells. The cost to the state to properly close these known orphan sites is over $64 million. Also, over 184,000 additional wells are believed to exist with unknown status and location, likely increasing the number of orphan sites (Pennsylvania Department of Environmental Protection, 1998). Proper well closing can be much more costly. For example, the Peace River Well in Alberta, drilled into a high-pressure saline aquifer, cost over $6 million to be properly decommissioned (Turcza, 2004).

Large numbers of abandoned wells whose locations are unknown, and may never be known, exist across the U.S. and Canadian Great Lakes Basin. A number of key identifiers can be used to determine if there is an abandoned well on a property (Figure 14). The first step is to try to find old drilling records or billing statements that would indicate the depth and location of a well (Michigan DEQ, 2005). Often, there are no records of older wells and other means must be used to discover their locations (Michigan DEQ, 2005; Shortt, 2004). These include:

- Distressed vegetation
- Settled ground
- Oily or salty water seeps
- Smell of natural gas or crude oil (sulphurous odour)
- Water well contaminated with hydrocarbons

Figure 14. Old windmills are beacons for locating abandoned water wells
Photo by: D.W. Alley, 2007.

- Piles of rock and other debris
- Concrete slabs and old foundations
- Metal pipes protruding from the ground (both indoors and outdoors)
- Old pumps
- Electrical switch boxes
- Hand pumps
- Old barns, windmills, pump houses and other brick or stone structures

Unfortunately, discovering abandoned wells can sometimes be difficult or nearly impossible. Wells get built and paved over. Because many people view abandoned wells as eyesores, pipes are sawed off below ground level often leaving only a slight ground depression to indicate their presence. The use of metal detectors can sometimes aid in their discovery and resistivity, and magnetics were utilized in a recent study as a cost-effective method for locating abandoned wells (Borton, Vincent and Onasch, 2007; Michigan DEQ, 2005).

RECOMMENDED ACTION

Several measures must be implemented to help alleviate the stresses and dangers that improperly abandoned wells are placing on groundwater quality in the Great Lakes Basin:

- Development of a targeted program to monitor high-risk private, single-family, well-water systems (Great Lakes Commission, 2006).
- Mandate stricter and more encompassing well testing for bacterial and viral contamination.
- To ensure enforcement of proper well closings, provide Ontario MOE with the means of obtaining more trained employees.
- Employ licensed well drillers and pump installers to properly close abandoned wells (Wisconsin DNR, 2006).
- Enforcement and regular inspection of private drinking water well construction and maintenance is greatly needed. Ontario MOE has no staff dedicated to these inspections on an ongoing basis (ECO, 2007).
- Amend Ontario's well regulations to be more direct, leaving fewer opportunities for individual interpretation (ECO, 2006).
- Undertake an inventory to determine accurate numbers of functional and abandoned wells.
- Implement programs to help properly educate well owners regarding well construction, maintenance and decommissioning.

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GLOSSARY

Abandoned Well – A well which (1) has its use permanently discontinued, (2) is in such disrepair that its continued use for the purpose of obtaining groundwater is impractical, (3) has been left uncompleted, (4) is a threat to groundwater resources and (5) is or may be a health or safety hazard (Michigan DEQ, 2005).

Aquifer – An underground formation of permeable rock or loose material which can produce useful quantities of water when tapped by a well.

Aquitard – An underground formation of low permeable material that restricts the flow of water between aquifers.

Borehole – A narrow hole drilled into the ground. Used in exploration for oil, gas, water etc. or to determine the structure and makeup of the area. Also used to extract goods from the earth including water, oil and gas.

Brine – Water saturated or nearly saturated with salt.

Brine Well – A well used for injecting fresh water into geologic formations comprised mainly of salt. The injected freshwater dissolves the salt and is pumped back to the surface as a saturated sodium chloride brine solution used as a feedstock in petrochemical refineries and in oil and gas well drilling and workover operations.

E. coli (Escherichia coli) – A gut flora bacterium discovered in 1885 which lives in the lower intestines of mammals.

Geotechnical Test Hole – Generally a narrow hole drilled into the earth to obtain a sample to be used for engineering purposes. Utilized to acquire an understanding of the geological materials, foundation, structure and properties of the test area.

ICBM silo – An underground vertical cylindrical container to house an intercontinental ballistic missile. These long-range missiles were designed for nuclear weapons.

Methemoglobinemia – A condition where the iron in the hemoglobin molecule is defective, making it unable to carry oxygen effectively to the tissues. May be inherited or acquired.

Sinkhole – A depression in surface topography due to the dissolution of underlying material. They can range in size from less then a meter to hundreds of meters.

Temporarily Abandoned Well – Is not in use, but is intended by the owner to be a source of groundwater. Well casing must be securely sealed with a threaded, welded or solvent-welded cap to prevent access into the well and eliminate openings into the well. The well also must comply with isolation distance and construction requirements (Michigan DEQ, 2005).

Private Wells – Any well not used to support a municipal water supply.

Well – Any hole made in the ground to locate or obtain groundwater (ECO, 2006).

Threats to Groundwater Quality in the Great Lakes Basin — De-icing Compounds

CONTENTS

INTRODUCTION

Salt is commonly used as a de-icing and anti-icing agent and to a lesser extent as a dust suppressant. Road salt is generally sodium chloride (NaCl). Other compounds that are also used, but to a much smaller extent, include calcium chloride ($CaCl_2$), potassium chloride (KCl) and magnesium chloride ($MgCl_2$) (Environment Canada, 2001). Environment Canada has defined road salt that contains inorganic chloride salts as toxic under the Canadian Environmental Protection Act, 1999 (Environment Canada, 2001). However, road salt still has not been officially listed on the List of Toxic Substances (ECO, 2007; RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006).

APPLICATION RATES

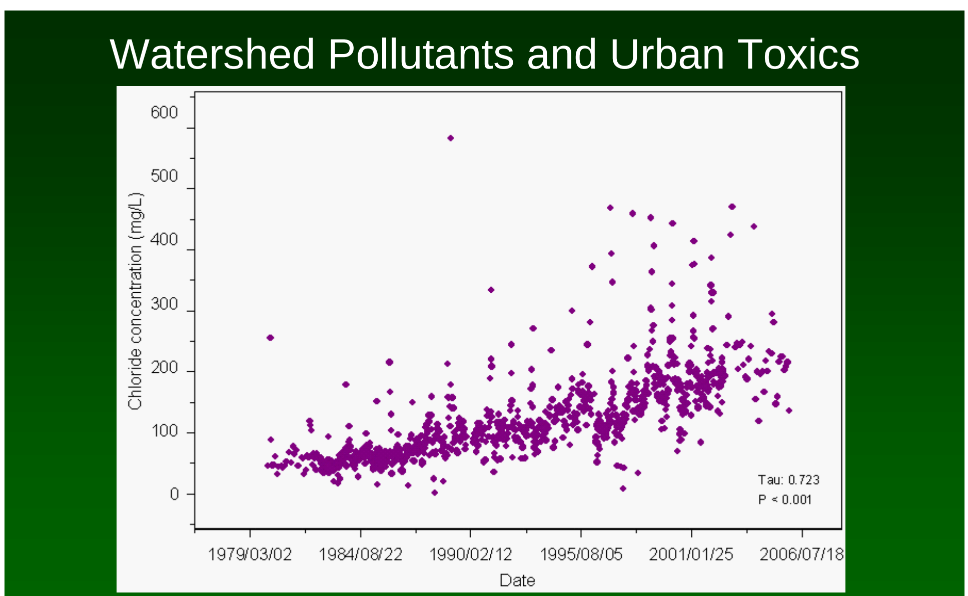
Average road salt use in Canada has risen from 4.9 million tonnes during 1997-1998 (Environment Canada, 2001) to 6.8 million tonnes in 2003 (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). It is estimated that of this amount 2 million tonnes are spread in Ontario (ECO, 2007), and about 500,000 to 600,000 tonnes are utilized by the Ontario Ministry of Transportation on 16,500 kilometres of provincial highway (Bradshaw, 2008b). This equates to an application rate of 30.3 to 36.4 tonnes/km.

In the United States annual road salt use fluctuates from 10 to 20 million tons per year (Schueler, 2005) and road salt use in the United States has increased a hundred fold from 1940 to 2005 (Jackson and Jobbágy, 2005). It is estimated that 9.5 million tons of salt is added to runoff in the United States every year (Stefan and Mohseni, 2007). Three-quarters of all road salt used in the United States is deposited on the roads within six of the Great Lakes states: New York, Ohio, Michigan, Illinois, Pennsylvania and Wisconsin (Jackson and Jobbágy, 2005).

However, these numbers are likely a gross underestimation for the winter of 2007-2008. An unusually harsh winter resulted in record high road salt usage throughout much of the United States and Canada. Fond du Lac County, Wisconsin, used 3,357 tons of road salt in December 2007 in comparison to the 464 tons used in December 2006 (Zezima, 2008). The Wisconsin Department of Transportation estimated that more than 700,000 tons would be used on state highways in 2008, a 73% increase over 2007 (Bergquist, 2008). New Hampshire is estimated to have used twice as much road salt in 2007 as in 2006 (Zezima, 2008). State roads alone in Michigan during 2007-2008 had more than 757,000 tons applied (State of Michigan, 2008). Gladwin County, Michigan, deposited 2,700 tons during January 2008, the same amount used for the entire winter season in 2006-2007 ("Road salt," 2008). Toronto uses an estimated 125,000 to 140,000 tonnes of road salt each winter (Ferenc and Kalinowski, 2008; Gray, 2004). An additional 1,000 tonnes is purchased by Toronto GO transit for areas such as platforms (Ferenc and Kalinowski, 2008). By February 2008, Toronto had already applied 100,000 tonnes (Bradshaw, 2008a) and it is estimated that 170,000 tonnes would be applied in total for the 2007-2008 year (Bradshaw, 2008b).

TOXICITY

Road salt is toxic to animals and native plants, results in groundwater and surface water contamination and may produce adverse health effects in humans (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006; Jackson and Jobbágy, 2005; Environment Canada, 2001)(Figure 1). The effects are



Chloride concentrations in the Credit River downstream of the Town of Orangeville are rising over time
Source: Aaron Todd, Environmental Monitoring and Reporting Branch, MOE

Figure 1.

far reaching. Road salt can inhibit the absorption of water and nutrients by plants and can result in the degradation of ecosystem biodiversity (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). Additional ions from road salt deposited into lakes can result in unnatural stratification. This can prevent seasonal mixing of lakes, changing nutrient and oxygen distributions (Environment Canada, 2001). High salinity levels in waters have likely allowed for initial invasion and subsequent adaptation and dispersal of exotic algae species within the Great Lakes (Jude, Stoermer, Johengen and Perakis, 2002). Road salts can have harmful effects on soil, changing physical and chemical properties including structure, permeability and conductivity as well as resulting in soil swelling and crusting (Environment Canada, 2001; RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). These effects can be seen up to 100 feet from a major highway and 50 feet from a two-lane road (Schueler, 2005). Road salt can create an artificial salt lick on roads which attracts animals and birds, resulting in an increased amount of roadkill (Schueler, 2005; Environment Canada, 2001).

CHEMICAL COMPONENTS

Chloride, the main component of road salt, is extremely soluble in water and once in a watershed becomes nearly impossible to remove (Schueler, 2005). Increasing use of road salts has resulted in a rise in chloride levels in ground and surface waters (Jackson and Jobbágy, 2005; Kaushal et al., 2005; Godwin, Hafner and Buff, 2003; Siver, Canavan, Field, Marsicano and Lott, 1996; Peters and Turk, 1981). A water quality study (see Table 1) across the Lake Ontario drainage basin from 1980-82 to 1996-98 showed an increasing trend level of chloride in 71% of monitored sites (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). While natural levels of chloride are generally only a few mg/L, chloride concentrations in runoff from roadways and uncovered salt piles has been measured in upward of 18,000 mg/L and 82,000 mg/L, respectively (Environment Canada, 2001). Levels of chloride in groundwater adjacent to storage yards have been measured as high as 2,800 mg/L (Environment Canada, 2001). It is estimated that 30-45% of all chlorides in the Great Lakes are a result of winter road salt application (ECO, 2007). Southern Ontario and Southern Quebec are among the provinces facing the greatest risk of groundwater contamination from road salts due to high road density (Environment Canada, 2001). In Minnesota, water quality standards for chloride concentrations are exceeded in some fresh water bodies (Stefan and Mohseni, 2007).

Concentrations of chloride in water strongly correlate to seasonal use of road salt (Jackson and Jobbágy, 2005; Kaushal et al., 2005). A water quality monitoring study by Ehlinger recorded a jump in chloride levels from 900 to 11,000 ppm in Underwood Creek in Milwaukee, during a rain storm after roads had previously been salted (Bergquist, 2008). However, Kaushal et al. demonstrate that when road salt is not being used chloride does not return to baseline levels due to salt build-up in surrounding soil and groundwater (Jackson and Jobbágy, 2005) and reduced water flow during the summer and ion travel time (Environment Canada, 2001). It can take centuries before groundwater will return to pre-contaminated levels even after road salt application is totally eliminated (Jackson and Jobbágy, 2003; Burtt, 2003; Environment Canada, 2001).

A study of 23 springs in Toronto found chloride levels to be greater than 1,200 mg/L as a result of road salt contamination (Kaushal et al., 2005). Chloride levels above 250 mg/L render water non-potable. In 2004 the city implemented a reduction goal of 25% to take place over three years (Gray, 2004). To accomplish this, the city was adding water tanks onto its salt trucks so that brine could be sprayed on the roads, making the de-icing process more efficient. In 2004, 45 of the 185 trucks had been altered (Gray, 2004).

Table 1. Peak Chloride concentrations in Water

Source	Peak Chloride Concentration
Normal Freshwater	20-50 mg/L
Urban Streams in winter	Over 1,000 mg/L
Groundwater	2,800 mg/L
Snow Cleared from Roadways	3,000-5,000 mg/L
Highway Runoff	Over 18,000 mg/L
Ocean Water	25,000-30,000 mg/L
Salt Storage Area Runoff	82,000 mg/L

Source: RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006.

In Waterloo, Ontario, residential development is taking place over important groundwater recharge areas, threatening groundwater quality due to increased road salt application. Additional complications occur during periods of heavy precipitation. Excess runoff, with high road salt concentrations, cannot be accommodated by stormwater management ponds and instead is released directly into the Grand River (Burtt, 2003).

Madison, Wisconsin, has been monitoring chloride levels in water utility drinking wells and in area lakes. Overall there has been an increase over the past 30 years. Increases were as high as 551% from 1975 to 2004 in one well, and Lake Mendota had a 185% increase from 1972 to 2004. According to a 2006 report by the city task force, three drinking wells exceed the federal recommended sodium standard (Bergquist, 2008). The city has implemented a reduction plan. However, in 2004-2005 48% more road salt was applied per mile as compared to 1972-1973 (Hausbeck, Sorsa and Schneider, 2005). Milwaukee, Wisconsin, uses twice as much road salt per lane mile as Madison. A 2007 water quality study by Corsi in Milwaukee found that 7 out of 12 streams tested showed signs of acute salt toxicity toward small aquatic life (Bergquist, 2008).

Other road salt constituents include phosphorus, nitrogen, copper and cyanide, which comprise between 2% to 5% (Schueler, 2005). Cyanide comes from ferro-cyanide added to prevent caking (Environment Canada, 2001), which can dissociate into cyanide in the presence of light (Environment Canada, 2001). Within one mile of a four-lane highway two pounds of cyanide can be deposited (Schueler, 2005). While cyanide becomes toxic at 20 ppb, in urban streams levels of up to 270 ppb have been recorded (Schueler, 2005).

LEGISLATION

In Canada there are currently no provincial or federal regulations which govern the use or concentration of road salt, nor are there bylaws or statutes controlling use and storage of road salts or methods of snow disposal (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). As noted by the RiverSides Stewardship Alliance and Sierra Legal Defence Fund, the Environment Protection Act – Classes of Contaminants – Exemptions, R.R.O. 1990, Regulation 339 specifically exempts "any substance" that is a contaminant and used by a road authority "for the purpose of keeping the highway safe for traffic under the conditions of snow or ice or both" from the Act and associated regulations. This conflicts with the Ontario Water Resources Act and prevents the Ministry of the Environment (MOE) from implementing Certificates of Approval with conditions for road salt storage, application and snow disposal (ECO, 2007; RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). In 2006 the RiverSides Stewardship Alliance and Sierra Legal Defence Fund submitted an application for review of Regulation 339. The application was denied by MOE (ECO, 2007). The 2006-2007 report of the Environmental Commissioner of Ontario states that MOE should have approved the request to review Regulation 339 (ECO, 2007).

In September 2004 a voluntary code of practice for the environmental management of road salt was released. This program applies to road authorities using greater than 500 tonnes/year or applying near vulnerable ecosystems (ECO, 2007). Environment Canada has been working with road authorities to develop the Code of Practice for the Environmental Management of Road Salts. The goal of the Code is to ensure environmental protection while maintaining road safety (Environment Canada, 2007b). However, compliance with the code is voluntary and there are a number of organizations that have not regularly sent in reports (Ontario Good Roads Association, 2008).

OTHER SOURCES

De-icing and anti-icing compounds used at airports also can cause groundwater contamination. While toxicity levels of de-icing compounds currently in use are less than those used in the 1990s, anti-icing compound toxicity has not decreased (Corsi, Geis, Loyo-Rosales and Rice, 2006). Anti-Icing compounds are frequently more toxic as a result of additives. The identities of many of the additives are not publicly available (Corsi et al., 2006). Studies indicate that concentrations frequently found at airports of both anti-icing and de-icing compounds surpass toxicity levels. Furthermore, these compounds are generally used in highest concentrations during periods of bad weather, making the runoff difficult to contain (Corsi et al., 2006). A study by Corsi of water quality near Mitchell International Airport in Milwaukee found that chloride levels reached acute toxicity levels on 54% of winter days tested in 2005, 61% in 2006, 36% in 2007 and 86% during January and February 2008 (Bergquist, 2008).

Other sources of excess salt include water softener salt and backflushing into septic and sewer systems. Regulations concerning water softeners are currently in place in a number of states and vary from restricting new water softener installations to total water softener bans (Cupp, Thomson and Kuziara, 2004). However, many communities are showing great resistance against these regulations (Cupp et al., 2007; Meyer, 2003).

DESALINIZATION

Potential water shortages across the United States have placed increasing pressure on desalinization (Boyle, 2008). Currently 0.4% of the water used in the United States is generated by desalinization. However, the United States capacity to desalinate water grew by approximately 40% between 2000 and 2005 (Boyle, 2008). Environmental impacts of desalinization are uncertain. By-products of desalinization, including brine, cleaning and conditioning agents, must be properly handled and disposed of lest they be released into and contaminate water supplies (Committee on Advancing Desalination Technology, 2008).

RECOMMENDED ACTION

Immediate steps need to be taken to help alleviate groundwater contamination and other associated problems as a result of road salt use. Dayton, Ohio, banned road salt usage to protect groundwater quality in the aquifer located beneath the city (Hall, 2001). Other communities are looking into the use of alternative de-icing products. Alternative anti-icing and de-icing products, many of which are significantly more environmentally friendly than traditional salt, are being offered by numerous companies (Glacial Technologies™, 2008; SynTech® Products, 2008). Massachusetts uses a calcium chloride spray on selected roadways which is more effective and able to be applied in smaller doses than sodium chloride, and calcium magnesium acetate, which has low toxicity and is biodegradable, on bridges (Adam and Sanders, 2005). London, Ontario, is using alternatives including beet juice, a non-corrosive organic product, to minimize road salt which is only applied to one-third of its roadways (Simunac, 2007). Toronto has installed computer controls on salt trucks allowing for more accurate application of salt as well as utilizing snow melting machines in areas where sewers and stormwater systems are combined (Adam and Sanders, 2005). A study by Kahl (2002) using agricultural by-products, residues from the processing of grains and other agricultural products, for anti-icing and de-icing compounds in Michigan has shown promise. Pre-wetting rock salt reduced its use by 28-38%. Within Canada 80% of road authorities have a Salt Management Plan, 89% have salt stored under a permanent roof and 34% have equipment equipped with electronic spreading controllers (Environment Canada, 2007a). However, the quantity of road salt that is being applied still needs to be drastically reduced. In order to achieve a reduction it is recommended that a comprehensive and integrated approach be established. The RiverSides Stewardship Alliance and Sierra Legal Defence Fund recommends the implementation of best management practices for storage and application, improving application techniques, using alternative products and implementing policies to promote social change. The following recommendations should be implemented in order to achieve these goals.

- Proper storage and handling of salt piles at patrol yards reducing losses through weathering, transfers, equipment washwater and release of storm water (Schueler, 2005; Environment Canada, 2001).
- Educational programs and improved training for workers (Schueler, 2005).
- Calibrated spreaders must be installed, allowing for the lowest needed doses to be applied (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006; Schueler, 2005).
- Improved forecasting systems, including infrared thermometers and road surface friction sensors, allowing roads to be treated at the most effective time (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006; Schueler, 2005).
- Change application from dry salt to a salt brine, increasing efficiency (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). Studies in Denmark indicate that brines containing 26% less sodium chloride would have the same effect as pre-wetted salt (Fonnesbech, 2000).
- Proper disposal techniques for road salt-laden snow. Removed snow should be deposited in the least environmentally sensitive areas or storm sewers. Sufficient dilution of the snow melt also should be undertaken before the meltwater is released back into the environment (Environment Canada, 2001).
- Designate low-salt application zones near environmentally sensitive areas (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006; Schueler, 2005).
- Alternative compounds should be utilized where economically feasible. These include calcium chloride, potassium chloride, magnesium chloride, calcium magnesium acetate, potassium acetate, sodium acetate, sodium formate, potassium formate and M-50 products (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006; Jackson and Jobbágy, 2005; Environment Canada, 2001; Adam and Sanders, 2005).
- Educational programs regarding the effects of road salt need to be made available to citizens, as well as encouragement to use alternatives, such as calcium chloride, which can be applied in lower doses (Hausbeck et al., 2005; Schueler, 2005).
- Encourage the reduction of winter speed limits and increased winter tire use in order to reduce the sole reliance on road salt (RiverSides Stewardship Alliance and Sierra Legal Defence Fund, 2006). By law winter tires are mandatory in Quebec from November 15 to April 15 of every year ("Quebec first," 2007).

Six additional recommendations made by the RiverSides Stewardship Alliance and Sierra Legal Defence Fund to the Province of Ontario and the federal government should be considered for implementation.

1. The Environmental Protection Act, Classes of Contaminants – Exemptions, R. R. O. 1990, Regulation 339 be immediately revoked.

2. The Ontario Ministry of the Environment immediately implement a phased-in mandatory road salt management regime requiring all road authorities to seek a Certificate of Approval under the Environmental Protection Act for road salt storage, application or snow disposal in Ontario.

3. Ontario's Bill 43 require that all drinking water source protection plans address the issue of road salt, regardless of the threat assessment on current and potential drinking water sources, until such time as the permit system can be implemented.

4. The Ontario government institute an educational and regulatory program to reduce the incidence of accidents on winter roads. Specifically, mandatory reductions in speed limits during winter conditions and mandatory requirements for snow tires under the Highway Traffic Act.

5. Road salts be immediately listed on Schedule 1 under the Canadian Environmental Protection Act, 1999.

6. The federal government pursue changes to the Great Lakes Water Quality Agreement that would require proper management of road salts use throughout the Great Lakes Basin.

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Threats to Groundwater Quality in the Great Lakes Basin — Confined Animal Feeding Operations

CONTENTS

INTRODUCTION

In 2003 there were an estimated 1.3 million livestock farms in the U.S. Of these approximately 257,000 were animal feeding operations (AFOs), which produced more than 500 million tons of manure annually (U.S. EPA, 2003b). AFOs are locations where animals have been, are or will be confined, and fed or maintained for a total of 45 days or more in any 12-month period, and where vegetation is not sustained in the confinement area during the normal growing season (U.S. EPA, 2003b). The largest AFOs are known as Concentrated Animal Feeding Operations (CAFO) or Intensive Farming. CAFOs are defined by the U.S. Environmental Protection Agency (U.S. EPA) as AFOs that are of a given size. The number and type(s) of animal(s) the operation houses and the extent to which waste from the operation may pollute surface water and groundwater determine whether the U.S. EPA considers a feeding operation to be a CAFO (CDC, 2004). The Ontario Ministry of Agriculture, Food and Rural Affairs defines a CAFO as an AFO having the capacity to accommodate more than 10,000 pigs or 1,500 dairy cows (Environmental Commissioner of Ontario (ECO), 2000). AFOs also can be designated as CAFOs on a case-by-case basis if the facility is determined to be a significant contributor of pollutants to water (U.S. EPA, 2003b). In the U.S. there are an estimated 15,500 CAFOs, responsible for producing more than 300 million tons of manure annually (U.S. EPA, 2003a).

CONTAMINANTS

CAFOs are a pressing environmental concern due to the large volume of manure produced, small storage space for the manure and disposal of manure through land application (U.S. EPA, 2004). Common pollutants that affect watersheds as a result of CAFOs include nutrients, pathogens (including parasites, bacteria and viruses), sediments, solids, endocrine disrupting chemicals (EDCs), antibiotics, hormones, pesticides, trace elements and mineral salts (CDC, 2004; U.S. EPA, 2004). Contaminants enter waterways directly due to poor storm water management or failure of containment facilities and indirectly through runoff and percolation. Currently, the array of effects which these pollutants may have on humans and the watershed are unknown (U.S. EPA, 2004).

Figure 1. Road killed animals are a common sight in Great Lakes Basin jurisdictions
Photo provided by: Cornell Waste Management Institute, 2007

Improper management of manure from CAFOs is a threat to surface and groundwater quality and has caused serious acute and chronic water quality problems (U.S. EPA, 2003a). Substandard construction, aging storage facilities and illegal disposal methods can lead to large amounts of waste being released into surrounding areas. In Manitowoc County, a farm agreed to pay a $59,000 state fine for spilling liquid animal waste into a Lake Michigan tributary and killing thousands of fish (Egan, 2007).

Another potential source of groundwater contamination is wild and domestic animal carcass disposal. With high CAFO animal density, especially where fowl are raised, there are proportionally high numbers of animal deaths. On-site burial is a common method of carcass disposal (Spellman and Whiting, 2007). Burial site selection is therefore crucial to avoid contamination of water supplies. Disposal in local landfill sites is often not an option (Rennie and Hill, 2007).

Road kill carcass disposal poses even greater problems. It is a pressing issue in all Great Lakes basin jurisdictions due to the huge number of wild and domestic animal carcasses which must be disposed each year. In a month-long survey of road kill in just five states, 15,000 reptiles and amphibians, 48,000 mammals and 77,000 birds were counted (Havlick, 2004). About 1.5 million deer-vehicle crashes occur each year in the U.S. (Kolb, 2006). In Pennsylvania contractors remove approximately 45,000 deer carcasses per year from highways at a cost of $30 to $40 each (Maryland Survey) in addition to 30,000 in Ohio and 65,000 annually in Michigan (Havlick, 2004). A wide variety of practices are utilized to dispose of road kill carcasses. These include burial on the highway right of way or in adjacent wooded areas and disposal in local landfills, where permitted (Maryland Survey; Rennie and Hill, 2007). However, there are currently no uniform practices across the provinces or states, and groundwater protection is rarely considered (Maryland Survey; Rusk, 2007; Carlson, 2009). Some jurisdictions are considering the potential of composting road-killed animals as an environmentally friendly and cost effective alternative; however, concerns about chronic wasting disease (CWD) prions in ungulate carcasses may confound this disposal method (Kolb, 2006; Chambliss, 2007).

Traditional cemeteries have long been recognized as threat to groundwater quality since they are most often located in groundwater recharge zones on hilltops in easily excavated soils and are 'hotspots' for many contaminants including embalming fluids containing arsenic, formaldehyde and gluteraldehyde (Stowe, Schmidt and Green, 2001; Konefes and McGee, 2001). The recent trend to 'natural burials' has the potential to further compromise groundwater quality (Righton, 2008; White, 2007).

Figure 2. Road killed deer carcasses dumped in a roadside pit awaiting burial
Photo provided by: Elisabeth Kolb, NYS DOT

NUTRIENTS

Excess nutrients, including ammonia, nitrogen, phosphorus and carbon from manure, can enter waterways bringing about impaired water quality, eutrophication and reduced oxygen levels resulting in fish fatalities (CDC, 2008; U.S. EPA, 2004; ECO, 2000). In 1996 it was estimated that five of the ten areas in Canada that produced the most manure per hectare (between 4,000 to 6,000 kg of manure per hectare annually) were in southwestern Ontario (McRobert, 2004). There are an estimated 20 million farm animals in Southwestern Ontario which produce an estimated 15 million tonnes of manure a year (Richmond, 2007). As of 2000, Ontario alone had more than 3.4 million hogs which produced as much raw sewage as the province's entire human population (ECO, 2000). Of these hogs approximately 1.8 million are located within Southwestern Ontario (Richmond, 2007). CAFOs can produce as much manure as a medium-size city (U.S. EPA, 2004). In 1998, seven families in Hope Township had their water wells contaminated by manure from a hog farm (ECO, 2000). In 1999 a pig farm in Chatham, Ontario, discharged 1.5 million liters of manure, some of which entered a nearby drain and Lake Erie (ECO, 2000).

High animal density destroys vegetation and results in greater production of manure than can be utilized by crops. The U.S. Department of Agriculture (USDA) indicates that between 1982 and 1997 there was a 20% increase in the amount of excess nutrients produced through increased manure, and a corresponding decrease of 1.4 acres per 1000 pounds of live animals (U.S. EPA, 2003a). Total manure nitrogen and phosporus produced in the United States each year is approximately 12.9 and 3.8 billion pounds respectively (U.S. EPA, 2004). The ECO noted that large-scale farms produce vast quantities of manure yet they often do not have corresponding large areas of farm land (ECO, 2000). Bare ground and insufficient crop land allows run-off, rich in nutrients from manure, to enter and contaminate groundwater. Over-application of manure to farm land results in a buildup of excess nutrients. Build-up of mineral salts including sodium, calcium, magnesium, potassium, chloride, sulfate, bicarbonate and nitrate is also a concern since they can contribute to surface water salinization and leaching salts can affect groundwater quality (U.S. EPA, 2004). In a risk assessment report by the U.S. EPA (2004) it was stated that, "Underlying all the environmental problems associated with CAFOs is the fact that too much manure accumulates in a restricted area. Traditional means of using manure are not adequate to contend with the large volumes present at CAFOs."

Since rapid drainage is desired when applying liquefied manure to fields, tile-drained areas are frequently utilized. Drain tiles are placed approximately 2 to 4 feet below the surface, with the expectations that contaminants will be filtered out before reaching the drain (Haack and Duris, 2008). However, in areas where the soil is clay-based, there can be an abundance of worm holes, desiccation cracks and other openings such as animal burrows which can form conduits for contaminants to reach the tiles. This results in little to no filtration before liquid manure reaches the drain (Egan, 2007).

ANTIBIOTICS

Antibiotics, natural and synthetic hormones and trace elements including arsenic, copper, selenium and zinc are now being implemented in farms to enhance livestock growth and to act as biocides (U.S. EPA, 2004). Overcrowded living conditions, such as in CAFOs, result in the use of large quantities of antibiotics in order to prevent the spread of disease. Since the 1950s the recommended level of antibiotics in animal feed has increased to upwards of 20 fold to 200 ppm (Richmond, 2007). Unfortunately many animals are provided with more than the recommended levels. In one study animals were found to have been given 25% higher levels of antibiotics in their feed. More than 40% of the antibiotics administered in the U.S. are given to animals (Richmond, 2007). Antibiotics given to animals include bacitracin, chlortetracycline, ery-thromycin, tylosin, neomycin, thromycin, lincomycin, oxytetracycline, lenicilin, streptomycin and virginiamycin (Richmond, 2007). It is postulated that the release of large amounts of antibiotics to the environment could result in antibiotic-resistant pathogens (CDC, 2004).

The Centers for Disease Control and Prevention (CDC) has shown that chemicals and infections compounds in animal wastes are able to travel through soil and water near CAFOs (CDC, 2004). In 2000, contaminated groundwater resulted in the tragic *E. coli* outbreak in Walkerton, Ontario, which resulted in seven deaths and more than 2,000 illnesses. The source of *E. coli* was identified as a nearby cattle farm (Howard, 2004). It has been found that Ontarians living in rural areas with high cattle density are at an elevated risk of *E. coli* infections (ECO, 2000). The U S. EPA reported that source waters from which drinking water is obtained for up to 43% of the United States comes from waters that are impaired by pathogenic contamination from CAFO operations (U.S. EPA, 2004).

REGULATIONS

As of April 14, 2003, new regulations and guidelines were put into effect in the U.S. designating the proper management for CAFOs (U.S. EPA, 2003a). The new regulations are a revision of the National Pollutant Discharge Elimination System (NPDES) and the Effluent Limitation Guidelines in response to the Clean Water Act which designates CAFOs as point sources of pollution (U.S. EPA, 2003a). The rule mandates that all CAFOs are required to apply an NPDES permit and implement a nutrient management plan (NMP) (U.S. EPA, 2003b). The guidelines outline appropriate storage and land application methods for animal wastes and identify site-specific actions to be taken by CAFOs to ensure proper and effective manure and wastewater management, including compliance with the Effluent Limitation Guidelines (U.S. EPA, 2003a). This regulatory program also is designed to support voluntary and other programs implemented by the USDA, the U.S. EPA and the states that help smaller animal feeding operations not addressed by this rule (U.S. EPA, 2003a).

Province-wide standards came into effect in Ontario in 2003 with the Nutrient Management Act, 2002 (NMA). Previously, as noted in a 2000 report by the ECO, there were no legally binding standards for constructing manure storage facilities or for the application of manure, no monitoring mechanisms to ensure that farmers use best practices for managing manure, and the Ontario environmental legislation specifically exempted some aspects of manure management since the Environmental Protection Act did not apply to animal waste (ECO, 2000). The NMA also restricts the Farming and Food Production Protection Act, 1998 (FFPPA). The FFPPA was implemented to disallow municipal bylaws from restricting normal farm practices. This law was used in 1998 to overturn a municipal bylaw attempting to control intensive farming operations in order to protect local wells in the township of Biddulph, Ontario (ECO, 2000). In 2002, the FFPPA was amended to state that a practice that is inconsistent with a regulation made under the NMA is not a normal farm practice.

The NMA was put in place "to provide for the management of materials containing nutrients in ways that will enhance protection of the natural environment and provide a sustainable future for agricultural operations and rural development." The regulation is aimed at reducing the risk of nutrients entering surface or groundwater and wells (ECO, 2004). The regulation has nine classifications for agricultural operations, which are determined based on the nature of the operation and the amount of nutrients generated and received (McRobert, 2004). Large-scale operations, such as CAFOs, must meet more stringent regulations than small farms. The NMA regulates various aspects including storage facilities, application of materials containing nutrients (such as manure and biosolids), NMPs and Nutrient Management Strategies (NMSs) (ECO, 2006; McRobert, 2004).

Since coming into force in 2003 the NMA has undergone significant changes. The original NMA required new livestock farms producing more than 5 nutrient units (NU) and existing livestock farms expanding to 300 NU or greater to complete an NMS and NMP (ECO, 2006; 2004). The NMA was changed by O. Reg. 551/05, and after December 31, 2005, livestock operations that generated fewer than 300 NU annually no longer required NMSs or NMPs unless they were captured through another scenario outlined within the NMA (ECO, 2006). Other changes include that livestock operations generating 300 NU or more only require OMAFRA approval of their first NMS and only if the operation is located within 100 metres of a municipal well (ECO, 2006). O. Reg. 551/05 implemented the added requirement that NMSs and NMPs must be reviewed and updated annually and records of the review and update must be kept (ECO, 2006).

The majority of the estimated 53,000 livestock operations in Ontario will not be covered under the NMA. Instead, operations that are expanding but remain fewer than 300 NU will continue to be covered under municipal nutrient management bylaws. This results in difficulty for the public to know whether a livestock operation must comply with the NMA or with municipal bylaws (ECO, 2006).

Research is needed to help develop more effective methods of managing impacts that CAFOs have on groundwater. Significant amounts of animal wastes from CAFOs are entering Lake Michigan; and while monitoring stations are needed to help improve environmental safety, little is being done to install them. This is because research would require putting CAFO operators at risk from lawsuits and provisions of the Clean Water Act (Egan, 2007). A water sample, taken in Manitowoc County by a local community group, containing 5,000 *E. coli* colonies per 100 ml (well above the state standard of 235) was tested to determine its source. Initial results indicated that nearly 100% of the fecal pollution in the sample was from cattle. The local group was prevented from locating the source of pollution since they did not have legal access to the farm land and official agencies were not taking action (Egan, 2007). As the price for synthetic oil-based fertilizers continues to rise, resulting in an increase in the use of manure for fertilizers, one can expect to find increased groundwater contamination by manure.

RECOMMENDATIONS

The following recommendations are from the U.S. EPA (2004):

- Reduce the volumes of manure created by changing waste management, handling practices and feed utilization efficiency.
- Treat manure to kill pathogens, attenuate hormones and other organic contaminants and stabilize metals.
- Increase use of anaerobic treatment and composting to control odors, nutrients, pathogens and generate renewable energy.
- Reduce the use of antibiotics to stem the development of antibiotic resistant pathogens.
- Increase soil conservation methods to reduce runoff and erosion from fields to which manure has been applied. Reduced tillage, terraces, grassed waterways and contour planting offer conservation benefits.
- Install barriers such as riparian zones and wetlands to prevent manure-laden runoff from fields from reaching streams.
- Change barn ventilation and manure management and handling practices to minimize the airborne release of stressors.
- Where economic factors work against making changes to CAFO management practices, eliminate them or provide incentives for making such changes.

ECO (2006) recommended that Ontario MOE and OMAFRA prescribe the NMA under the Environmental Bill of Rights for applications for investigation and to designate NMSs and NMPs for livestock operations as instruments.

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GLOSSARY

Agricultural Source Material (ASM) – nutrients that are generated by livestock operations, such as manure.

Endocrine Disrupting Chemicals (EDC) – an exogenous agent that interferes with the synthesis, secretion, transport, binding, action or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis, reproduction, development and/or behaviour.

Non-Agricultural Source Material (NASM) – nutrients such as biosolids that are generated by the pulp and paper industry and municipal sewage treatment plants.

Nutrients – materials, such as manure, biosolids (e.g. sewage sludge) and washwater, which are applied to land for the purpose of improving crop growth.

Nutrient Management Plan (NMP) – a document including information about the farm and its fields; an analysis of the nutrients to be applied, how much will be applied and at what rate; setbacks from sensitive features, such as wells; and how the nutrients will be stored.

Nutrient Management Strategy (NMS) – a document including a description and sketch of the farm, a list of the types and quantities of nutrients produced and of the storage facilities, and to whom the nutrients are distributed.

Nutrient Unit - the amount of nutrients equivalent to the commercial fertilizer replacement value of the lower of 43 kg of nitrogen or 55 kg of phosphate.

Threats to Groundwater Quality in the Great Lakes Basin — Conveyance Losses

CONTENTS

INTRODUCTION

Leaking underground municipal water mains and sewer lines are of significant concern to groundwater and surface water quality in the Great Lakes region. In the "Report on the State of Municipal Infrastructure in Canada" a key finding was that sewage systems, water distribution systems and water supply installations are among the oldest infrastructure facilities in Canada (FCM, 1996). It has been estimated that between 1997-2012 $88.4 billion will be needed for new and upgraded water and wastewater infrastructure in Canada (Canadian Water and Wastewater Association, 1997).

In the United States the situation is similar with the majority of the water infrastructure "near the end of its expected life span" (AWWA, 2001). Within the United States 55,000 public water systems process more than 40 billion gallons of water a day (Village of Sugar Grove Publics Work Department, 2006). However, many older pipes may be losing upward of 50% of the transported water (Gallagher, 2006). Each day 6 billion gallons, or 15%, of processed water is lost. The greatest source of the loss is often leaks in customer pipes off the main piping system (Village of Sugar Grove Publics Work Department, 2006). In Detroit alone an estimated 35 billion gallons of water leak out of the system each year resulting in residents paying $23 million for lost water (Gallagher, 2006). The American Water Works Association (AWWA) (2001) estimates that over the next 30 years $250 billion (not including the wastewater infrastructure) will be needed to replace drinking water pipes.

Currently, about 10 % of U.S. municipal water systems are operated by private companies; however, it has been estimated that this number will increase to 65 % or more by 2020 (Melosi, 2008). There are more than 1.2 million miles of sewers underground across the United States (Wheeler and Smith, 2008). By the year 2020, 85 % of U.S. water infrastructure will have reached the end of its useful/designed life (Liquid Assets, 2008), and about 45% of the sewer pipes in the U.S. will be categorized as being in poor or worse condition (Insituform, 2007).

MUNICIPAL SEWER LINES

Leaking sewer lines are a major concern regarding water quality in the Great Lakes Basin. "It's one of the greatest problems localities face these days. The systems are old. They're outdated. They need updating," stated New York's Senator Charles Schumer (Meyer, 2007). Leaks in sewer lines can happen for numerous reasons, including blockage from tree roots, soil slippage, washout resulting in loss of foundation, sewage backup, faulty material, improperly constructed pipelines, lack of corrosion protection, age, traffic and ground subsidence (Adams, 2009).

Leakage from a sewer line consists of raw sewage mixed with varying amounts of industrial waste chemicals, along with pharmaceuticals, personal care products and a myriad of other compounds (Pendersen, 1997). Although sewer line leaks can be the main source of sulphate, chloride and nitrogen compounds in urban groundwater (Eiswirth and Hötzl, 1997), in some areas not enough effort is being put forward to fix the problem. In Toronto, Ontario, only 0.35% of the wastewater network is being replaced per year. Since more than 50% of the city's sewer infrastructure is already over 50 years old, at this rate the last sewer pipe will not be replaced until it is over 300 years old (Levy, 2004). Recently, a 50-year-old, 40-metre-deep, 2.4-metre-diameter trunk sewer serving 750,000 people was found, during a routine robotic camera inspection, to be cracked and shattered and in imminent risk of collapse, which would lead to a catastrophic event and unimaginable environmental damage. The City of Toronto quickly recommended a $30 million emergency repair, but the bypass work will take 12-18 months to complete and neighbouring residents are being warned about a potential disaster by city officials (Weese, 2009a; Weese, 2009b). A study in the U.K. found that 13% of the nitrogen load in groundwater was due to sewer leakage (Wakida and Lerner, 2005).

Sewer lines are generally constructed in a manner that allows them to operate using gravity flow. These gravity fed systems are much more cost efficient than those requiring pumping. This is often accomplished by placing pipes in topographical lows such as wetlands and streambeds (beside or within the channel) (U.S. EPA, 2006). Unfortunately, due to their placement, when a leak occurs it is all the more likely to result in contamination of surface or groundwaters. If the sewer line is installed deep within the ground then it also may be below the biologically active portion of the soil and often below the water table. Because the released sewage is already well below grade it does not have to pass through the intense biodegradation and filtration that it would normally undergo as it passed through the soil. This allows contaminants, including pharmaceuticals, microorganisms, pathogens (such as *E. Coli*), organic matter, trace metals and toxic chemicals, to directly enter groundwater (Pendersen, 1997). This can be extremely dangerous if private or community wells are nearby (Borchardt, Bradbury, Gotkowitz, Cherry and Parker, 2007). Contaminated groundwater eventually discharges into surface water bodies where it can contaminate streams and lakes making them unsuitable for recreational purposes and destroying the natural habitat. Recreational water impairments and beach closings (Figure 1) have been linked to groundwater discharge from malfunctioning septic systems and leaking sewer lines (NRDC, 2008). Every year between 1.8 and 3.5 million illnesses (hepatitis, dysentery, cryptosporidiosis) result from people swimming in sewage-contaminated water (Clean Water Action, 2005). In addition, another 500,000 illnesses are the result of people drinking sewage-contaminated water (Clean Water Action, 2005). A study in Milwaukee County found the genetic marker for human fecal bacteria in 27 out of 45 storm sewer pipes that discharge directly into recreational waters (Behm and Egan, 2007).

Significant quantities of antibiotics, pharmaceuticals and other chemicals are being released into the groundwater through leaking sewer lines. These include endocrine disruptors and antibacterial agents. (Rutsch, Rieckermann and Krebs, 2006; Glaser, 2004). Antibacterial agents such as triclosan are found in a high percentage of soaps, toothpastes, facial cleansers, deodorants, cosmetics and fabrics. Triclosan has been found to cause health and environmental effects, to be highly toxic to certain types of algae, compound antibiotic resistance and bioaccumulate (Glaser, 2004). A study in Sweden found triclosan in breast milk of three out of five women (Glaser, 2004; Adolfsson-Erice, Pettersson, Parkkonen and Sturve, 2002).

All too frequently sewage ends up in stormwater systems which likewise leak and contaminate groundwater and which also empty directly into streams and lakes without any prior treatment. Some of the largest sewage-related problems are due to the use of, now outdated, combined sewage and stormwater systems. Many older communities, including Detroit, Milwaukee, Cleveland and Toronto, still have combined sewer systems (Price, 2005b). In these systems there is no separation of stormwater from sewage water, producing an excess amount of water for treatment, especially during wet-weather conditions. In the Niagara Region alone there are approximately 283 overflow locations (Dongen, 2007). In a 2004 report the U.S. EPA estimated that 850 billion gallons of stormwater mixed with raw sewage is dumped into U.S. waters as a result of combined sewers (Wheeler and Smith, 2008). The Detroit sewage plant, one of the largest in the world, is the single largest polluter of the Detroit River (Olson, 2003). In 2006 more than 1.6 billion gallons of sewage was dumped into Lake St. Clair due to sewage overflows, a one-third increase over 2005 (Selweski, 2007). The Sierra Legal Defence Club reported that 24 billion gallons of sewage overflow is dumped into the Great Lakes annually (Selweski, 2007).

In addition to leaks, improper sewer hookups are also an issue, accounting for an additional 3 to 10 billion gallons of raw sewage in these systems (Wheeler and

Figure 1. Geyser resulting from a water main break
Source: http://www.flowmetrix.ca/Leak.php

Smith, 2008). In 2001 sewer and stormwater hookups were improperly connected at the new Miller Park baseball stadium in Milwaukee. Human sewage was flowing into a storm sewer that emptied into the Menomonee River. At the same time rainwater was being collected in the sanitary line, adding a significant amount of water in need of costly treatment (Behm, 2007b). Sump pumps illegally connected to sanitary instead of storm sewers can be another issue. Beaconsfield, Quebec, set up a program to find all illegal hook-ups in the city by 2008 (Legatos, 2007). Even in communities where water and rainwater is supposed to be kept separate, infiltration and surcharge through cracks in the pipes allows significant quantities of water to enter into sewage lines, again overburdening the system (HWEA, 2006).

As the population grows treatment plants are unable to handle the large influxes in wastewater. During times of heavy rainfalls it is not uncommon for plants to become overwhelmed leaving them with two choices, either dump the waste water without treatment or let it build up, backing up and overflowing into city streets and basements. During these times enormous amounts of raw sewage containing bacteria, viruses, parasites, pollutants (pesticides and motor oil) and 'floatables' (diapers, bottles, condoms, cigarette butts etc.) are dumped into the Great Lakes. Within North America there are more than 40,000 sanitary sewer overflows a year (Insituform, 2007; Rooney, 2006). The answer to sewage overflow used to be "solution by dilution" (Rooney, 2006). However with an ever-expanding population that is living closer together this option is no longer viable. These problems are only expected to increase in the future with a rapidly growing and expanding urban population placing extra strain on sewer systems and with older plants not being upgraded fast enough. Although an exact amount of released sewage is unknown, it is estimated to be in the hundreds of billions of gallons (Price, 2005a). Following are a few examples of recent releases:

- 2004: Michigan dumped more than 27 billion gallons of sewage/stormwater into the Great Lakes according to the Department of Environmental Quality (Price, 2005b).
- March 2, 2007: A sewer main ruptured in Muskegon, Michigan, allowing 10-25 million gallons of untreated sewage to be released into Muskegon, Mona and Bear lakes (Alexander, 2007; Gunn, 2007).
- May 2004: Milwaukeek dumped more than 4 billion gallons of sludge into Lake Michigan (Price, 2005b).
- 2008: 161 Wisconsin communities discharged hundreds of million gallons of untreated sewage into waterways (Bergquist and Behm, 2008).
- January 2008: 20 million gallons of sewage was released into Pennsylvania's Schuylkill River from a ruptured pipe (Wheeler and Smith, 2008).

The presidential task force recently estimated that $20 billion would be needed to clean up the Great Lakes, of which over $13 billion would be needed to deal with sewage issues (Price, 2005b). However, even with these staggering figures President Bush proposed over 40% in cuts to sewage infrastructure (Clean Waters Action, 2005). In 2002 the U.S. EPA estimated that each year funding is $13 billion short of what is necessary to properly upgrade sewer systems (Meyer, 2007). In 2008 the federal government allotted $687 million for improvements to meet clean water requirements (Wheeler and Smith, 2008). However, the cost of one project alone in Indianapolis is over $1.2 billion (Wheeler and Smith, 2008). Furthermore, the National Association of Clean Water Agencies has estimated that $350 to $500 billion will be needed over the next 20 years to meet clean water requirements (Wheeler and Smith, 2008).

In Canada it has been estimated that $10 to $20 billion will be needed over the next 20 years to address the inadequate performance of waste water systems (De Souza, 2008). Furthermore, the government has yet to clean up waste water polluting 15 hot spots in the Great Lakes (De Souza, 2008).

In many places it will be the residents that foot the bill. Duluth, Minnesota, is starting a mandatory inspection of sanitary sewer pipes for over 20,000 homes which, if found to have leaking pipes, could have to pay upward of $7,500 in repairs (Stahl, 2008).

Enforcement regarding deteriorating pipes, sewer overflows and other violations must be taken seriously. However, in the United States legislation that would require sewer authorities to notify the public of overflows and spills is still pending in Congress (Wheeler and Smith, 2008). In Canada there is yet to be a national standard for the regulation of wastewater (De Souza, 2008) and there has been no update to the national Water Act since the 1970s (Eggertson, 2008). The contamination of groundwater by leaking sewage infrastructure is therefore likely to continue unabated.

MUNICIPAL WATER MAINS

Leaking municipal water mains are another source of groundwater contamination in the Great Lakes. Due to an ever-increasing amount of impervious cover (parking lots, roads, etc.) recharge of groundwater is being inhibited (Garcia-Fresca, 2002). Leaking municipal water mains act as a significant source of urban and suburban groundwater recharge; however, the drawbacks may significantly outweigh the benefits.

A significant amount of water is lost every day during the distance travelled from the treatment plant to the consumer, known as "unmetered water." Unmetered water includes losses from leaking pipes (Figure 2), resulting from improperly constructed pipelines, lack of corrosion protection, poorly maintained valves, metering

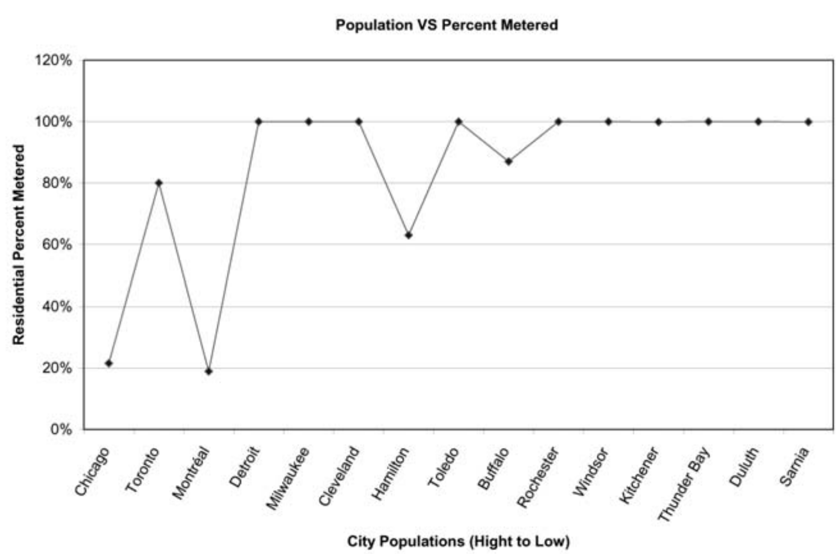

Figure 2. **Population vs residential percent metered of 15 cities within the Great Lakes – St. Lawrence basin. Overall decrease in percent metered with increasing population.** Source: Sereres, 2006

errors (human or mechanical), public use (fire fighting, pipe flushing), malfunctioning distribution systems and theft (Hunaidi, 2000; Lahlou, 2001). In many parts of the world, up to 60% of drinking water leaks from pipes before it reaches a single home (Insituform, 2007). In the U.S. this amount is estimated to be between 20 to 30% (Insituform, 2007; Subcommittee on Water Resources and Environment, 2004). However, depending on the age of the water mains this volume may be as high as 50% (Subcommittee on Water Resources and Environment, 2004). In 2006, Detroit, Michigan, was unable to account for 17% or 31-35 billion gallons (over 117 million m^3) of water (Kolker, 2007; "Leaky pipes," 2002). An estimated $6.79 billion is needed over the next two decades to repair Michigan's drinking water infrastructure (ASCE, 2005). For Canada it is estimated that over 50% of water supply lines are in need of repair, and municipal infrastructure systems have reached about 80% of their life expectancy (McFarlane and Nilsen, 2003).

A 10% to 20% allowance for unaccounted-for-water is generally viewed as acceptable (Javed, 2007; Lahlou, 2001). However, water levels of the Great Lakes are currently at the lowest in years. It is therefore even more important to reduce water consumption and make conveyance as efficient as possible. With technological advances losses and unaccounted-for-water should be able to be reduced to less than 10% (Lahlou, 2001).

Approximately 60% of water losses are considered to be "real" and the remaining 40% as only "apparent" (Thorton, 2002; Garcia-Fresca, 2002).

REAL LOSSES

Leaking water mains correspond to "real losses" and can be brought about by many factors including material, composition, age and joining methods of the system; temperature, aggressiveness and pressure of the water; as well as external conditions including contact with other structures, excess loads, vibrations from traffic above, stray electrical currents and ground movement due to drought or freezing (Lahlou, 2001; Hunaidi, 2000; Lambert and Hirner, 2000; Habibian, 1994). A small 1.5 mm hole in a water main results in significant water loss, leaking over 300 litres a day (Hunter Water Corp., 2000). In San Francisco, stray currents from a light rail line are believed to be causing high levels of corrosion in metal pipes resulting in excess leaks. Nearly two dozen leaks where found in a single block (Werner, 2007).

Following are a few recent examples:

- April 2008: Just north of New York a 70-year-old tunnel is leaking 36 million gallons of water a day (Long, 2008).
- 2008: In Chicago an 80-year-old water main broke losing thousands of gallons of water (Long, 2008).
- March 2008: 10 million gallons rushed out of a broken water main in Cleveland and collapsed the street in the Public Square, totaling over $1 million in repair costs (Kropko, 2008).
- February 2008: In Denver a 30-year-old pipe broke releasing 2-4 million gallons of water and shutting down I-25 (Bunch and McPhee, 2008; Long, 2008).
- 2007: An 84-year-old pipe burst creating a geyser in New York (Long, 2008).
- October 2007: A break in a 60-year-old water main in London, Ontario, resulted in a large sinkhole in the heart of the city (Maloney, 2007; Matyas, 2007).

As pipes continue to age breaks in the system are likely to become even more frequent. Factors such as geology of the area, pressure, use and material of the pipe all greatly affect the life expectancy of a typical water main. Therefore estimates vary greatly between 40 to 120 years depending on the source ("Pipe Nightmares," 2007; Spears, 2006; American Water Works Association, 2001). Yet even with such a wide range many cities water systems are fast approaching (or have surpassed) their expected life span. More than 70 miles of pipes in Cleveland are over 125 years old (Kropko, 2008). In Windsor, Ontario, approximately 60% of the city's water mains are past their life expectancy (Lajoie, 2007). In London, Ontario, there are between 150 to 200 burst water mains per year (Maloney, 2007). Windsor spent $2.1 million fixing water main breaks in 2008 (Battagello, 2009).

Case Study – Water Infrastructure Efficiency

Note: The following information about water infrastructure efficiency was extracted in large part from a thesis entitled *Surpassing Efficiency: Providing a Rationale for the Water Soft Path in the Great Lakes Basin*. The thesis was prepared by Clayton S. Sereres in partial fulfillment of the requirements for the degree of Honours Bachelor of Science at Lakehead University, Thunder Bay, Ontario, in 2007. The broader focus of the thesis was on the philosophy associated with management of municipal drinking water conveyance systems for 16 communities in the Great Lakes - St. Lawrence River Basin. The information was compiled from published literature, interviews with municipal representatives and additional information provided through the interview process.

The impact of conveyance losses on groundwater quality and quantity is inferred from the material presented. It provides a rationale for the water soft path in the Great Lakes Basin.

Water conveyance is defined as the systematic and intentional flow or transfer of water from one point to another

(U.S. EPA, 2006). The majority of the basin's drinking water supply systems were constructed before World War II (Tate, 1990). In the 1960s, water utilities were expanded to accommodate increasing urbanization. Since then, few upgrades have been implemented (Renzetti, 2003). As a result of capacity problems and the associated costs of maintenance and repair (Brooks, 2005), the drinking water conveyance infrastructure is leaky and water loss high. Inadequate infrastructure and capital limitations have resulted in water quantity and quality problems for cities in the Great Lakes - St. Lawrence River Basin (Maas, 2003). A leak of only one drop per second represents a water loss of 10,000 litres per year (Environment Canada, 2000). It's noteworthy that it is at least three times more expensive to repair a water line after it fails compared to the costs associated with regular inspection and maintenance (Liquid Assets, 2008).

Toronto, for example, experiences about 1,600 watermain breaks per year (Gray, 2008). Officials report that aging pipes, including a batch installed in the 1950s that have corroded faster than expected, are to blame for the increasing number of breaks. Breaks can be sudden and catastrophic, such as one in 2006 that resulted in a 10-metre-wide sinkhole that closed a major road for several months. In another case, a prior watermain break washed away soil beneath another heavily travelled artery (Gray, 2008). Ultimately, in February 2008, freezing and thawing temperatures, coupled with the continuous pounding of traffic, weakened the road, leading to a cave-in 30 metres deep.

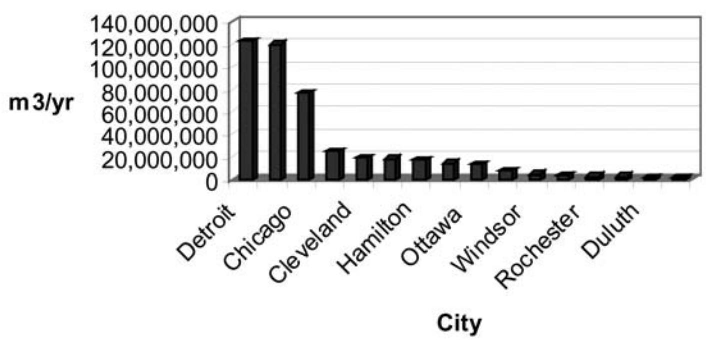

Figure 3. Amount of water lost per year due to conveyance

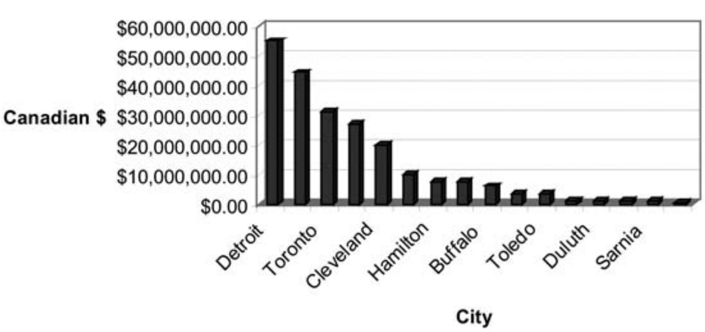

Figure 4. Amount of money lost per year due to conveyance

To ascertain the efficiency of the urban water infrastructure in the basin, data and information collected from interviews were combined with materials published by Environment Canada and the U.S. EPA to estimate the percent of water loss due to conveyance for 16 cities in the basin. Only the residential sector was considered.

The consequences of deteriorated urban water infrastructure can be expressed as the volume of water lost due to conveyance leakage (Figure 3) and as the monetary cost to the city based on the charge for water (Figure 4).

- Detroit has one of the largest, most inadequate infrastructure systems in the basin. Conveyance losses of approximately 17.2% equal 122,966,261 m^3 per year at a cost of approximately $ 55,088,884.
- Montreal is losing approximately 40% of its total output, which equals 119,858,800 m^3 per year at a cost of approximately $ 44,347,756.
- Toronto, which displays a more adequate infrastructure system, is losing approximately 10% of its total output to conveyance losses, which equals 24,531,156 m^3 per year at a cost of approximately $ 31,277,233.
- Smaller cities such as Rochester, Duluth, Thunder Bay and Sarnia have less urban water infrastructure, leading to much lower losses from leakage in the conveyance system.

To correct its water infrastructure deficits, Toronto plans to hike water rates 62% by 2012 to fund a ten-year plan to upgrade and repair the city's 16,000 kilometres of aging water and sewer lines. If funding were continued with the current price structure, approximately 200 years would be required to replace water and sewer lines (Gillespie, 2004).

In addition to monetary costs to the municipality and, ultimately, the user, leaking municipal drinking water conveyance systems allow a sizable quantity of potable water to infiltrate the groundwater. Based on this information, one can infer significant groundwater infiltration of untreated water from leaking sewage and stormwater conveyance systems. The relative and absolute impact on groundwater quality and quantity should be investigated.

Apparent Losses

Old meters are likely to blame for the majority of "apparent losses" (Kolker, 2007). As meters age they slow down. For example, for every 100 litres that passes through only 90 litres may be measured, resulting in an apparent loss of 10 litres. To compensate for water meter errors cities are forced to charge higher rates. Wyoming, Michigan, is currently replacing all residential meters at an estimated total cost of $1.8 million (Kolker, 2007). Also, in some older communities in Chicago and Toronto houses are still not hooked up to a water meter. These communities pay a flat rate for their water services, not keeping track of actual amounts used; or in some extreme cases they may be paying nothing at all. Metering has many advantages including the incentive for customers to conserve water, providing information regarding water leakage between the plant and customer, allowing for better use of repair and maintenance resources and improving accountability (Kitchen, 2007).

A study to determine the percent of unmetered water within the Great Lakes – St. Lawrence River basin was undertaken by Sereres. Water metering information was gathered from 15 cities (7 Canadian and 8 American) of varying population size. The study showed that as population and city size increases the percent of residential metered water tends to decrease (Figure 2) (Sereres, 2006). See Table 2 for water metering data of individual cities.

Not only do leaks result in water loss but also in economic loss as raw water, treatment and transportation are costly. Cities are losing millions from pipes leaking treated water (Javed, 2007). In Toronto the exact percent of water loss is still uncertain, ranging from an estimate of 7%, by Toronto's works and infrastructure committee chairman, to 25%, by the Ontario Sewer and Watermain Construction Association (Versace, 2007). Although down significantly from 2001 losses of over $31 million (Sereres, 2006), Toronto is still having approximately 1,300 water-main breaks a year (Spears, 2006), resulting in losses of greater than 120 million cubic metres per year, approximately $23 million dollars (Versace, 2007). In 2002 Toronto was having approximately 30 breaks per 100 km of pipe, yet only 0.5% of the water network was being replaced per year (Levy, 2004). Other communities are having similar problems. Detroit has raised water rates five times between 1995 and 2002 to deal with this issue ("Leaky pipes," 2002).

Figure 5. **Broken water main along I-96 freeway**
Photo by: John T. Greilick

In the previously mentioned study by Sereres, the total amount of water loss for 15 cities in the Great Lakes – St. Lawrence Basin was determined to be over 170 million m³ in the eight Canadian cities and over 260 million m³ in the seven American cities. These water losses represent an economic loss greater than $218 million (Sereres, 2006).

Leaks also can be detrimental to the remaining pipe system, resulting in an even greater economic loss. Existing leaks cause cracks to grow, heightening

Table 1. Estimated Water Loss from Leaking Pipes

Loss of Total Output	Reference	Cities
40%	Environment Canada, 2000	Montreal
20%	Environment Canada, 2000	Hamilton, Ottawa, Kitchener, Thunder Bay, Sarnia
17.2%	van der Leeden et al., 1990	Chicago, Detroit
11%	USEPA, 2006	Cleveland, Milwaukee, Buffalo, Rochester, Duluth
10%	City of Toronto, 2002	Toronto

problems. A spectacular break occurred in July 2007 when a water main broke flooding the eastbound lanes of I-96, shutting down the freeway in Livonia, Michigan (Figure 5) (Bouffard, Greenwood and Ferretti, 2007). Leaks also cause erosion of the pipe bed, which can in turn weaken road and building foundations resulting in costly repairs (Hunaidi, 2000). On August 11, 2007, a portion of Keele St. in Toronto was shut down after a water main leak washed away aggregate underneath the road causing it to buckle (Burgmann, 2007).

Even without these added monetary losses a 2003 estimate for Ontario municipalities indicated that water-related revenues only covered 64% of the costs of providing water and water services. Insufficient funding leads to more leaks and high risk to ground-water contamination as failing infrastructure is not replaced (Kitchen, 2007; Report of the Water Strategy Expert Panel, 2005). The National Round Table on the Environment and the Economy (NRTEE) (1996) estimated that a 100% increase in water prices would result in a 30% decrease in water usage which would, in turn, decrease financing required for infrastructure.

Leaking pipes frequently result in reduced water pressure in the supply system. This can result in potential health and environmental hazards. Decreased pressure, combined with cracks in the pipes, provides a means of entry through which pathogens and other contaminants can enter the water supply (Hunaidi et al., 2000). Older systems that are still in use may still have service lines that are made of lead (House Subcommittee on Water Resources and Environment, 2004). Generally the response to decreased pressure in a supply system is to raise the pressure, making up for losses and to ensure adequate water pressure for fire

Table 2. Data on Water Usage and Loss in 15 Cities in the Great Lakes – St. Lawrence Basin

Water Usage and Loss in the Great Lakes - St. Lawrence Basin								
City	Year	Population	Residential water use (m^3/yr)	Estimated % Loss do to Conveyance	Amount lost per year do to Conveyance (m^3/year)	Amount lost per year do to Conveyance (dollars)	% Res. Metered	Res. Water Price per m^3
Canadian Cities								
Toronto	2001	2,397,000	245,311,560	10.00	24,531,156	$31,277,223.90	80.00%	$1.28
Montréal	2001	1,583,590	299,647,000	40.00	119,858,800	$44,347,756.00	18.90%	$0.37
Hamilton	2001	322,252	84,105,681	20.00	16,821,136	$11,068,307.62	63.00%	$0.66
Windsor	2001	200,062	22,718,400	20.00	4,543,680	$1,208,618.88	100.00%	$0.27
Kitchener	2001	184,100	16,535,880	20.00	3,307,176	$3,670,965.36	99.90%	$1.11
Thunder Bay	2001	117,000	11,088,700	20.00	2,217,740	$1,024,595.88	100.00%	$0.46
Sarnia	2001	70,000	7,372,876	20.00	1,474,575	$840,507.85	99.90%	$0.57
Average					24,679,180	$13,348,282.21	80.24%	$0.67
Totals					172,754,263	$93,437,975.49		
US Cities								
Chicago	2005	2,886,251	453,384,380	17.20	77,982,113	$27,371,721.77	21.50%	$0.35
Detroit	2001	925,051	725,228,960	17.20	124,739,381	$55,883,242.72	100.00%	$0.45
Milwaukee	2004	590,895	143,193,417	12.70	18,185,564	$7,583,380.16	100.00%	$0.42
Cleveland	2005	467,851	154,751,802	12.70	19,653,479	$20,164,469.29	100.00%	$1.03
Toledo	2005	309,106	61,666,481	12.70	7,831,643	$3,618,219.11	100.00%	$0.46
Buffalo	2004	287,698	113,663,855	12.70	14,435,310	$8,242,561.74	87.00%	$0.57
Rochester	2006	217,158	20,659,174	12.70	2,623,715	$611,325.60	100.00%	$0.23
Duluth	2005	86,419	16,281,579	12.70	2,067,761	$1,393,670.61	100.00%	$0.67
Average					33,439,871	$15,608,573.88	88.56%	$0.52
Totals					267,518,966	$124,868,591.00		

*Conversion Factor: 1m^3 = 260.417 gallons

Source: Sereres, 2006

Figure 6. **Examples of Windsor, Ontario's, rusty pipes with hardened scale corrosion. An eight-inch water main will become a two-inch main after about 50 years due to scale/precipitate build-up; an obvious problem for fire suppression in older municipalities. (Liquid Assets, 2008).** Photo by: D.W. Alley, 2007

suppression. This results in increased energy consumption, further damaging leaks and can cause more severe environmental impacts (Lahlou, 2001).

In an effort to minimize water loss and the associated economic and health hazards, significant effort is being put forward to implement leakage-control programs that detect, locate and repair leaks. These programs generally consist of water audits and leak-detection surveys (Hunaidi et al., 2000).

Figure 7. **Veterans Memorial Beach in St. Clair Shores, one of many beaches to experience a closing due to unhealthy levels of bacteria in the water**

Source: Price, 2005a; Photo by McTurf, 2005

On average, the savings in water no longer lost through leaks outweighs the cost of leak detection and repair (Lahlou, 2001). For example, in Windsor, the Windsor Utilities Commission increased the price of water by 36% in 2007 to pay for the estimated $600 million that will be spent over the next 30 years to replace old inefficient water mains (Lajoie, 2007). Windsor is currently losing an average of 15% of its water per year, valued at about $2 million a year. With 60% of Windsor's water mains at or beyond their life expectancy (Figure 6), continued use will require additional chemicals and treatment to be implemented as well as allowing for possible elevated risk of bacteria (Lajoie, 2007). Cost to replace old iron pipes with new PVC plastic pipes can be upward of $1,000 per metre. Some municipalities are therefore looking at the possibility of flushing water pipes to remove precipitate buildup (Pearson, 2007). However, without long-term studies there are no guarantees that the removal of "scaling" from pipes will in fact significantly extend the life of water pipes.

STORMWATER PONDS

Although few studies are available, researchers have noted that stormwater retention (wet) and detention (dry) ponds have the potential to affect the quality and quantity of urban and suburban groundwater (vanLoon, Anderson, Watt and Marsalek, 2000; Marsalek, Anderson and Watt, 2002). These ponds are a familiar part of any new residential, institutional or commercial landscape. However, improper pond siting in groundwater recharge zones and on highly permeable sub-soils often occurs in these developments (i.e., the pond site is often governed by space availability within the development rather than on a thorough

Figure 8. **Stormwater ponds, Windsor, Ontario**
Photo by: D.W. Alley, 2007

hydrogeological/geotechnical assessment of the site). Currently, there are about 714 stormwater ponds in Toronto Region Conservation Authority jurisdiction, and similarly large numbers exist in all of the other Great Lakes basin municipalities (Mather, 2006).

Stormwater ponds are designed to accept snow melt and wet weather flows from impervious urban and suburban surfaces, minimize flooding and allow contaminants including PAHs, metals, pesticides, fertilizers, pathogens, BTEX compounds and road salt to "settle-out" before the stormwater is released to surface receiving waters (Stinson and Perdek, 2004). Contaminants therefore accumulate in stormwater pond sediments and, although concentrations of many compounds are low, the loading to groundwater can be quite large because of high influent stormwater flow rates (Fischer, Eg and Beahr, 2003). Water percolating through these contaminated sediments carries a wide range of pollutants to the underlying groundwater, which are then insulated and isolated from filtration and attenuation as they flow toward discharge zones, pumping wells or wetlands (Pitt, Clark, Field and Parmer, 1996; Fischer et al., 2003; Schueler, 2008). Maintenance dredging and proper disposal of the contaminated dredge spoil is, therefore, a key part of stormwater pond management (Tsihrintzis and Hamid, 1997).

Portage, Michigan, has been divided into three groundwater risk areas based on time of groundwater travel to the city's municipal well field. Many "high-risk" groundwater contamination activities are discouraged in the highest risk category. The city further requires that stormwater pond sediment be removed (dredged) "when it reaches a depth equal to 50% of the depth of the forebay, or 12 inches, whichever is less" and requires that maintenance of stormwater ponds be vested with the owner or authorized operator (Fishbeck, Thompson, Carr and Huber Inc., 2003). This latter requirement is an effort to avoid burdening local taxpayers with stormwater pond maintenance costs like those recently estimated by Richmond Hill, Ontario. That town identified about 40 stormwater ponds within its jurisdiction that require maintenance dredging. Cleaning out just ONE of these ponds will require a Class Environmental Assessment, a Certificate of Approval from the Ministry of the Environment and $4 million to complete the dredging and disposal (Mather, 2006).

Figure 9. Recent repairs to an undercut, leaking sewer line at a stream crossing in Lake County, Illinois
Photo by: Michael Adams, 2007

RECOMMENDATIONS

With ever-improving technologies and ever-decreasing water levels in the Great Lakes, leaking municipal water and sewer lines cannot be taken lightly. Laws need to be passed giving uniform standards, allowing for easier and consistent enforcement.

- Legislation should be passed requiring sewer authorities to notify the public of overflows and spills.
- A national standard for the regulation of wastewater needs to be implemented.

Improved leak detection methods are available and should be taken full advantage of (National Research Council Canada, 2005; Hunaidi et al., 2000; Hunaidi and Giamou, 1998). There are many benefits to leak detection and repair including increased knowledge about the distribution system, more efficient use of existing supplies, improved environmental quality, reduced property damage, reduced legal liability, reduced risk of contamination (Lahlou, 2001). Furthermore, with ever-improving technologies leakage rates of more than 10% should no longer be viewed as acceptable.

In order to make significant improvements in sewage and water systems significant government funding is needed for a dedicated program. The AWWA (2001) has put forward the following recommendations regarding the need for an increase in federal assistance:

- Significant increased federal funding for projects to repair, replace or rehabilitate drinking water infrastructure
- An increase in federally supported research on infrastructure management, repair and replacement technologies
- Steps to increase the availability and use of private capital

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The Châteauguay Transboundary Aquifer

CONTENTS

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INTRODUCTION

The Châteauguay transboundary aquifer system is the only international aquifer in the Great Lakes Basin. Located southwest of Montreal it extends across the border with the U.S. into New York State. The total area of the aquifer system is 2,500 km^2, divided approximately 55% in Quebec and 45% in New York. Its average thickness is about 500 m.

The watershed encompasses two distinct physiographic regions: the St. Lawrence Lowlands, mainly in Canada, and the Adirondack Mountains in New York. The Chateauguay River flows from the Upper Chateauguay Lakes in New York into Lake St. Louis on the south shore of the St. Lawrence River. The aquifer system is composed mainly of a succession of sedimentary rocks, overlain principally by till and clay. At some places, sand and gravel deposits are in direct contact with the bedrock aquifer. The aquifer system is semi-confined.

The recharge of the aquifer occurs mostly in the U.S., and the regional groundwater flow follows a general north-northeast direction. Recharge on the Canadian side is approximately 80 mm, which is equivalent to 200 Mm^3/year. On the Canadian side, the population in the region is relatively dense, 100,000 habitants, 65% of whom rely mainly on groundwater for their water supplies. The aquifer storage is estimated to be 1,250 km^3 in Canada, and 37.5 km^3 in the U.S.

Industrial activity in the region resulted in one of the most important contamination cases in Canada in the early 1970s, when DNAPL contamination of the Mercier Esker forced the authorities of the towns of Mercier and Sainte-Martine to abandon their municipal wells. In rural regions, increased use of fertilizers and pesticides and manure spreading potentially contribute to changes in groundwater quality. Currently, one bottling company (Danone) withdraws groundwater for commercial purposes. Applications for two more permits are being considered. The steadily increasing groundwater use in addition to the prolonged drought conditions in 2000-2003 contributed to potential conflicts between groundwater users on the Canadian side, making this transboundary aquifer an important issue. Groundwater use on the American side is not as intense.

The Geological Survey of Canada and the Quebec Ministry of Environment performed a comprehensive groundwater assessment of the aquifer from 2003 to 2006. The assessment included surface water-groundwater use and interactions and distribution of recharge. A 3-D numerical model of the regional groundwater flow was built to evaluate the sustainable yield of the aquifer. The Geological Survey of Canada, the U.S. Geological Survey and the Plattsburgh State University of New York cooperated very closely in the regional assessment.

GEOLOGY

The regional aquifer system consists mainly of fractured Paleozoic sedimentary rocks. An aquifer unit consisting of coarse sandy to gravelly sediments of fluvio-glacial origin occasionally overlies the sedimentary rocks. In general, regional aquifers are covered with glacial sediments. They form more or less continuous aquiclude units permitting only limited and mainly vertical groundwater flow. In the St. Lawrence Lowlands to the north, regional aquifers are further confined with fine marine sediments.

BEDROCK

The basal Paleozoic formation is the Cambrian sandstone of the Potsdam Group. Sandstones occupy the central part of the watershed where Covey Hill is the predominant topographical feature. At the base, it consists of fluvial to shallow marine interbeds of locally conglomerate fine- to medium-grained quartz and feldspar, the Covey Hill Formation. The upper part of the group, the Cairnside Formation, consists of light grey to creamy white quartz arenite. The maximum thickness of this formation is about 100 m. Based on drilling and sonic logs, Cairnside was found to be the hardest sedimentary rock in the region. The sandstone sequence grades upward into dolomite rocks. The Beauharnois Formation is formed of sandy black dolomite at the base and grayish crystalline dolostone interbeds at the top containing subordinate limestone, sandstone and shale. The density of interbeds and vertical fractures increases as the group evolves from sandstones to dolomites. In the watershed, both dolomite formations are less than 50 m thick each. The youngest sedimentary rock formation consists of foreland basin carbonates of Chazy, Black River and Trenton groups and overlying syn-orogenic clastics (Utica, Lorraine and Queenston groups). Various limestone rocks are found in the northeastern corner of the study area. This bedrock sequence represents the regional-scale fractured aquifer.

QUATERNARY

Till represents a regional unit as it extends in a more or less continuous layer over the entire Chateauguay region. It is found just above the bedrock and underlies the clay sediments of the St. Lawrence plain. It crops out mainly on the U.S. side of the watershed and represents a major component of most of the hill formations (drumlins) in Quebec. Elongated forms of fluvio-glacial sediments are found at several locations in the study area. Deposited by strong currents of ice melt water, these sediments are generally sorted and stratified. As a result of water transport, the grains are sand and gravel sized and generally well rounded. They are loose in consistency, and drainage of surface water is mostly infiltration. Fluvio-glacial sediments are usually in direct hydraulic contact with the underlying bedrock and are often partially or entirely covered with lower permeability sediments. The silty and clayey soils in the region were deposited in standing bodies of water during and after the glacial retreat. They are regularly found at altitudes of less than 60 m and in small depression between the drumlin hills. These grained materials represent the major confining unit that, when present, hinders the interaction between the regional aquifer units and the surface water network. It is believed that the vertical flux through these sediments is minimal. Deposition of coarse alluvial sediments occurs in generally shallow sheets along the shorelines of post-glacial lakes and sea current streams. Due to their local laternal extent and thickness of several meters, they do not represent a major aquifer unit.

CONCEPTUAL MODEL

In practice, the various hydrogeological contexts of regional aquifers are assessed on the basis of the physical properties of overlying unconsolidated sediments and their corresponding thickness. For the Chateauguay regional hydrogeological assessment, confined flow conditions were defined in areas covered with more the 5 m of fine marine sediments characterized with low hydraulic conductivity. Semi-confined flow conditions were inferred for areas characterized with fine marine sediments of less the 5 m and/or areas with at least 3 m of glacial sediments (till). The areas with rock outcropping or covered by thin till layer (less than 3 m), and/or by coarse sediments with high permeability regardless of their thickness, are designated as unconfined, water-table, aquifers. Based on this classification, the recharge rate is lowest for the confined water flow conditions.

NUMERICAL MODEL

A 3-D numerical model of the Chateauguay aquifer was built to evaluate detailed water balances, groundwater sustainability and aquifer vulnerability. The water balance of the aquifer estimated with the calibrated numerical model provided the following:

- Effective porosity = 1%.
- Aquifer volume = 300 km³.
- Aquifer storage = 3,000 Mm³.
- Regional flow (renewable rate) = 3.2%.
- Groundwater use = 0.6% of the groundwater storage.
- Present groundwater use is 12% of regional flow.

ESKERS AND GROUNDWATER CONTAMINATION: CITY OF MERCIER

The Mercier Esker is exposed at the surface over 9 km and forms a gently sloped ridge up to 15 m higher than the surrounding plain. In its northern part, it is directly deposited on, and bordered by till, while its southern part is partially covered by the clays of the Champlain Sea that totally cover it at the level of the Esturgeon River. Its south-southwest orientation is due to the change of glacial flow induced by the presence of Lake Iroquois that caused rapid ice flow toward this precursor of present day Lake Ontario (Prichonnet, 1977; Ross, 2005). It is composed of several central ridges of sand and gravel that typically constitute these glacial landforms. These sub-glacial sediments were deposited under pressure by streams that drained the inside of the glacier. Laterally, a succession of sandy-silty sediments and gravels was deposited when the glacial melt waters emerged in the waters of Candona Lake forming sub-aqueous outwash cones or deltas and locally eroding the underlying tills. Locally, under stagnant ice meltdown conditions a layer of diamicton was deposited over the esker ridge that was finally partially covered by clays. These fine-grained sediments had settled out of marine waters that had invaded the continent (the Champlain Sea) that was, at that time, depressed due to the weight of continental ice. At the time of the marine retreat, the esker was under littoral conditions that reworked the top of the ridge and left sand and gravel beaches. A seismic survey, supported by drilling data, shows both types of observed fluvio-glacial sediments, the clays of the Champlain Sea as well as the underlying till and bedrock.

For nearly 40 years, a portion of the Mercier Esker has been contaminated by organic chemical compounds. Between 1969 and 1972, after receiving permits from the Water Control Board and the Department of Health, Lasalle Oil Carriers deposited about 170,000 m³ (BAPE, 1994) of used oil and solvents in lagoons located in abandoned gravel pits. As early as 1971, several nearby wells were contaminated by organic compounds and had to be abandoned. In 1972, the Quebec government forbade further disposal into the lagoons and enacted a decree on chemical waste disposal for the Province of Quebec. Between 1972 and 1975, Goodfellow Combustion (replaced by Tricil Inc., then by Laidlaw) built an incinerator to eliminate the used oil in the lagoons.

In 1980, part of the non-pumpable wastes remaining in the lagoons was excavated and stored in a containment cell located on the nearby Champlain Sea clays. However, some of the organic wastes remained in place and was neither excavated nor incinerated. An estimated volume of 90,000 m³ of liquid organic chemical compounds (BAPE, 1994) remained in the Mercier Esker under the lagoons and in the underlying bedrock.

In July 1982, the Quebec government enacted a regulation respecting the protection of ground water in the region of the town of Mercier (Q-2, r.18.1), in order to provide a framework for groundwater exploitation in the region. As a consequence, the town of Mercier abandoned a project to extract groundwater from the esker; and the municipality of Sainte-Martine, located to the south, had to stop pumping its wells and connect to a regional water line supplied by the wells of Chateauguay.

In 1984, the Ministry of Environment (MENV) built three wells and a groundwater treatment plant. At that time, it was believed that the lagoons did not constitute a source of contamination and that a pump-and-treat system would allow full decontamination over a period of five years.

In 1991, several years after the implementation of the pump-and-treat system, the levels of contaminants remained elevated and an investigation at the site of the former lagoons conducted by MENV led to the excavation of hundreds of barrels and several transformers, many still containing organic and chemical compounds.

In 1992, MENV informed the Laidlaw Company that it would have to: (1) excavate all the contaminated soils and the contaminated residues located in the area of the former lagoons and (2) eliminate or treat in an authorized site or store in a safe place all the excavated contaminated soils and contaminated residues. However, MENV was not successful in persuading Laidlaw to decontaminate the site. Laidlaw still maintains today that the excavation of contaminated soils is useless because complete decontamination is impossible, due to the presence of heavy oils which have contaminated the deeper fractured aquifer.

In 1993, a group of international experts (The Mercier Remediation Panel) mandated by Laidlaw, filed a report that concluded that it would be too risky to excavate the site where the lagoons were located. They proposed rather to confine them and ensure the maintenance of the hydraulic trap. One of the recommendations was to examine the feasibility of emplacing lateral containment walls.

In 1994, another international expert committee mandated by MENV filed its own report and proposed to confine the lagoons (lateral walls and capping) as well as to carry out the research and development necessary to decontaminate *in situ* the site in order to minimize the concentrations of the current contamination.

In 1994, MENV created a commission on the restoration of the Mercier contaminated site to study the proposed solutions and to hold public hearings on the question. In its report, the commission recognized the health risks related to excavation at the site, accepted the proposed solution by the expert committee of MENV and recommended the construction of containment walls and an impermeable covering as well as the immediate excavation of the uppermost part of the contaminated soils.

It is now known that several organic chemical compounds in immiscible phase have migrated through the esker sands and gravels and reached the fractured aquifer through a window where the till is absent at the base of the esker. Elsewhere, the silts and compact till play the role of an aquiclude that has prevented these same compounds from percolating farther down. The compounds are DNAPLs and are very difficult to flush out of the fractures; furthermore they tend to degrade slowly into soluble and carcinogenic compounds that can then migrate with the groundwater flow.

The distribution of contamination at the site of the old lagoons appears as follows:

- The lagoons contain an unknown volume of organic chemical compounds in immiscible phase (heavy oils) which remain an important active source of contamination for the groundwater circulating in the sand and gravel aquifer.
- Immiscible phase compounds also are present in the rock, at depth, and they constitute another active source of contamination for the groundwater that circulates in the rock aquifer which is used regionally.
- Contaminated plumes of dissolved phase compounds resulting from the contact of groundwater with the active sources are present both in the esker and in the bedrock aquifer.

Presently, the hydraulic containment system operated by the Ministère du Développement durable, de l'Environnement st des Pares provides efficient control of the contamination and prevents its migration.
A publishing ban covers the technical documents surrounding this case since, on the legal side, the lawsuit between the government and the owner of the site is still not settled.

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Summary of Laws Affecting Goundwater in the Great Lakes Basin

CONTENTS

INTRODUCTION

Groundwater law across the Great Lakes Basin consists of a patchwork of statutes, regulations and common and civil law principles. This patchwork lacks consistency among jurisdictions. Groundwater law is primarily state and provincial, but includes some elements of federal, Tribal, First Nations and municipal law.

This appendix reviews legal rules regulating groundwater allocation and use as well as maintenance of groundwater quality. It is not intended as a comprehensive review of all laws affecting groundwater in all basin jurisdictions. The approach is selective, intended to show the range of approaches, some commonalities and major differences among basin jurisdictions.

COMMON LAW PRINCIPLES

Groundwater rights are rights to *use* water and are linked to land ownership. Traditional common law and civil law principles distinguish between surface water and groundwater. Owners of lands abutting surface watercourses traditionally enjoyed "riparian rights" that allowed certain uses without restriction and some control over the quality and quantity of water flowing past one's land. These rights balanced the interests of all riparian owners along a watercourse. By contrast, because the nature and movement of groundwater was "unknowable," different rules were applied. The traditional starting point in most jurisdictions is an absolute right in the owner of overlying land, known as the "rule of capture," to take and use as much groundwater percolating through the soil as he or she wanted regardless of the effect on others.

The common law rules have been tempered in all jurisdictions. Most Great Lakes states now apply a "reasonable use rule," as defined by statute or the courts, or as elaborated in the *Restatement of Torts (Second)*. The reasonable use rule provides that groundwater is a property right but its use cannot cause unreasonable harm to a neighbour by lowering the water table or reducing artesian pressure, cannot exceed a reasonable share of the total store of groundwater in an aquifer and cannot create a direct or substantial effect on a surface watercourse. Another groundwater doctrine, applied in Minnesota, is the "correlative use" rule, which allows the courts to allocate rights to use groundwater among all users of an aquifer.

Voters in Ohio recently approved a constitutional amendment that confirms the property rights of landowners to make reasonable use of the groundwater underlying their lands. The amendment also provides that groundwater underlying private land cannot be held in trust by the government, unless voluntarily conveyed, but that the government may regulate such waters.

Ontario and Quebec follow legal rules similar to the property rights and reasonable use principles of U.S. law. In June 2008, the Quebec government introduced Bill 92 into the National Assembly to facilitate comprehensive water resources management. The bill includes a declaration that both surface and groundwater are "part of the common heritage of the Quebec nation and may not be appropriated except under conditions defined by law…" The bill also creates an action for damages or restoration that may be brought by the Attorney General "in the name of the state as custodian of the interests of the nation in water resources." Quebec groundwater law is found in the Civil Code, statutes and regulations. Ontario groundwater law maintains a common law foundation but has been significantly modified by statute, as discussed below.

REGULATION OF GROUNDWATER ALLOCATION AND USE

Groundwater allocation and use are regulated by individual states and provinces according to each jurisdiction's idiosyncratic rules and institutions. There is only limited commonality across the basin.

Half of the jurisdictions – three states and both provinces – regulate groundwater withdrawals by requiring a government permit if the amount of the withdrawal exceeds a specified threshold or is intended for a particular use. The other five states require government notification or registration of some or all withdrawals, usually above a threshold amount. In Ohio, for example, registration is only required if the capacity is 100,000 gallons/day or more, but a lower threshold may be established in groundwater stress areas. Registrants are required to file annual reports with the state on the amount of groundwater withdrawn. Other groundwater users are not required to meter actual use. This is similar in most Great Lakes jurisdictions.

All jurisdictions in the basin have established standards for the location, design and construction of wells.

Many of the basin jurisdictions have identified areas of special concern for the management of groundwater. For example, the southeast section of Wisconsin and the Lower Fox River Valley each must implement a coordinated strategy to address problems caused by over-pumping of the deep aquifers. In Ontario, a special regime protects the regionally significant recharge zone in the Oak Ridges Moraine north of Toronto.

Regulations in the five jurisdictions with permitting systems vary in a number of ways. The threshold amount to trigger the need for a permit ranges from 10,000 gallons per day (g/d) in Minnesota to 2 million g/d in Michigan, as follows:

Michigan	2 million g/d	76 million l/d
Minnesota	10,000 g/d	38,000 l/d
Ontario	13,000 g/d	50,000 l/d
Quebec	19,500 g/d	75,000 l/d
Wisconsin	100,000 g/d	380,000 l/d

However, there are exceptions to these amounts. Michigan uses a lower trigger of 1 million g/d for certain circumstances and 200,000 g/d for bottled water production. As well, assessment, registration and reporting is required for many other "large quantity withdrawals," defined as more than 100,000 g/d. Ontario, Minnesota and Quebec exempt domestic uses from the permit requirement. In Quebec, the province must authorize withdrawals of more than 75,000 l/d, but *any* withdrawal of "mineral" or "spring" water requires a permit. General withdrawals of fewer than 75,000 l/d require municipal authorization. Ontario prohibits permits for certain purposes in specified locations and withdrawals in the summer in a low water region.

The criteria considered for obtaining a permit also varies among jurisdictions, and sometimes within individual states, according to the size of the withdrawal or the particular end use. For example:

- In Wisconsin, a permit for a withdrawal of 100,000 g/d or more cannot be approved if it would impair "public water supplies"; but if the withdrawal is for more than 2 million g/d, other adverse effects may be grounds for not issuing a permit.
- Minnesota requires a withdrawal to have "minimal impact" on the waters of the state and to be consistent with any water management plans, but special criteria apply for animal feedlots and livestock operations.
- In Michigan, for a general permit, a withdrawal cannot cause an "adverse resource impact." This has been defined as a decreased flow in a stream so that its ability to support fish populations is functionally impaired, but this definition will become more detailed starting February 1, 2009. More expansive criteria apply if the withdrawal will be for bottled water.
- In Quebec, the criteria relate to ensuring sufficient long-term groundwater quantity and quality and to minimizing negative repercussions on surface water, existing groundwater users and associated ecosystems.
- Ontario's criteria are the most comprehensive. They include the protection of ecosystem function (including stream flow, habitat and interrelationships between ground and surface water), long-term water availability (including sustainable aquifer yield and accommodation of competing uses and low water conditions) and the use of conservation best practices for the relevant sector.

Even jurisdictions that do not require permits for most groundwater withdrawals may require a permit for diversion of state waters outside the Great Lakes Basin or between drainage basins. For example, in Ohio, a permit is required to divert 100,000 g/d or more out of the Lake Erie drainage basin, or for a consumptive use of more than 2 million g/d. The Great Lakes Charter requires notification to other basin jurisdictions.

Permit fees are usually charged. However, royalties or water charges are not imposed on groundwater withdrawals in basin jurisdictions. Ontario recently adopted enabling legislation to allow for water charges. The first charges will be phased in beginning January 2009 and will initially apply to highly consumptive commercial and industrial uses, including beverage manufacturing, water bottling, aggregate processing and ready-mix concrete manufacturing. Other sectors are expected to be added later. Quebec also is expected to begin charging for water and is discussing a variety of possible models.

The Great Lakes St. Lawrence River Basin Sustainable Water Resources Agreement and Compact were designed to effect the regulation of groundwater resources. The prohibition on diversions applies to all water in the Great Lakes Basin, including groundwater. The only exceptions are for "intrabasin diversions" within the larger Great Lakes St. Lawrence River Basin and to communities and counties that "straddle" the surface water divide. Water in a container of 20 litres or less is not considered to be a diversion.

All ten jurisdictions will be expected to adopt a "program for the management and regulation of new or increased withdrawals and consumptive uses by adopting and implementing measures consistent with" a "common decision making standard." The Compact was approved by all eight Great Lakes states, the Congress and the President and came into force on December 8, 2008. Thus, the states will have to ensure their programs are in place by December 8, 2013. These programs must apply to groundwater as well as surface water within the basin. States/provinces can set their own thresholds, but otherwise the default threshold for application of the standard is withdrawals of 100,000 g/d. Regulation of existing withdrawals and those below the threshold is left to each jurisdiction. The common standard is a minimum standard for all jurisdictions (which some already exceed). It requires that:

- Water withdrawn be returned to its source watershed, less an allowance for consumptive use.
- There be no significant individual or cumulative adverse impacts to the quantity or quality of waters or water-dependent natural resources and the source watershed.
- Environmentally sound and economically feasible conservation measures be incorporated.
- The withdrawal comply with all municipal, state and federal laws, relevant agreements and the Boundary Waters Treaty.
- The use be "reasonable" – that is, it minimizes waste, ensures efficient use of existing supplies, balances competing uses, considers the supply potential of the water source, avoids or mitigates adverse impacts on other users and the ecosystem.
- Restoration of hydrologic conditions or functions be considered.

Some jurisdictions have already adapted their laws to comply, and others are in the process of doing so. It is expected that these requirements eventually will result in improved regulation and greater commonality in groundwater law across the Great Lakes Basin.

REGULATION OF GROUNDWATER QUALITY

The quality of groundwater that is used for *public* water supply is highly regulated in all jurisdictions in the basin. However, water supplied from individual residential wells and groundwater not directly used for drinking supply generally falls outside these regulations.

There are drinking water standards and minimum treatment requirements for public water supplies in all jurisdictions. Standards are set for a range of parameters including organic and inorganic chemicals, disinfectants and disinfection by-products, microorganisms and radionuclides. In the U.S., drinking water standards are set out in federal law; while in Canada, each province sets its own, but usually following federal guidelines.

Under the U.S. federal *Safe Drinking Water Act*, a Ground Water Rule was adopted in 2007. The new rule is intended to protect drinking water sources from pathogens, including viruses. States have until 2009 to implement the rule. It requires states to conduct periodic "sanitary surveys." undertake targeted monitoring of source water and then take "corrective action" if contamination is found. Corrective action can include removing the source of contamination, providing alternative drinking water sources, repairing system deficiencies or treating the water to inactivate viruses.

Ontario regulates the quality of drinking water for public water systems under the *Safe Drinking Water Act, 2002*. Drinking Water Standards are set for total coliforms and *E. coli*, but the Procedure for Disinfection of Drinking Water in Ontario was amended in 2006 to include a treatment standard for protozoa, with the objective of achieving greater than 99% removal or inactivation of viruses, protozoa and bacteria. Groundwater that is not under the influence of surface water must at a minimum undergo disinfection prior to delivery to customers. Small-scale drinking water systems are in the process of being shifted from the Ministry of the Environment to local health units under the oversight of the Ministry of Health and Long Term Care. Site-specific risk assessments for these systems and their source water will be done to determine the appropriate level of treatment necessary.

Quebec has a regulation respecting the quality of public drinking water supplies and standards for bottled water quality. Bottled water quality standards also are found in federal regulations under the *Food and Drugs Act*.

Over the last two decades, all basin jurisdictions have moved toward greater protection of drinking water sources through a multi-barrier approach. In the U.S., starting in 1986, all states were required to develop well-head protection programs that assess and protect groundwater that is a source of drinking water, and to have those programs approved by the U.S. EPA. There is variation among state programs. Some require local drinking water systems to develop management plans (e.g., Minnesota), while others rely on education, grants and technical assistance to encourage management actions. For example, the program in Michigan provides grants to public water supply systems for activities such as delineation studies, abandoned well search and management programs, educational materials, zoning bylaw language and spills response training.

The U.S. *Safe Drinking Water Act* was amended in 1996 to require all states to undertake Source Water Assessment Programs. These are intended to serve as plans to analyze existing and potential threats to the quality of drinking water, whether it comes from surface or groundwater. The U.S. EPA expects that state and local programs to protect drinking water sources will be developed based on the risks revealed by the assessments, and provides support for protection activities. Studies show that progress has been made in conducting assessments for all drinking water systems, but *use* of those assessments in developing local protection actions has been far more limited. Some of the obstacles to action include lack of local human, technical and financial capacity, lack of integration with other environmental programs and lack of coordination among agencies.

Since 2000, Ontario has moved to implement a multi-barrier approach to the protection of drinking water sources, including groundwater. Most recently, in 2007, the *Clean Water Act, 2006* was proclaimed. This Act mandates the assessment of existing and potential threats to public municipal drinking water sources and the development of source protection plans. This work will be done on a watershed basis. Once plans are developed, by the end of 2012, actions to protect vulnerable sources will be instituted by local governments and Conservation Authorities.

All basin jurisdictions have regulations governing a number of potential groundwater contamination sources, including landfills, wastewater discharges, underground storage tanks and agricultural operations. In the U.S., many *Clean Water Act* programs promote watershed protection, including the Nonpoint Source Program, the Total Maximum Daily Load Program and the National Pollutent Discharge Elimination System Program. These programs are implemented at the state level.

The following sections highlight two source types that are not well regulated but are of particular concern to groundwater quality in the Great Lakes Basin: septic systems and abandoned wells.

Septic Systems

Millions of on-site waste water (or “septic”) systems are in use in the Great Lakes Basin, and use is increasing with new development (30-50% of new development relies on septics.) All jurisdictions have standards for the design, siting, materials and construction of septic systems. Michigan has no binding statewide code but has criteria that are used by local health departments to guide the development of their rules. In all jurisdictions, permits are required for construction. Municipal (county or local) governments issue the permits and enforce construction standards. Even so, many systems are installed by “do-it-yourselfers,” especially in rural areas, and enforcement is variable.

However, the primary problem with septic systems for groundwater is with lack of maintenance and with aging systems. It is estimated that 50% of systems in use are older than their design life. These factors contribute to very high failure rates. The U.S. EPA encourages the adoption of appropriate guidelines for management of septic systems at the state and local levels. In 2003, the agency issued Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems. These management guidelines discuss five different management models that could be applied to different local circumstances and risks. However, because responsibility for septic systems is usually at the county level and there are few state requirements, inspection and maintenance requirements and enforcement are inconsistent across the basin. Most agencies do not even have records or inventories of all septic systems within their jurisdictions. In Michigan, for example, significant resistance from the real estate industry prevented passage of state standards, but at least six counties have adopted mandatory inspection requirements that apply when land is sold. Because of growing understanding of the adverse consequences of failing septic systems, a number of Great Lakes jurisdictions recently have made changes in their rules to address the issue of poor system maintenance.

Recent changes to Minnesota legislation required the state Pollution Control Agency to adopt minimum standards for the design, location, installation, use and maintenance of septic systems. These new standards were adopted in 2008. They include the requirement that local governmental units adopt ordinances and administrative programs and that those programs include inspection, record keeping and reporting. Rule 7080 also now mandates that every owner of a septic system assess or pump it at least every three years.

The Minnesota statute also provides that a seller of real property must give a prospective purchaser a written disclosure statement about how sewage is managed on the land. If there is a septic system, its location and whether it is in compliance with the standards must be disclosed to the purchaser. There is no statewide requirement for septic system inspection or repair at the time of sale of a property, but local ordinances may, and some do, require this.

In Wisconsin, regulation of septic systems is primarily done at the county level. State legislation establishes minimum criteria that can be enhanced by local ordinances and programs. One requirement of the legislation is that a maintenance program be established that includes mandatory inspection or pumping at least every three years, or, alternatively, a maintenance plan. New rules proposed in 2008 and still under consideration would require local authorities to conduct an inventory of all septic systems within their boundaries within two years and to develop and implement a comprehensive maintenance program within five years of the effective date of the rules. This would require regular maintenance and reporting by individual landowners.

An example of an innovative county ordinance is in Door County, Wisconsin. There, since 1986, evaluation of a septic system at the time land is sold is mandatory. Despite early scepticism, the program has been successful. Owners often delayed maintenance and, at the start of the program, 50-60% of systems were found to be failing. Now, with a high level of awareness and state grants to landowners to repair or replace failing septic systems, more than 80% of systems pass inspection.

In Ontario, septic system construction permits are issued and inspections done by designated local agencies (usually public health units) in accordance with provincial standards set out in the *Ontario Building Code*. There is evidence, however, that up to 20% of septic systems are installed without a permit. There are standards for septic system operation and maintenance, but maintenance standards have been poorly enforced. Municipalities have authority to establish ongoing inspection programs and at least 23 municipalities have done so. Financial institutions are increasingly pushing for inspections when lending to prospective purchasers. The *Clean Water Act, 2006*, adopted in 2007, included amendments to the *Building Code Act* authorizing the provincial cabinet to adopt regulations guiding the establishment of septic system inspection and maintenance programs. It is intended that such programs would be mandatory in prescribed drinking water source protection areas and discretionary in other areas.

Quebec regulations require that septic systems for year-round residences be pumped every two years and, for seasonal residences, every four years.

Ohio amended its sewage code in 2005 and adopted new standards in 2007 that will ensure greater consistency across the state in the siting and construction of septic systems. Local boards of health are given authority to adopt more stringent standards and to establish inspection programs, but are not required to do so.

A major impediment to better management of septic systems in all jurisdictions is a lack of trained inspectors and resources to hire and train staff.

Abandoned Wells

There are millions of unplugged wells across the basin that are direct conduits into the groundwater for contaminants. They also pose a safety hazard. Most jurisdictions now require a landowner who abandons a well to ensure it is plugged in accordance with state or provincial standards specifying how this must be done and by whom. In practice, when a well is being immediately replaced, most existing wells are plugged. Although there are few requirements to locate and plug long-abandoned wells, many Great Lakes jurisdictions do provide incentives or cost-share programs to encourage this.

Legal liability for harm caused by an abandoned well lies with the landowner. Illinois law makes a landowner whose abandoned well contaminates the groundwater of others responsible for providing a safe and sufficient alternative supply of water to them.

Michigan has an Abandoned Well Management Program that provides state grants to locate and plug abandoned wells. This program was implemented though local health departments. The state paid 75% of the cost of decommissioning and the local government paid the rest.

Wisconsin law requires local governments to have a well filling and sealing ordinance. The state provides "Well Abandonment Grants" to individual landowners to pay 75% of the cost of decommissioning an abandoned well found on their property.

Minnesota is the only Great Lakes jurisdiction with a well disclosure law. Whenever land is being sold, the owner must disclose to the purchaser the location and status of all wells on the land prior to signing an agreement of purchase and sale. At closing, the vendor must sign a certificate attesting to this disclosure, and a deed cannot be registered without this certificate. The information is also provided to the Department of Health, which follows up evidence of abandoned wells by taking action to decommission them.

Ontario regulates wells at the provincial, rather than the local, level. Similar to other jurisdictions, it has standards and reporting requirements for decommissioning a well. However, provincial inspection and enforcement of both construction and decommissioning dropped off significantly in the late 1990s, leading to a number of problems. A provincial study estimated that nearly 90% of Ontario wells are in need of repair or maintenance. Other evidence suggests that the major entry point of contamination into wells is breached casings. Due to the Walkerton Inquiry, the Ontario government has been pushed toward improving enforcement. The Ministry of the Environment in partnership with the Ministry of Agriculture, Food and Rural Affairs, the Association of Professional Geoscientists and community organizations undertook an active education program for well users. In addition, the Agriculture Ministry funded a cost sharing pilot program for upgrading and decommissioning abandoned wells. It was successful, but some of the money allocated went unspent, suggesting the need for greater awareness and education on the part of rural landowners.

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Chapter 40 – Soil and Water Resources Conservation
16 U.S.C.A. Ch. 40, §2001 *et seq.* (2008)

Title 42. The Public Health and Welfare
Chapter 6A - Public Health Service
Subchapter XII - Safety of Public Water Systems
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42 U.S.C.A. Ch. 6A, Subch. XII, Pt. A, §300f *et seq.* (2008)

Part B - Public Water Systems
42 U.S.C.A. Ch. 6A, Subch. XII, Pt. B, §300g *et seq.* (2008)

Part C – Protection of Underground Sources of Drinking Water
42 U.S.C.A. Ch. 6A, Subch. XII, Pt. C, §300h *et seq.* (2008)

Part D – Emergency Powers
42 U.S.C.A. Ch. 6A, Subch. XII, Pt. D, §300i *et seq.* (2008)

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42 U.S.C.A. Ch. 6A, Subch. XII, Pt. E, §300j-1 *et seq.* (2008)

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Public Water Supply Regulation Act, Ill. Comp. Stat. Ann. 415/40 (West 1990) (current to 2008)

Public Water Supply Operations Act, Ill. Comp. Stat. Ann. 415/45 (West 1990) (current to 2008)

Illinois Groundwater Protection Act, Ill. Comp. Stat. Ann. 415/55 (West 1987) (current to 2008)

Environmental Protection Act, Ill. Comp. Stat. Ann. 415/5, T. III (West 1970) (current to 2008)

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Illinois Rivers-Friendly Farmer Program Act, Ill. Comp. Stat. Ann. 505/106 (West 2000) (current to 2008)

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Water Authorities Act, Ill. Comp. Stat. Ann. 70/3715 (West1990) (2008)

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Subchapter H: Water Resources

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Part 3730: Allocation of Water from Lake Michigan
Ill. Admin. Code tit. 17, Ch. I, Subch. H, Pt. 3730 (1980) (2008)

Title 35: Environmental Protection
Subtitle C. Water Pollution

Part 301. Introduction
Ill. Admin. Code tit. 35, Subt. C, Ch. I(3), Pt. 301 (1979) (2008)

Part 302: Water Quality Standards
Ill. Admin. Code tit. 35, Subt. C, Ch. I(3), Pt. 302 (1978) (2008)

Part 303: Water Use Designations and Site Specific Water Quality Standards
Ill. Admin. Code tit. 35, Subt. C, Ch. I(3), Pt. 303 (1978) (2008)

Part 305: Monitoring and Reporting
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Part 306: Performance Criteria
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Part 352: Procedures for Determining Water Quality-Based Permit Limitations for National Pollutant Discharge Elimination System Dischargers to the Lake Michigan Basin
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Part 373: Third Stage Treatment Lagoon Exemptions
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Part 374: Design Criteria of Pressure Sewer Systems
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Part 375: Combined Sewer Overflow Exception Criteria and First Flush Determination
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Part 560: Design Criteria for Field Application of Livestock Waste
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Part 607: Operation and Record Keeping
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Part 611: Primary Drinking Water Standards
Ill. Admin. Code tit. 35, Subt. F, Pt. 611 (1990) (2008)

Part 615: Existing Activities in a Setback Zone or Regulated Recharge Area
Ill. Admin. Code tit. 35, Ch. I(5), Pt. 615 (1992) (2008)

Part 616: New Activities in a Setback Zone or Regulated Recharge Area
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Chapter 281. Water and Sewage
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Title 15 – Water Supply
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Title 16 – Great Lakes Water Conservation and Management
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Chapter 12. Wastewater Management
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327 Ind. Admin. Code 2-1-1 *et seq.* (2008)

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327 Ind. Admin. Code 2-1.5-1 *et seq.* (2008)

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327 Ind. Admin. Code 2-11-1 *et seq.* (2008)

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327 Ind. Admin. Code 8-2-1 *et seq.* (2008)

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Ontario Water Resources Act – O. Reg. 900

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- Règlement sur l'evacuation et le traitement des eaux usées des résidences isolées, RRQ, c. Q-2, r. 8 (2000)
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The Great Lakes-St. Lawrence River Basin Sustainable Water Resources Agreement

The Great Lakes Water Quality Agreement

The Canada-Ontario Agreement

Boundary Waters Treaty

APPENDIX M

List of Acronyms

ADHD – attention deficit hyperactivity disorder

ADI – acceptable daily intake

AFO - animal feeding operation

AMCL – Alternative maximum contaminant level

AO – aesthetic objective

AST – aboveground storage tank

ATSDR – Agency for Toxic Substances and Disease Registry

AWWA – American Water Works Association

BOD - biological oxygen demand

BTEX – benzene, toluene, ethylbenzene and xylene

CAFP - concentrated animal feeding operation

CCME – Canadian Council of Ministers of the Environment

CCL – Contaminant Candidate List

CDC – Centers for Disease Control and Prevention

CERCLA – Comprehensive Environmental Response, Compensation and Liability Act

CESD - Commissioner of the Environment and Sustainable Development

CI – confidence interval

CJD – Creutzfeldt-Jakob Disease

CMHC – Canada Mortgage and Housing Corporation

CNS – central nervous system

CPRS-R – Revised Connors' Parent Rating Scale

CTRS-R – Revised Connors' Teacher Rating Scale

CWD – chronic wasting disease

DCA - 1,2-dichloroethene

DDE – dichlorodiphenyldichloroethylene

DDT – dichlorodiphenyltrichloroethane

DEET – N,N-diethyl-m-toluamide

DEQ – Department of Environmental Quality

DHFS – Department of Health and Family Services

DIPE - diisopropyl ether

DMRM - Division of Mineral Resource Management (Ohio DNR)

DNA – deoxyribonucleic acid

DNAPL – dense non-aqueous phase liquid

DNR – Department of Natural Resources

ECO – Environmental Commissioner of Ontario

EDB - 1,2-dibromoethene

EDC - endocrine-disrupting chemical

EPA - Environmental Protection Agency

ERCA - Essex Region Conservation Authority

ETBE - ethyl tertiary butyl ether

FCM - Federation of Canadian Municipalities

FFPPA - Farming and Food Production Protection Act

FRP - fiberglass-reinforced plastic

GAC - granular activated carbon

GAO - Government Accounting Office or Government Accountability Office

GCDWQ – Guidelines for Canadian Drinking Water Quality

GI – Gastrointestinal

GIS – geographic information system

GLWQA - Great Lakes Water Quality Agreement

GNHS – Geological and Natural History Survey

GTA - Greater Toronto Area

HUS – hemolytic uremic syndrome

IARC – International Agency for Research on Cancer

ICBM – intercontinental ballistic missile

IJC – International Joint Commission

IWRA - Indiana Water Resources Association

LOAEL – lowest observed adverse effect level

LUST – leaking underground storage tank

MAC – maximum acceptable concentration

MALT lymphoma – mucosa-associated lymphoid tissue lymphoma

MCL – maximum contaminant level

MCLG – maximum contaminant level goal

MEDLINE – a comprehensive source of life sciences and biomedical bibliographic information provided by the U.S. National Library of Medicine and the National Institutes of Health

MENV - Ministry of the Environment

µg/kg bw – micrograms per kilogram of body weight

mg/kg bw – milligrams per kilogram of body weight

MMT - methylcyclopentadienyl manganese tricarbonyl

MMWR – *The Morbidity and Mortality Weekly Report*

MOE – Ministry of the Environment

MTBE – methyl *tert*-butyl ether

NAWQA – National Water Quality Assessment

NEIWPCC - New England Interstate Water Pollution Control Commission

NHL – non-Hodgkin's lymphoma

NMA - Nutrient Management Act

NMP - nutrient management plan

NMS - nutrient management strategy

NOAEL – no observed adverse effect level

NPDWR – National Primary Drinking Water Regulations

NRC – National Research Council

NRCS - Natural Resources Conservation Service

NRDC – Natural Resources Defense Council

NRTEE - National Roundtable on the Environment and the Economy

NRTMP - Niagara River Toxics Management Plan

NSDWR – National Secondary Drinking Water Regulations

NTP – National Toxicology Program

OG – Operational Guidance Value

OMAFRA - Ontario Ministry of Agriculture, Food and Rural Affairs

OPG - Ontario Power Generation

OPGMN – Ontario Provincial Groundwater Monitoring Network

OR – odds ratio

O. Reg. – Ontario Regulation

OWTS – on-site wastewater treatment system

PAH – polynuclear aromatic hydrocarbon

PCB – polychlorinated biphenyl

PCP – personal care products

PD – Parkinson's disease

PERC – perchloroethylene

RCRA – Resource Conservation and Recovery Act

RCRS - Revised Conners' Rating Scale

RNA – ribonucleic acid

RT-PCR – reverse transcription polymerase chain reaction

SAB - Science Advisory Board

SAR – sodium absorption ratio

SARA - Superfund Amendments and Reauthorization Act

SMR – standardized mortality ratio

STORET – Storage and Retrieval Information System

TAME - tert-amyl methyl ether

TCE – trichloroethylene

TDI – tolerable daily intake

TSSA - Technical Standards and Safety Authority

TT – treatment technique

TTP – thrombotic thrombocytopenic purpura

USDA - United States Department of Agriculture

USGS – United States Geological Survey

UST - underground storage tank

UV – ultraviolet

vCJD – variant Creutzfeldt-Jakob Disease

VOC – volatile organic compound

WBDO – waterborne disease outbreak

WCELRF - West Coast Environmental Law Research Foundation

WHMD - Waste and Hazardous Materials Division