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

February 2010

INTERNATIONAL
JOINT
COMMISSION
Canada and United States

Groundwater in the Great Lakes Basin

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

February 2010

The views expressed in this report are those of the individuals
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They are not the views of the International Joint Commission.

Citation:

Great Lakes Science Advisory Board to the International Joint Commission (IJC), 2010. Groundwater in the Great Lakes Basin, 2010. IJC, Windsor, Ontario, Canada.

ISBN 1-894280-97-0

International Joint Commission
Great Lakes Regional Ofþce
100 Ouellette Ave., 8th Floor
Windsor, Ontario N9A 6T3
Canada

Telephone: (519) 257-6700, (313) 226-2170

World Wide Web: http://www.ijc.org

This report is available in English in pdf format at: http://www.ijc.org/en/reports/2010/groundwater-in-the-great-lakes-basin

This report, minus the Appendices, is available in French in pdf format at: http://www.ijc.org/fr/reports/2010/groundwater-in-the-great-lakes-basin

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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

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 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 scientiþc issues are:

- Better characterization of subsurface conditions, especially the hydraulic conductivity of geologic materials.
- Identiþcation 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 ÿows 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 þndings to the public, by allowing a user to òseeó aquifer prospects at speciþc 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 quantiþed 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, landþlls, hazardous waste sites, abandoned wells, leaking sanitary sewers, conþned animal feeding operations, land application
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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 ÿow 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 þndings were never released. Further, calculations are based not on actual measurements but on actions taken. In addition, many signiþcantly 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

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 þndings 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 signiþcant 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 qualiþed 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 ofþcials. 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

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, landþlls 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 certiþcation.

7. State and provincial governments should regulate conþned 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 identiþed in this report and the appendices affecting groundwater within the Basin, and report regularly on progress. The Parties should each designate a lead agency

Transmittal Letter

Groundwater/Annex16 Recommendations

July 31, 2006

IJC Commissioners

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

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 þndings 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 scientiþc understandings, calling on the Parties to:

a. Recognize and reÿect 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 signiþcance of groundwater contamination in the Great Lakes Ecosystem.
- Many land use practices pose a signiþcant risk to groundwater quality and resources. These practices need to be further assessed and modiþed 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 speciþc 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 þnds 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 ÿows may be indistinguishable, the IJC can and has considered groundwater ÿows under References issued pursuant to Article IX of the treaty and can consider impacts on groundwater ÿows 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 deþne òwaters of the Great Lakes basinó 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 scientiþc knowledge concerning the quality, quantity and ÿow of groundwater, that any regime should be ÿexible 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

Acknowledgements, Activities and Meetings, Membership

The capacity of the Science Advisory Board to address priority issues and stay abreast of the latest scientiþc information is only possible through the dedication of its members, the involvement of the wider Great Lakes scientiþc community and the participation of interested citizens and agency ofþcials. The Board also routinely seeks outside expert advice to ensure that the most current scientiþc 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 Baseÿow 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

APPENDICES

Appendices A through L provide relevant technical and background information in support of the þndings 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 –

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

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 conþning units.
- Systematic estimation of natural recharge of water to the groundwater system.
- Groundwater discharge to surface water as an important source of baseÿow 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,

Mapping Hydrogeological Units

Recent Research

Groundwater is present throughout the Great Lakes Basin, but the amount of water available from the

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 conþning units. Mapping will help determine the local and

DESCRIPTION OF HUMAN IMPACTS

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 coefþcients. Preliminary discussions with state agencies indicated that reþnement of consumptive-use data and coefþcients 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 coefþcients. This þrst, by Shaffer and Runkle (2007), is a compilation of consumptive-use coefþcients by water-use categories. That report contains:

- An annotated bibliography of references with consumptive-use coefþcients
- An appendix with detailed consumptive-use coefþcient tables from selected references
- Consumptive-use coefþcients for domestic and public-supply, industrial (including industrial use by major standard industrial classiþcation 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 coefþcients by water-use category and provides a starting point for facilities managers, water managers and scientists to compute water consumption and return ÿow.
The second consumptive water-use report compares the consumptive-use coefþcient statistics (median and 25th and 75th percentiles) computed by Shaffer and Runkle (2007) to consumptive-use coefþcients computed from monthly water-use and return-ÿow 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 coefþcients by water-use category.

Recommended Future Research

Water-use analysis is becoming more important as stresses on water 520iity Kincrease. Additional work on consumptive water use is especially important to future water 520iity Kdevelopment. 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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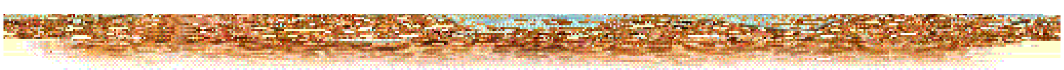
APPENDIX B

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 identiþed 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; landþlls; cemeteries; injection wells; waste and stormwater lagoons; and surface water, all of which can impact groundwater quality (Figure 1).



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;

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 þve 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,

Table 1.

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.

Speciþc types of bacteria known as coliform bacteria have been used for over 100 years as indicators of microbial water safety, fecal contamination and disinfection efþcacy 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 deþned is usually not a pathogen, but its presence indicates the potential for the presence of pathogenic organisms (Grifþn, 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 deþciencies 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 þeld-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 sufþcient 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.

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 20^{o}C, whereas most Great Lakes Basin groundwater is about 10^{o}C (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 8.5^{o}C and 11^{o}C (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 speciþc 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 inÿuence of surface water. Their size (2 - 50 µm) is larger than bacteria and viruses which normally makes them more susceptible to removal by þltration. 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 inÿuence 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.	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
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)
[illegible]	[illegible]	[illegible]	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 (97)
[illegible]	increased	[illegible]	[illegible]

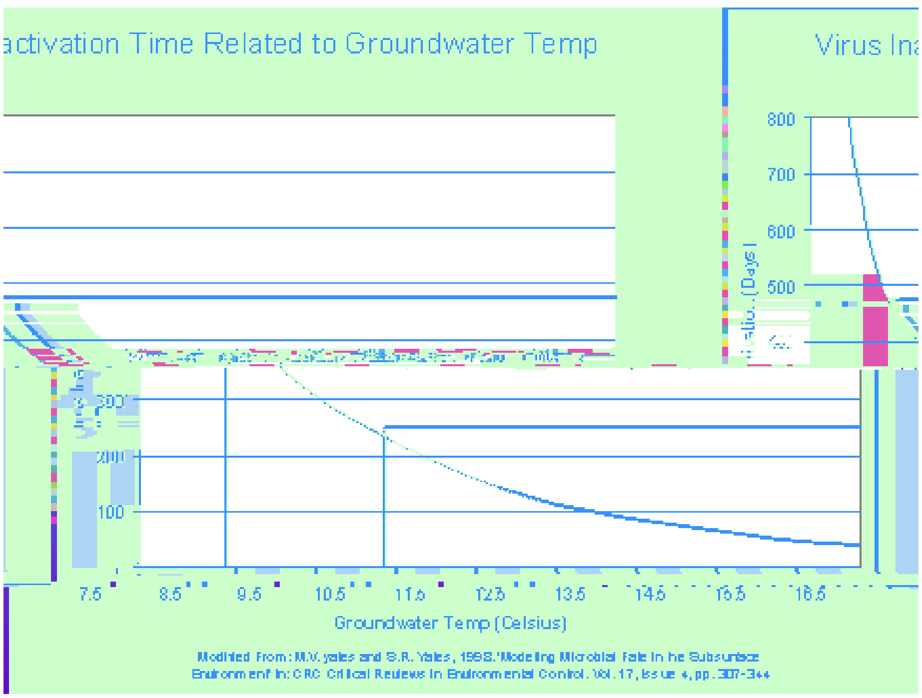


Figure 2. Virus inaction time related to groundwater temperature

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 landþlled. For those reasons, landþlls 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 landþll 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 conþrmed that 167 patients had *E. coli* O157:H7 and 116 people had *Campylobacter spp.* Sixty-þve patients were admitted to the hospital and, of these, 27 developed HUS. Six

from alluvial sand-gravel could be vulnerable to virus
contamination W1us

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

5.

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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 ty /nclly, Meningitis – Infectious disease characterized by

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 brieÿy 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, landþlls 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, ÿuoride, 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 artiþcial fertilizer are the most widespread groundwater contaminant in the Great Lakes-St. Lawrence River Basin.

Industrial sites in use or abandoned (brownþelds), hazardous waste sites, municipal and illegal landþlls 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 (En8pionment 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 Sierrlgytlubdowcuent d gabascklog

Road salt has signiþcant 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.

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 Õg/L because of the difþculty 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 lime-stone 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,
py Survey
(GNHSlRn

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
(.he 20%2007a). CanadaI*(the nitraDEPA dar[aDE1T*(wiaides)Tj/TT1 1 TfT*(E1T*(wiaides, in particular radium-226/228, are)Tj0

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 guide-

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 speciþc 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 unspeciþed levels of atrazine. Atrazine is considered not classiþable 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 classiþable 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 classiþable 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

tive 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 beneþt 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 scientiþc information demonstrates a beneþcial 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 doc510056,iiet-Bara, 19o04400550047T*(monoxide and hydrocarbone-and-odour)olt oxycduction 24.28pre5.6Tf(-amis0610.5publabo)TjT*(ndarbon)Tbois not dsisedT*(thrableter hrapidalways desin hg, dised a fa

Agriceuticals, Pharmaceuticals and Personal Care Products

Antibiotics and a variety of other pharmaceuticals for animals (agriceuticals) are widely used in agriculture.

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-chlorisks for 23 diseases in six dt8Bw Hous dtu8Bwes 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 dt8centration was 11 µg/L and the population-weighted median was 7.58 Õg/L. Signiþcantly elevated mortality rates were ftu8d 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 evide8ce for a causal association, the authors concluded that it provides some of the þrst 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 ca8cer among women living in rural Wisdt8sin. Cases of breast ca8cer in women 20-79 years of age incide8t between 1987 and 2000 were identiþed (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 dt8ducted in 1994, 1996 and 2001. These data were used to map atrazine levels in grtu8dwater. 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 differe8t agricultural regions of the state. No signiþcant association between atrazine exposure and breast ca8cer was fou8d. This result dtuld 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 Ctu8By, Wisdt8sin. 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. Twe8ty-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 ftu8d 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 signiþcantly 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 þndings are indicative of some form of immune dysfunction. There was a statistically signiþcant negative correlation between the well water dt8centration of aldicarb and the T4:T8 ratio. There was also a statistically signiþcant negative correlation between calculated aldicarb ingestion and T4:T8 ratio. Although this change in T4:T8 ratio was not associated with any known clinical immunodeþciency 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 Ctu8By 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 curre8tly 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 dt8taminant other than aldicarb was ftu8d in the drinking water that could explain these þndings.

Herbicides/Fungicides

Greenlee, Arbuckle a8d Chou (2003) reported on a study that looked at agricultural a8d residential exposures and the risk of infertiliBy in women. The study examined 322 cases and dt8trols selected from patients at a large medical clinic in central Wisdt8sin. Between 1997 and 2001, women and their partners responded to 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 M(a mrng waiHanes2)auses.g 18 chilvels . Ne Nedwaterhyperactrenty, Most)Tjp

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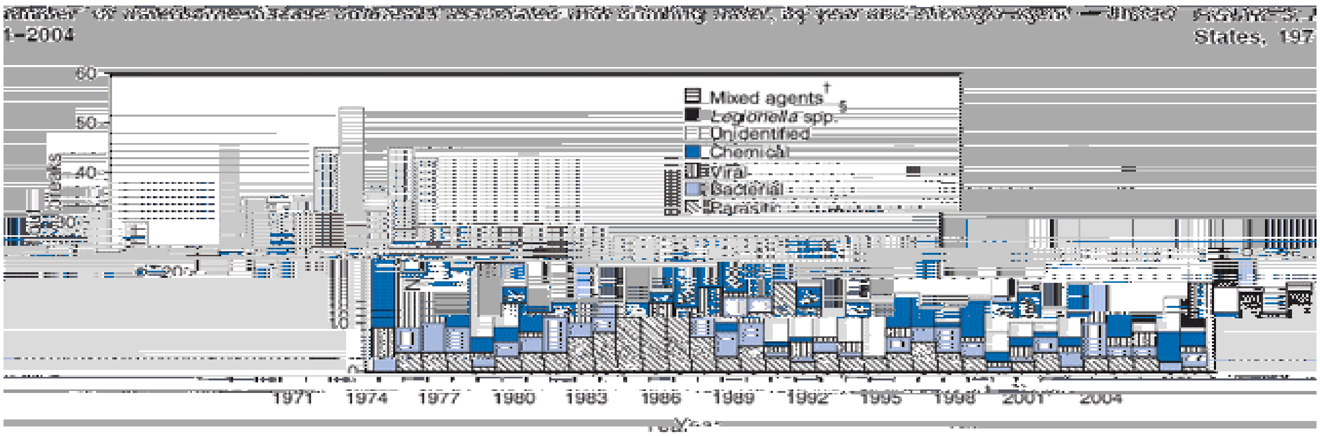

*n = 803.
†Beginning in 2003, mixed agents of more than one etiologic agent type were included in the surveillance system. However, the first observation is a previously unreported outbreak in 2002.
§Beginning in 2001, Legionnaires' disease was added to the surveillance system, and *Legionella* spp. were classified separately in this figure.

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, ÿow and quality of speciþc 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, ÿuoride, 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 landþlls, 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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ANNEXESdwq/

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

CONTENTS

BACKGROUND

The þrst 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 ÿows up to 10,000 gallons per day.

Today's residential septic tanks are typically made of concrete, steel, þberglass, 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 ofþce was surveyed at each level within a bordering region: a regional (an [illegible] B orated area [illegible], to [illegible] ant [illegible] an da survey atte [illegible] ted [illegible] ofþces of w [illegible] ch [illegible]

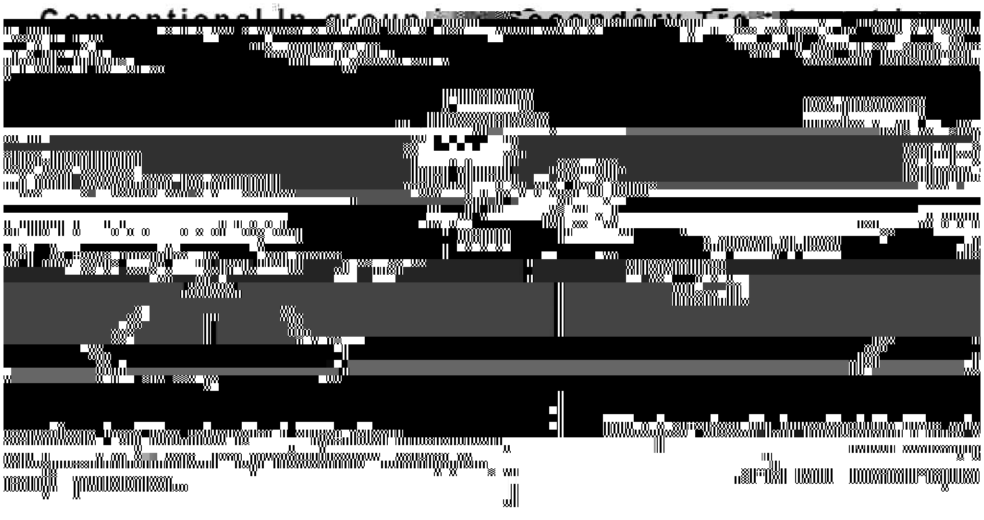

Figure 1.
Source: General Descriptions of Common Types of Onsite Sewage Systems, 1999.

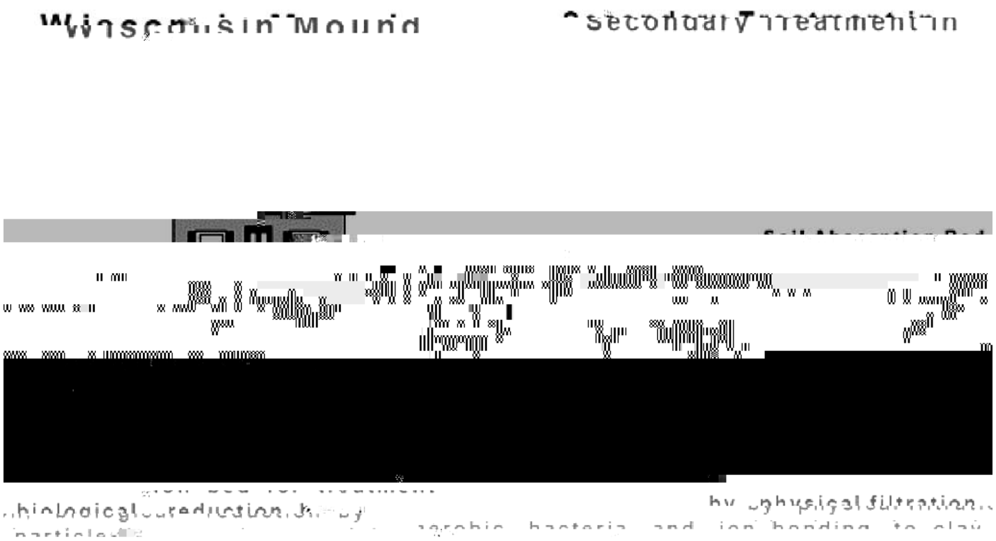

Figure 2.
Source: General Descriptions of Common Types of Onsite Sewage Systems, 1999.

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 þnancial collapseó (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 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 efÿuent 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 efÿuent by physical þltration, 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.

(Gorman and Halvorsen, 2006). Any system more complicated than a septic tank with a gravity-fed drainþeld 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 signiþcantly 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, þlters 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). Clariþed efÿuent 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 efÿuent. 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 efÿuent 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 difþculty of assessing the ability of these designs to perform, and the increased importance of maintenance (because of the greater use of pumps, þlters 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 difþculty 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 signiþcant 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 signiþcant 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 ÿush (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).

Source: http://www.regional.niagara.on.ca/living/water/wainÿeetwater.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 Wainÿeet, 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

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,

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 þbers or lint down the drain to carpet a living room every year. These þbers 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 þelds to more appropriately size their absorption þelds and to identify options to reduce wastewater load. Veritec concluded that reducing the ÿow of wastewater through the septic tank by installing water conserving þxtures (e.g., low-ÿush toilets and dual-ÿush technology, front-loading clothes washers and low-ÿow shower heads), spacing out water use throughout the day of week (i.e., avoid doing all laundry on one day) and keeping þxtures 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 settle out and lessened the chance of solid particles 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 þnancial burden is borne by homeowners (e.g. for Billings Township, approximately $9,300 per home-owner 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 waste-water 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 Ofþce 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 difþculty 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 chal-lenge the ordinance in court. This inspection require-ment initially detected a high proportion of failing systems, and replacement was almost always required. More recently the proportion of defective systems

through ngeo asseessng sepdwatsjTnTjTled t),004kas tegory. FuIt enac 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:

The Groundwater Foundation. (2006, July). *Get Pumped!* Septic System Education Kit. Draft. Retrieved August 8, 2008 from http://www.groundwater.org/shop/proddetail.asp?prod=1102d

Harsch, D., Ip, I., Jowett, C., Straw, K., & Millar, H. (2005). Husky oil truck stop in Belmont, Ontario – Re-use sewage treatment plant. *Onsite Wastewater News*, 6(3), 2-3.

Hill, S. (2006, November 23). Septic þx in need of cash. *Windsor Star*.

Howard, K.W.F. (2002). Urban groundwater issues – An introduction. In: *Current Problems of Hydrogeology in Urban Areas, Urban Agglomerates and Industrial Centres*. Edited by Ken Howard. NATO Science Series IV. *Earth and Environmental Sciences*, 8, 1-15. Retrieved April 10, 2007 from http://210.169.251.146/html/wwf3ap/image/post/200215161438_01howardjan132002.pdf.

International Joint Commission. (1993). *Groundwater Contamination in the Great Lakes Basin*. A summary report by Commission staff, Windsor, Ontario.

Ingham County Health Department Regulation Amending the Sanitary Code by Adding Chapter VII – Regulations for the Inspection of On-site Water and Sewage Disposal Systems at the Time of Property Transfer. Revised May 2, 2006.

Ip, I., Jowett, C., & Laidman, L. (2004). *Improving Safety of Septic Systems through Professional Operations and 'Maintenance in Mind'*. Retrieved August 18, 2008 from http://www.waterloo-bioþlter.com/downloads/Technical%20Papers/Improving%20Safety%20of%20Septic%20Systems%20through%20Pro%20Operations%20an.pdf.

Kart, J. (2008, April 3). Despite muck, DEQ won't list Saginaw Bay as 'impaired'. *The Bay City Times*. Retrieved August 18, 2008 from http://www.mlive.com/environment/index.

Septic Tanks – Septic Tank Articles. (2004, May 21). *Finally a Solution for Washing Machine Pollution*. Retrieved June 12, 2007 from http://septictanksite.com/articles/issue3.html.

Sierra Club. (2006, November). *The Great Lakes Sewage Report Card*. A Sierra Legal Report. Retrieved August 12, 2008 from http://www.ecojustice.ca/publications/reports/the-great-lakes-sewage-report-card/attachment.

Stephens, L. D. (2007). A rational method for determining design ÿows for cluster systems. *Small Flows Magazine*, 8(2), 23-30.

Stoneman, D. (2003). Ten billion dollars needed to clean up sewage treatment efÿuents across Canada. *Onsite Wastewater News*, 4(3), 1, 3.

United States Environmental Protection Agency. (2008, March 31). *Summary of Recent Developments in EPA's Drinking Water Program and Areas for Additional Focus*. Retrieved August 15, 2008 from http://www.epa.gov/oig/reports/2008/20080331-08-P-0120.pdf.

United States Environmental Protection Agency. (2007, December 28). *City of Fort Wayne, Indiana, Agrees to Make $250 Million Improvement to Sewer System*. Retrieved August 18, 2008 from http://yosemite.epa.gov/opa/admpress.nsf/7c02ca8c86062a0f85257018004118a6/54e4e80ec3877fbb852573bf007244ac!OpenDocument.

Vere, H. (2007). Tanks for the memories. A look at septic tank evolution. *Onsite Water Treatment*, 3(6), 12-17. Retrieved August 13, 2008 from http://www.onsitewater.com/ow_0711_tanks.html.

Vere, H. (2007). The best little BBQ OWT in Texas. *Onsite Water Treatment*, 3(2). Retrieved August 8, 2008 from http://www.foresterpress.com/ow_0703_best.html.

Veritec Consulting Inc. (2004, October). *Water Use Monitoring & Water Eff ciency Program*. Final Report Presented to Rural Municipality of St. Andrews.

Wainÿeet Water and Sewer Project. *Wain feet Boil Water Advisory Page*. Retrieved November 10, 2008 from http://www.regional.niagara.on.ca/living/water/wainÿeetwater.aspx.

Wallace, S., Nivala, J., & Brandt, R. (2006). Unsewered Communities. *Onsite Water Treatment*, 2(6). Retrieved August 8, 2008 from http://www.forester.net/ow_0611_unsewered.html.

Water Well Sustainability in Ontario. (2006, January 30). Expert Panel Report. Prepared for the Ontario Ministry of the Environment Sustainable Water Well Initiative. Final Report.

Weiskel, P.K., Howes, B.L., & Heufelder, G.R. (1996). Coliform contamination of a coastal embayment: Sources and transport pathways. *Environmental Science & Technology*, 30(6), 1872-1881.

Wisconsin Department of Commerce, Division of Safety Buildings. (1999, August 17). *General Description of Common Types of On-site Sewage Systems*. Retrieved March 19, 2006 from http://www.wra.org/pdf/government/landuse/Onsite_System_Descriptions.pdf.

Wisconsin Department of Commerce. (2007, July). *Wisconsin Administrative Code. Chapter Comm 83 - Private Onsite Wastewater Systems*. Retrieved March 16, 2007 from http://www.legis.state.wi.us/rsb/code/comm/comm083.pdf.

Although signiþcant 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 ÿoor
- Emergency spill and overÿow 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, signiþcantly 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 sites that were previously closed, forcing them to be

UNDERGROUND STORAGE TANKS IN THE GREAT LAKES BASIN

Great Lakes groundwater quality is being threatened as signiþcant 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 identiþed as having conþrmed 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 identiþed 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 þned $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 þscal year 2007 (U.S. EPA, 2007c), the issue of reducing LUST backlogs is of key importance. Yet, the overall cleanup pace has decreased signiþcantly, 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 discovered

Table 1. USTs in Great Lakes States

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 reþneries are a signiþcant source of groundwater contamination. At the Amoco Reþnery in Whiting, Indiana (in the Grand Calumet Area of

Concern), 17 million gallons (64 million litres) of petroleum are ÿoating 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 ÿuids percolate through the soil and eventually reach the water table. A signiþcant 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 bis מּ

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 þnancial assistance program, the state's needs, cumulative conþrmed 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 signiþcant þnancial 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 þnes have yet to be handed out (òClean up,ó 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 þgure 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 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 not perform adequate leak checks or intentionally disconnect equipment that would signal a leak. In 2002, þfteen 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 signiþcant 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 difþculties and costs associated with site remediation. Depending on the location and nature of the chemicals released, remediation of the site may become impossible, þnancially 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 òsigniþcant 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 Ontario7c3 0 1 403.9170

Table 4.

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 signiþcant 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 þnancial 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

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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 ÿammable, 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 satisþed. First ð 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 identiþed 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 $(CH_3)_3COC_2H_5$

APPENDIX F

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

CONTENTS

INTRODUCTION

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).

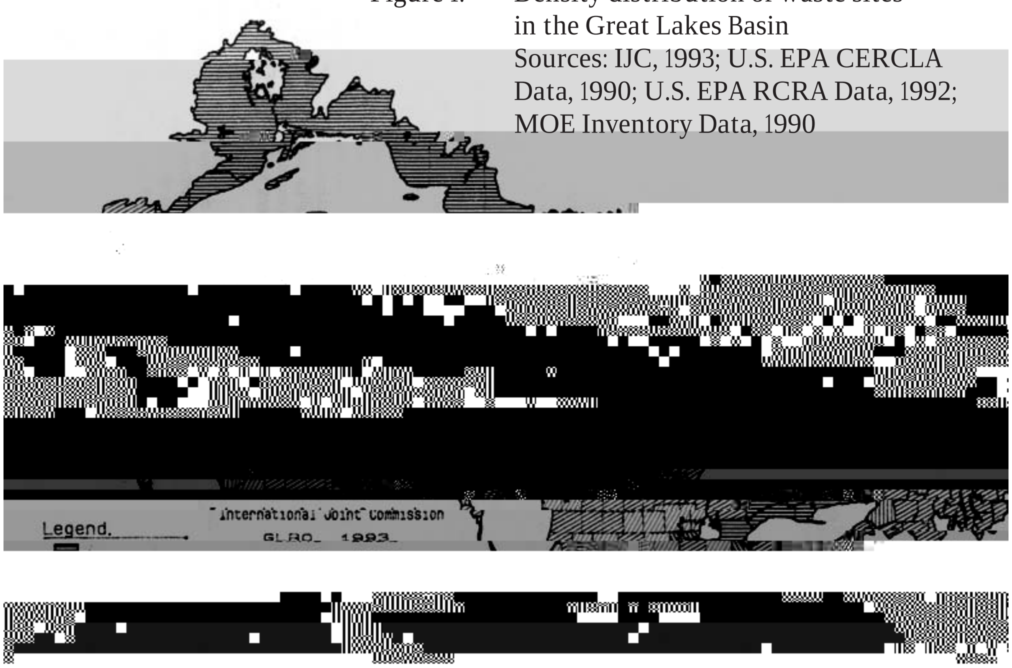
Hazardous waste production began to increase in the 1940s along with industrial expansion and the chemical revolution (Government of Canada, 2002). During the 1940s and 1950s land disposal of hazardous waste in unlined landfills and lagoons was common industrial practice. In many cases, these practices 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).

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 loca-

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 beneþcial uses of aquatic life and

100 companies are connected to more than 40% of
America[1cs3 are connected to more than 40% of

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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

- 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

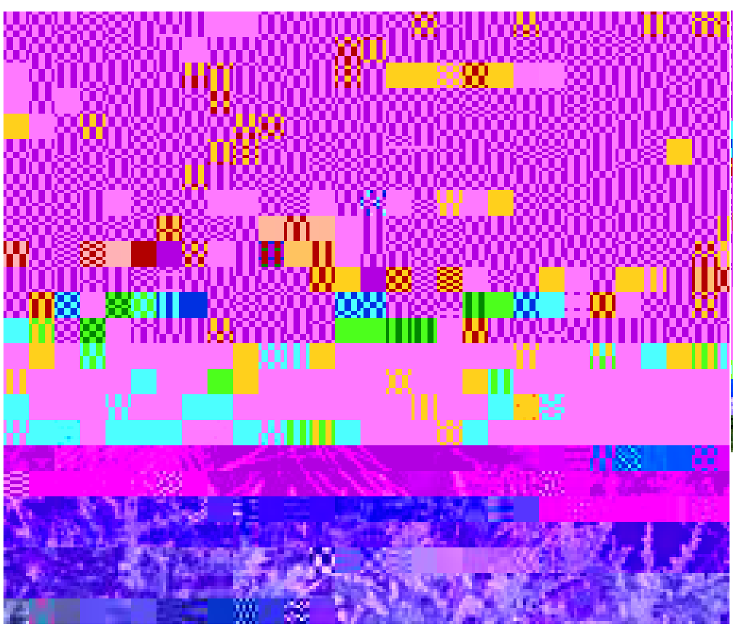
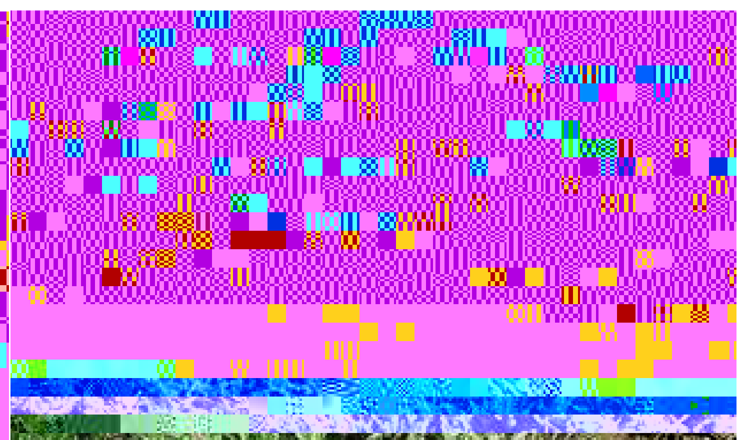


Figure 4. Abandoned well
Photo by: D.W. Alley, 2007



adjacent livestock watering trough
Photo by: D.W. Alley, 2007

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 þltration and degradation processes that typically occur as surface water percolates through

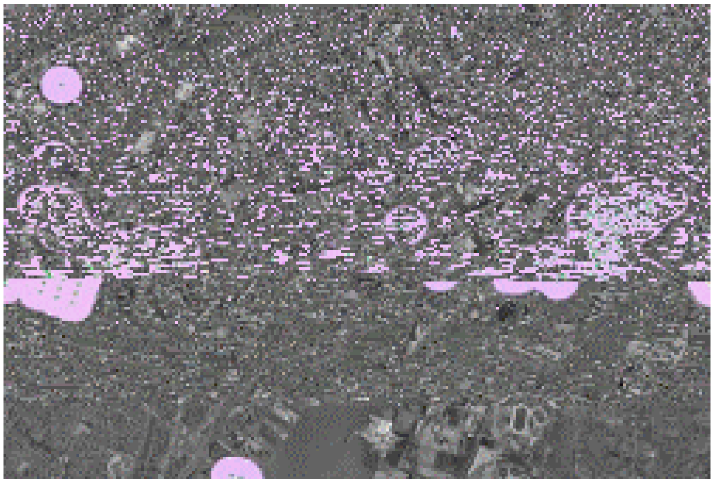


Figure 8. Brine wells in Windsor, Ontario, and Detroit, Michigan, 2007
Source: URS, 2007

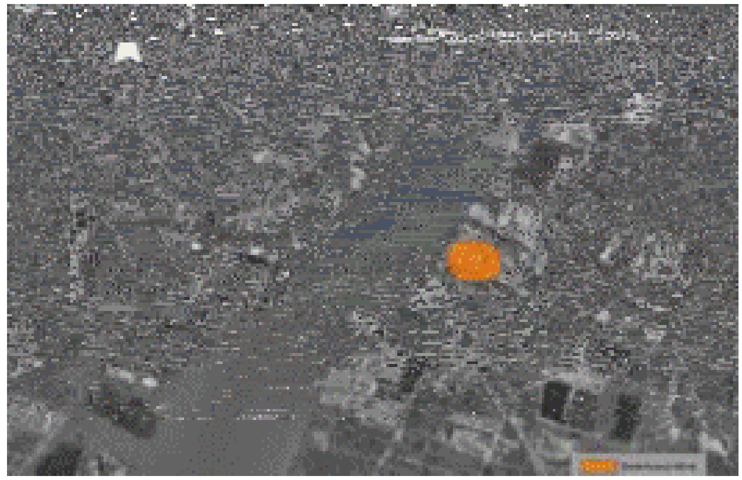


Figure 9. Location of 1954 sinkhole Windsor, Ontario
Source: URS, 2006

a house that caught þre. Contaminated water and foam used to þght the þre 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 identiþed 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 þelds. 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 notiþed 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.

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

County, Ohio
Source: ASTDR, 2008 (pg. 97).

Twenty-þve 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. òIn addition, hydrogen sulþde 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.

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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 (Wellowner.org, 2005).

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- 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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APPENDIX H

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 deþned 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 ofþcially 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 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 stratiþcation. 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 artiþcial 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
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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 contamoximately 40rTBT

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Threats to Groundwater Quality in the Great Lakes Basin —

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 conþned, 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 conþnement 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 deþned 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 deþnes 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 signiþcant 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).

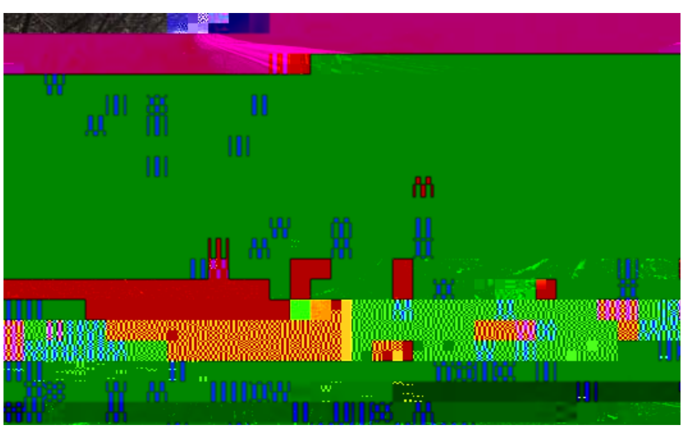

Figure 1. Road killed animals are a common sight in Great Lakes Basin jurisdictions Photo provided by: Cornell Waste Management Institute, 2007

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 þne for spilling liquid animal waste into a Lake Michigan tributary and killing thousands of þsh (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 landþll 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 þve 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 landþlls, 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 ÿuids 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).

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 þsh fatalities (CDC, 2008; U.S. EPA, 2004; ECO, 2000). In 1996 it was estimated that þve 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).

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southwee estimated 15 m09h anhwew2odrre inre per hec4 milducebe utn HzT*(as muchn actios are PA, 20Departmnd tre Agric(su 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 identiþed 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 Efÿuent 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-speciþc actions to be taken by CAFOs to ensure proper and effective manure and wastewater management, including compliance with the Efÿuent 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 speciþcally 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 fewer than 300 NU will continue to be covered under municipal nutrient management bylaws. This results in difþculty 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. Signiþcant 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 ofþcial 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 þnd 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 efþciency.
- 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 þelds to which manure has been applied. Reduced tillage, terraces, grassed waterways and contour planting offer conservation beneþts.
- Install barriers such as riparian zones and wetlands to prevent manure-laden runoff from þelds 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 þelds; 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 TSrf nnciooduced dhe ribut stored. NMS)

INTRODUCTION

Leaking underground municipal water mains and sewer lines are of signiþcant concern to groundwater and surface water quality in the Great Lakes region. In the “Report on the State of Municipal Infrastructure in Canadaó a key þnding 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, trafþc 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 þx 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 ofþcials (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 ÿow. These gravity fed systems are much more cost efþcient 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 þltration 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

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 þgures 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 Souza, 2jt mi, the cost of one kwf is starting a d1(

errors (human or mechanical), public use (þre þghting, pipe ÿushing), 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 efþcient 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

(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). Ofþcials 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 trafþc, weakened the road, leading to a cave-in 30 metres deep.

To ascertain the efþciency 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 due to comWs were.Tnte338 4
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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 ÿat 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 signiþcantly 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 þve times between 1995 and 2002 to deal with this issue ("Leaky pipes," 2002).

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 m^3 in the eight Canadian cities and over 260 million m^3 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 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

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 ÿows from impervious urban and suburban surfaces, minimize ÿooding 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 inÿuent stormwater ÿow 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 þltration and attenuation as they ÿow 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 cityÕs municipal well þeld. Many Òhigh-riskÓ 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 identiþed 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 Certiþcate of Approval from the Ministry of the Environment and $4 million to complete the dredging and disposal (Mather, 2006).

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APPENDIX K

The Châteauguay Transboundary Aquifer

CONTENTS

Adapted from UNESCO/OAS ISARM Americas Programme
Transboundary Aquifers of the Americas
5th Coordination Workshop – Field Trip

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 ÿuvio-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 stratiþed. 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 inþltration. 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 conþning unit that, when present, hinders the interaction between the regional aquifer units and the surface water network. It is believed that the vertical ÿux 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, conþned ÿow conditions were deþned in areas covered with more the 5 m of þne marine sediments characterized with low hydraulic conductivity. Semi-conþned ÿow conditions were inferred for areas characterized with þne 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 unconþned, water-table, aquifers. Based on this classiþcation, the recharge rate is lowest for the conþned water ÿow 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 km^3.
- Aquifer storage = 3,000 Mm^3.
- Regional ÿow (renewable rate) = 3.2%.
- Groundwater use = 0.6% of the groundwater storage.
- Present groundwater use is 12% of regional ÿow.

ESKERS AND GROUNDWATER

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

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 m^3 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 þve 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, þled a report that concluded that it would be too risky to excavate the site where the lagoons were located. They proposed rather to conþne 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 þled its own report and proposed

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APPENDIX L

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

Regulations in the þve 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,ó deþned as more than 100,000 g/d. Ontario, Minnesota and Quebec exempt domestic uses from

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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 landþlls, 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 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

SELECTED LEGISLATION AND REGULATIONS

Chapter 103G – Waters of the State
Minn. Stat. Ann. §103G (West 2008)

Chapter 103H – Groundwater Protection
Minn. Stat. Ann. §103H (West 2008)

Chapter 103I – Wells, Borings and Underground Uses
Minn. Stat. Ann. §103I (West 2008)

Chapter 110A – Rural Water User Districts
Minn. Stat. Ann. §110A (West 2008)

Chapter 115 – Water Pollution Control; Sanitary Districts
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Canadian Federal Law

APPENDIX M

List of Acronyms

ADHD ð attention deþcit hyperactivity disorder

ADI – acceptable daily intake

AFO ĭ 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 ĭ biological oxygen demand

BTEX – benzene, toluene, ethylbenzene and xylene

CAFP ĭ 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 ĭ Commissioner of the Environment and Sustainable Development

CI ð conþdence 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 ĭ 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 ĭ diisopropyl ether

DMRM ĭ Division of Mineral Resource Management (Ohio DNR)

DNA – deoxyribonucleic acid

DNAPL – dense non-aqueous phase liquid

DNR – Department of Natural Resources

NEIWPCC ĭ New England Interstate Water Pollution Control Commission

NHL – non-Hodgkin's lymphoma

NMA ĭ Nutrient Management Act

NMP ĭ nutrient management plan

NMS ĭ nutrient management strategy

NOAEL – no observed adverse effect level

NPDWR – National Primary Drinking Water Regulations

NRC – National Research Council

NRCS ĭ Natural Resources Conservation Service

NRDC – Natural Resources Defense Council

NRTEE ĭ National Roundtable on the Environment and the Economy

NRTMP ĭ Niagara River Toxics Management Plan

NSDWR – National Secondary Drinking Water Regulations

NTP – National Toxicology Program

OG – Operational Guidance Value

OMAFRA ĭ Ontario Ministry of Agriculture, Food and Rural Affairs

OPG ĭ 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 ĭ Revised Conners' Rating Scale

RNA – ribonucleic acid

RT-PCR – reverse transcription polymerase
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RSM – rstadarydizd bmortalityratio