LINKING SCIENCE AND POLICY FOR URBAN NONPOINT SOURCE POLLUTION
IN THE GREAT LAKES REGION

November 2002

International Association for Great Lakes Research

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EXECUTIVE SUMMARY

While some environmental problems in the Great Lakes have been ameliorated in the last few decades, others have not. One problem that still resists solution is urban nonpoint source pollution: contaminated runoff from impervious surfaces (such as roads, parking lots, and roofs), and from other sources, such as lawns and construction sites. This form of pollution is rooted in fundamental aspects of the North American way of life, particularly the expansion of low-density suburban areas, much of which consists of impervious, contaminated surfaces or lawns.

Just as the origins of nonpoint source urban pollution are diffused across the landscape, so too is responsibility. Regulation of urban development largely rests with hundreds of municipalities or other regional bodies within the Great Lakes region. These are often poorly equipped to adopt a broad, ecosystem perspective to the issue; they also often lack the expertise necessary to understand the problem or to regulate its sources effectively.

The complexity of the problem, and the lack of capacity of many of the responsible agencies, pose a special challenge for science. Much scientific information is available regarding nonpoint source pollution: its sources, control, and remediation. There are also numerous scientific uncertainties. But attention needs to be focused not simply on research or information needs, but on identifying problems in the linkage between scientific information and land use decisions more generally.

In particular, the role of science in encouraging more innovative forms of urban development that can reduce nonpoint source pollution needs to be considered. Such forms—often under the rubric of "smart growth"—are more compact, efficient and environmentally sustainable than conventional suburban development. These virtues of smart growth have been widely noted, but the political and economic will to actually implement this form of development is often lacking.

A case study of an environmental controversy involving suburban development on the Oak Ridges Moraine, north of Toronto, illustrates some of the obstacles to smart growth, and the role that science might play in overcoming these obstacles. In particular, it highlights how science can contribute to broadening the basis for environmental protection, beyond managerial and technical approaches, by empowering communities to understand, and to protect their local environment, fostering a civic environmentalism.

To extend our understanding of the issues raised by this pilot study, and to further the objectives of the IAGLR/Joyce Foundation project on science and policy, IAGLR should consider partnerships with local agencies responsible for nonpoint source pollution. These partnerships—perhaps focused on two or three specific sites within the Great Lakes basin—would explore in more detail the factors that affect adoption of sustainable urban development patterns, and IAGLR's potential contribution to improving the effectiveness of science in the urban development process.

Other key conclusions and recommendations include:

- Urban nonpoint source pollution constitutes one of the most complex—scientifically and politically—environmental challenges facing the Great Lakes community.
- Some aspects of urban nonpoint source pollution can be ameliorated through managerial or technological strategies and practices. However the problem is also rooted in basic aspects of North American society, including dominant patterns of low-density suburban development. Therefore, political, as well as technical, solutions are required. Science can play a role in facilitating both kinds of solutions.
- Effective management of urban nonpoint source pollution requires a variety of approaches to research: basic research to identify emerging problems (such as the input of pharmaceutical products into waterways); focused research on managerial and technological innovations, with a view to continual improvement of BMPs; research aimed at perfecting selected environmental indicators, particularly those that allow for comparison with national and international trends, as well as a steady, sustained commitment to monitoring; and public communication and involvement in science, including community monitoring activities.
- Management of urban nonpoint source pollution is highly fragmented, discouraging ecosystem or watershed-based approaches. To be effective, solutions require coordination amongst a diverse array of agencies at the binational, federal, state/provincial and local levels. Efforts to improve scientific research and information dissemination must therefore be designed to encourage this coordination; ideally, science—through provision of an agreed-upon knowledge base—can provide a basis for interagency cooperation. The binational experience may be a useful source of models for cooperation at the local level on nonpoint source pollution.
- There is an essential role for senior governments in the science of urban nonpoint source pollution, both in requiring better coordination and planning at the local level, and in facilitating this with appropriate assistance: by conducting research, enhancing the capabilities of local governments to do their own research, and disseminating research results more widely to local staff (e.g. through training) and to the general public.
- Efforts to communicate scientific information to policymakers and other audiences should be informed by an understanding of the political and institutional contexts in which that information is applied, including the political

and economic obstacles to effective environmental protection. These communication efforts should especially ensure that scientific information is available to all members of a community.

- The assumptions that guide the application of scientific information to political and managerial decision-making—for example, regarding the appropriateness of the precautionary principle—must themselves be openly examined as an element of the decision-making process.
- More research on the benefits, economic or otherwise, of nonpoint source pollution control would be beneficial, to contribute to political support for control initiatives.

I. INTRODUCTION

Over the last century the Great Lakes have been subjected to many impacts from human activities: the release of nutrients and contaminants; resource harvesting, especially of fish; transformation of wetlands and other habitats; and entry, by accident or design, of nonindigenous species. But there has been progress in addressing these impacts: the lakes are in several ways cleaner today than they were in the 1960s, while awareness of the benefits of intact natural ecosystems and vigilance with respect to invasive species have increased.

One problem, however, remains unresolved, and indeed may have become worse in the last three decades: urban nonpoint source pollution (defined as urban runoff discharged into receiving waters in either of two forms: stormwater discharges from storm sewers, or overflows from combined sewer systems [Marsalek and Ng 1989]). This form of pollution has many origins. Contaminants generated in diverse ways—from atmospheric deposition to disintegrating tires—accumulate on impervious surfaces, and are then washed into streams and lakes. Septic systems release effluent. Millions of lawns are treated with pesticides and herbicides, much of which travels more widely.

Nonpoint source pollution from urban areas poses unique challenges. Most obviously, there are countless sources. Even more significantly, these sources cannot readily be eliminated, or cured through some "magic bullet". A variety of strategies have been developed to deal with nonpoint source pollution—some effective, others, less so. But this form of pollution is also rooted in fundamental aspects of the North American way of life: the expansion of low-density suburban areas; the fact that much of these areas consists of impervious, contaminated surfaces; and the transformation of natural habitats into suburban lawns, often drenched in herbicides and pesticides.

Just as the origins of nonpoint source urban pollution are diffused across the landscape, so too is responsibility for the problem. Regulation of urban development largely rests with hundreds of municipalities or other regional bodies within the Great Lakes region. These are often poorly equipped to adopt a broad, ecosystem perspective to the issue;

they also often lack the expertise necessary to understand the problem or to regulate its sources effectively.

Given the complexity of the problem, and the lack of capacity of many of the responsible agencies, the challenge of using science effectively is an especially critical one. Attention needs to be focused not simply on research or information needs with respect to managing urban nonpoint source pollution, but on identifying problems in the linkage between scientific information and land use decisions more generally.

This document will focus on this challenge of ensuring effective links between science and land use policy: connecting what we know, with what we do. We will begin with an overview of urban development and its impacts in the Great Lakes region, and of responses to this issue. Available scientific information will then be surveyed, identifying significant uncertainties and information gaps. The prospects for applying this information to reducing the impacts of development will then be considered. Challenges in linking science with land use policy are then examined. First, general challenges evident across the Great Lakes region are identified. Second, a specific case study, that of urban land use decisions on the Oak Ridges Moraine, north of Toronto, is examined, in order to understand how scientific information is drawn on in suburban land use decisions. The choice of this case study was guided by the view that these challenges can only be fully understood within their specific local political and ecological contexts. The report concludes with recommendations for improving the science-policy link with respect to urban nonpoint source pollution.

II. BACKGROUND INFORMATION

1. How significant is urban development in the Great Lakes region?

Recent population growth in the Great Lakes region has been accompanied by massive suburban development. Today, more than 33 million people live in the region; four-fifths of them in 17 metropolitan areas (Thorp et al. 1997: 3). While the population has increased quite slowly since World War II, the area occupied by this population has grown much more quickly. In southeast Michigan, a 1.6 percent increase in population increased urbanized land by 28 percent. From 1970 to 1990 the Chicago metropolitan area grew in population by four percent, but spread out across 35 percent more land (www.glc.org/bridges/sprawl/). These trends are expected to continue. By 2020 the population of greater Toronto is expected to grow by two million – and an additional 600 square kilometers will be developed. In Michigan it is predicted that a state population increase of 12 percent by 2020 may be accompanied by an 87 percent increase in developed land (Thorp et al. 1997: 4).

This rapid expansion of developed land, far outstripping population growth, reflects the significance of suburbia as, ever since World War II, the predominant form of urban expansion. Several features are characteristic of this urban form: low-density residential and commercial development, segregated land uses, reliance on the automobile (implying substantial infrastructure and energy requirements), and substantial ecological costs.

Both citizens and policymakers are expressing increasing concerns regarding the environmental implications of suburban development. These implications include loss of agricultural land and natural habitats, deterioration of wildlife populations and of rural human communities, heavy demands on energy and other resources, and air pollution generated by motor vehicles. Of particular relevance, however, is the significance of this form of development as a generator of nonpoint source pollution.

2. What are the impacts of urban development on Great Lakes water quality?

Some of the most pervasive effects of urban development are on water quality and quantity, as a result of replacement of the natural landscape with pavement and other impervious materials. Such surfaces "interrupt the hydrologic cycle, alter stream structure, and degrade the chemical profile of the water that flows through streams. These changes affect fish and wildlife in various ways, and are cumulative within watersheds" (Heinz Center 2002: 266-267). A recent report sponsored by several environmental organizations found that across the United States unchecked suburban development has had a significant impact on water supplies, sending water into streams and rivers as polluted runoff, rather than filtering it through the soil to recharge groundwater aquifers (American Rivers, et al., 2002). Increased urbanization, resulting in a higher proportion of the basin land surface being impermeable to rainfall and runoff, is one of the most important environmental trends now occurring in the Great Lakes region. As little as 10 percent impervious cover can substantially affect the amount of rainfall that filters into the soil, causing reduced groundwater recharge, increased flooding and bank erosion, and diminished stream stability (GLSAB 2000: 4). In summary, then, urban development substantially modifies the hydrological cycle (Figure 1); the environmental implications of this modification are diverse and pervasive.

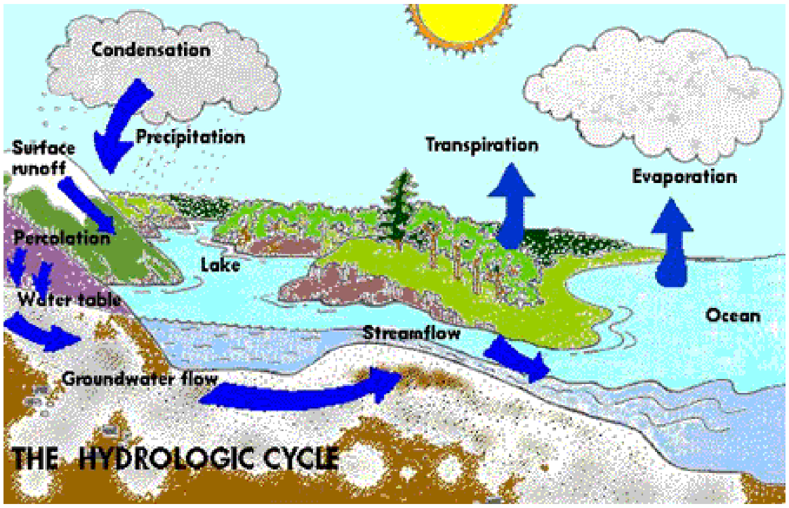

Figure 1: The Hydrologic Cycle
(Source: Environment Canada, The Hydrologic Cycle)

Urban development affects water quality in a variety of ways. Although phosphorus levels have generally decreased to target levels set by the Great Lakes Water Quality Agreement, the nutrient problem is far from resolved. Nitrogen levels in the water column have remained unchanged and soil phosphorus levels continue to increase (GLSAB 2000: 5). In 1995, the Ontario Ministry of the Environment found that the algae Cladophora exhibited continued growth in 16 areas of Lake Erie, and shoreline fouling was observed at four points between Fort Erie and Port Dover (Edsall and Charlton 1997: 59). While sources such as agricultural fertilizers and household detergents have been brought under control, excessive nutrient loads continue to make their way into the Great Lakes. Three urban nonpoint sources appear most significant: atmospheric deposition and subsequent runoff from impervious surfaces, septic system effluent, and lawn fertilization. Of these, atmospheric deposition and runoff is most significant, responsible for 70 to 95 percent of nitrogen, and 20 to 35 percent of phosphorus in urban runoff (Schueler and Caraco 2000: 12).

Urban areas are also partly responsible for elevated contaminant levels in streams and lakes. Roads, parking lots and other impervious surfaces can trap and store volatile organic compounds (VOC's) in porous concrete and asphalt. These are then collected in storm water and rinsed into nearby streams and lakes (Lopes et al. 2000). Other contaminants commonly in urban runoff include zinc, cadmium, copper and PAHs. The Nationwide Urban Runoff Program of the early 1980s found that in many instances concentrations of heavy metals in urban runoff exceed EPA ambient water quality criteria and drinking water standards (Tsanis et al. 1994). Other urban sources of toxic substances include atmospheric deposition and lawn pesticides (IJC 2000: 30). Winter road salt can increase both sodium and chloride levels in water, generating human health concerns (Howard et al. 1993).

Over the last decade pathogenic microorganisms have re-emerged as a significant water quality concern. Since 1990 there have been three major outbreaks of illness as a result of contaminated drinking water. Over 4,000 Milwaukee residents were hospitalized after infection with the parasite Cryptosporidium, while a similar outbreak in Kitchener-Waterloo, Ontario resulted in 200 cases (Edsall and Charlton 1997). Most recently, an outbreak of Escherichia coli in Walkerton, Ontario, claimed seven lives and made over 2,300 ill (O'Connor 2002). The causes of these disease outbreaks are not yet entirely understood, although agricultural sources were likely most significant. But these outbreaks also drew attention to the fact that even after decades of investment, urban sewage systems continue to contribute to hazardous levels of bacteria in the Great Lakes. Many cities continue to use Combined Sewer Overflows, which carry both storm water and household wastewater. At times of heavy rain these systems allow wastewater (including sewage) to overflow into waterways (Lampe et al. 1996). Urban runoff contributes to this problem. City storm systems are designed to remove water quickly from built-up areas. But the network of impervious surfaces used to divert storm water into waterways also collects dirt, trash, sediment and animal feces, degrading water quality (GLSAB 2000). Non-human sources may play a large role in elevated bacterial levels in the Great Lakes. Animal feces, especially of cats and dogs, but also of urban wild animals such as raccoons, can have a major impact on water quality.

Studies suggest that as much as 95 percent of coliform in the Great Lakes is from non-human sources.

Finally, increased sedimentation originates, in part, from urban areas. Urban development, and accompanying transportation and storm water infrastructure, tends to transform the hydrological cycle, increasing water runoff into streams and decreasing infiltration into soil. At times of peak flow, this can lead to formation of temporary channels that erode stream banks, depositing sediment downstream or in the lakes themselves. Sediment from construction sites is particularly significant: suspended solids concentrations are often higher near construction sites than anywhere else. The impacts on streams from construction can be severe: "trees and topsoil are removed, soils are exposed to erosion, steep slopes are cut, natural topography and drainage are altered, and sensitive areas are often disturbed" (Schueler and Caraco 2000: 20).

3. How has the Great Lakes policy community responded to this issue?

The foundation for a binational approach to nonpoint source pollutants is the Great Lakes Water Quality Agreement. The GLWQA led to creation of the IJC Water Quality Board and the Science Advisory Board, and, ultimately, to the Pollution from Land Use Activities Reference Group (PLUARG). PLUARG was the first binational panel to explicitly acknowledge the link between urbanization and water quality problems.

Since the 1970s the legal basis for binational cooperation has continued to evolve. Nonpoint source pollution from urban areas is addressed through two annexes of the GLQWA. Annex 3 relates to the control of phosphorus, and includes among its provisions the requirement to undertake nonpoint source programs and measures, including urban drainage management control programs, extending to either level 1 (e.g. erosion controls, use of natural storage capacities and street cleaning), or level 2 measures (e.g. artificial detention and sedimentation of stormwater and runoff and reduction of phosphorus in combined sewer overflows). Annex 13—Pollution from Nonpoint Sources—specifies that Parties are required to identify land-based activities contributing to water quality problems in Remedial Action Plans and Lakewide Management Plans, and to develop and implement watershed plans. Significant progress was made in addressing nonpoint sources in the 1980s (especially from agricultural activities, through such innovations as conservation tillage), but progress has since slowed (GLSAB 2000: 3). According to Kellogg (1997), integration of land use concerns within Remedial Action Plans has been inconsistent.

More generally, there is growing interest in alternatives to low-density suburban development. Much of this interest has focused on "smart growth," defined as an approach to city planning that "aims to continue to provide the jobs, tax revenues and amenities that growth and development provide without degrading the environment, raising local taxes, increasing traffic congestion or breaking local government budgets. Smart growth strives to restore community and vitality to center cities and older suburbs and encourages more town-centered and pedestrian-oriented new development and transit." Ten principles of smart growth have been widely endorsed:

1. Mix land uses.
2. Take advantage of compact building design.
3. Create a range of housing opportunities and choices.
4. Foster walkable, close-knit neighborhoods.
5. Promote distinctive, attractive communities with a strong sense of place.
6. Preserve open space, farmland, natural beauty, and critical environmental areas.
7. Strengthen and direct development toward existing communities.
8. Provide a variety of transportation choices.
9. Make development decisions predictable, fair, and cost-effective.
10. Encourage citizen and stakeholder participation in development decisions.
(see: www.smartgrowthamerica.org)

A variety of smart growth initiatives are underway across the Great Lakes region, predominately at the state/provincial level (see: (www.glc.org/bridges/smartgrowth/).

Two important political dimensions of suburban development must be emphasized. First, the primary location of policy action on urban nonpoint source pollution, and urban development generally, is not at the federal or state/provincial level, but at the local level: in municipal and regional governments. This implies a highly fragmented responsibility for urban water quality. It also implies that those agencies with the most scientific expertise, such as the Environmental Protection Agency and Environment Canada, have no direct jurisdiction over the issue. Second, powerful forces continue to resist changes in suburban development patterns: many municipalities encourage growth as a means of increasing tax revenues, landowners often oppose efforts to control or redirect development, and continuing consumer demand for single-family housing encourages further suburban expansion.

III. SCIENTIFIC INFORMATION AND ITS APPLICATION

1. Current knowledge regarding water quality and urban development

Scientific research regarding urban development and water quality must meet several requirements. It must be relevant to existing management and policy priorities. It must also be open to changing conditions, including new knowledge, changing management priorities, and emerging environmental conditions. The capacity of science to respond to immediate priorities while building a long-term understanding is evident in the recent history of research on nonpoint source pollution.

PLUARG

PLUARG (Pollution from Land Use Activities Reference Group) was one of the first significant acknowledgements of the need to move beyond point sources of pollution, to consider nonpoint sources, such as agricultural fields, paved roads, and even the atmosphere (PLUARG 1978). The study also reflected the dominant concerns of Great Lakes region residents in the 1970s, in its primary focus on eutrophication and toxic substances. By 1976 phosphorus loadings had exceeded recommended levels in every lake, with approximately 30 to 40 percent of this from municipal sewage and industrial effluents from urban areas (PLUARG 1978: 4). Other pollutants were also noted, including sediment, mercury, lead, pesticides and PCBs. Microorganisms were described as a potential health threat, and it was noted that between 1975 and 1977 there had been 18 beach closings in Canada due to bacterial levels (PLUARG 1978: 40). Nevertheless, PLUARG viewed microorganisms as primarily a small, local problem (PLUARG 1978: 19).

While devoting much of its attention, including recommendations for remedial action, to agriculture and forestry, PLUARG did consider urban development and its effects on water quality, noting that impervious surfaces such as roads and buildings alter regional hydrology, and that this has consequences in terms of nonpoint pollution. Developing urban land was identified as a significant source of several pollutants; in particular, it contributed per hectare nearly five times as much suspended solids as any other land use (Kellogg 1997). The study group also suggested that governments develop management plans for urban storm water runoff, to maintain natural stream flow and control the flow of sediment and toxics from commercial and industrial areas (PLUARG 1978: 5-6).

PLUARG noted that lack of research on urbanization had inhibited political action on this source of pollutants. Few studies had addressed pollution in coastal areas resulting from land use activities, and only a handful of studies had taken an "holistic approach" to water quality. In particular, PLUARG's final report noted the need for a more precise definition of pollution, for more research on the movement of phosphorus, heavy metals and other toxics from land use activities to water bodies, and for greater knowledge of tolerable waste loads in the Great Lakes (PLUARG 1978).

Research and understanding since PLUARG

Some problems identified by PLUARG remain, including excess nutrient loads and contaminants, although aspects have been ameliorated. However, developments during the last decade have placed renewed emphasis on issues that PLUARG considered to be of only minor importance, such as microorganisms and sedimentation (IJC 2000: 30).

Most significant has been an orientation of concern from PLUARG's focus on agriculture and forestry, to the effects of urban areas. The first comprehensive effort to describe the quality of urban runoff—the Nationwide Urban Runoff Program—was undertaken soon after PLUARG was completed, in the early 1980s (Schueler and Caraco 2000: 11). The 1996 State of the Lakes Ecosystem Conference (SOLEC) concluded that urban growth and resulting nonpoint source pollution (tied especially to expansion of impervious surfaces) is a major source of stress on the Great Lakes ecosystem. This conclusion was subsequently reaffirmed by the Great Lakes Science Advisory Board (2000).

The major pollutants in urban waterways were summarized by the International Joint Commission (IJC 2000: 30):

Table 1: Urban Pollutants and their Sources

Pollutant Category	Probable Sources
Nutrients	• Atmospheric deposition and washout • Septic system effluent through groundwater or system overflows • Lawn fertilization
Pathogens	• Urban wildlife and domestic pets • Wastewater discharges
Sediment	• Channel erosion from increased storm water runoff due to impervious surfaces • Exposed soils at construction sites • Urban runoff (e.g. tire wear from city streets)
Industrial Chemicals and Pesticides	• Intermittent pulse exposures, often weather-related • Runoff and groundwater contamination from land-based sources, including waste disposal sites

One of the most significant developments in knowledge of the impacts of urban pollution has been elaboration of a broader understanding of its ecosystem context. Much of this understanding was codified in a recent report on the state of knowledge of American ecosystems, prepared by the Heinz Center for Science, Economics and the Environment. This report used 15 indicators to describe the environmental health of urban and suburban areas. Of these, seven are especially relevant to urban nonpoint source pollution and its impacts (Heinz Center 2002: 176):

- **Total impervious area**: How much urban/suburban land is covered with buildings, concrete, asphalt, and other "hard," or impervious, surfaces?
- **Stream bank vegetation**: What fraction of urban/suburban stream banks are vegetated?
- **Nitrate in urban and suburban streams**: How much nitrate is found in urban/suburban streams?
- **Phosphorus in urban and suburban streams**: How much phosphorus is found in urban/suburban streams?
- **Chemical contamination**: What levels of artificial compounds and heavy metals are found in water and soil?
- **Status of animal communities in urban and suburban streams**: What is the condition of fish and bottom-dwelling animals in urban/suburban streams?
- **Natural ecosystem services**: What other important ecosystem services are provided by urban/suburban areas?

Beyond placing urban nonpoint source pollution within an ecosystem context, recent research has identified new concerns. One example is groundwater quality. Although 8.2 million people within the Great Lakes region rely on groundwater as their primary source of drinking water, there are still significant unknowns regarding the effects of land use practices on these water supplies (Grannemann et al. 2000). However, one benefit of recent research employing a broader, ecosystem approach to urban nonpoint source pollution has been a better understanding of the relation between urbanization and groundwater quality. For example, research has elucidated the impact of road salt on Great Lakes water quality, and ultimately, on human health (Howard et al. 1993). The holistic approach of such research (i.e. linking human activity to groundwater pollution, and ultimately to Great Lakes ecosystem health) gives scientists avenues of research that may not be provided through less flexible methods.

As these evolving concerns and priorities suggest, scientists studying water quality must be responsive to changing circumstances. Several significant research issues of the 1960s and 1970s, such as lead contamination, had become virtually nonexistent by the 1990s. Meanwhile, other problems became major issues in nonpoint pollution prevention. For example, PLUARG documents virtually ignored the link between pet feces and elevated levels of microorganisms in Great Lakes water. This has since been recognized as a source of nonpoint pollution requiring additional research.

This illustrates how researchers must be prepared to adapt to new knowledge and changing political priorities in order to continue to provide relevant and meaningful information to decision makers. Given the diffuse sources of nonpoint pollution, and its diverse effects on the Great Lakes ecosystem, it is impossible to predict what issue will become the primary focus of future research. Flexibility in the content and methods of research will ensure that information generated is responsive to rapid urban and suburban change.

Scientific uncertainties and information gaps

Urban pollution presents formidable challenges to researchers. In part, the challenge is one of inadequate information. According to the Heinz Center, available data are not yet adequate to serve as a basis for evaluating many aspects of the urban environment, including the significance of nonpoint source pollution. In particular, the quality of data on which the seven indicators noted above are based varies widely: extensive data are available for nitrate and phosphorus in streams, and some data exist for chemical contamination (although the benchmarks necessary to evaluate the significance of contamination have not been developed for many individual compounds, let alone for mixtures of chemicals or seasonal pulses of high concentrations). The status of animal communities in streams is difficult to evaluate (it involves comparison of each stream with an appropriate reference from within the same region, but outside the urban/suburban area), and is only done in a handful of states. Indicators for stream bank vegetation require further development to allow for national comparisons, and scientists are uncertain about how even to measure ecosystem services in urban ecosystems (Heinz Center 2002).

A particular challenge is posed by the need to identify specific sources of pollutants. There are countless such sources, and their significance varies with the season (Hirsch et al. 2001). While scientists are able to identify sources of pollutants in terms of general land use categories, identifying the specific pathways by which pollutants travel, as well as characterizing the significance of the frequency and intensity of activities that lead to production of pollutants, is much more difficult (Marsalek and Ng 1989). A great deal of research is required to determine the quantity of nutrients released from each source, and how they are transported from urban areas to lakes and streams. Some sources have been easier to track than others. For example, it is generally understood how and to what extent nitrous oxide (an airborne pollutant generated by burning fossil fuels) increases nitrogen available to aquatic life. In contrast, little is known regarding the significance of septic system overflows and lawn fertilizers to nutrient levels in water bodies. Although fertilized lawns have a higher concentration of phosphorus than any other source, no scientific studies have convincingly linked fertilization with higher levels of phosphorus in the Great Lakes (Barth 1995, Schueler and Caraco 2000: 13).

There are also several unknowns regarding urban nonpoint sources of toxic substances. Linking their presence to specific sources has been difficult, both because of the many possible local sources (e.g. lawns that receive pesticide applications), as well as the potential significance of atmospheric transport of contaminants from outside the Great Lakes Basin (IJC 2000: 14). While researchers have identified numerous toxic substances and have tracked their origin to general nonpoint sources, they have not been able to determine the relative significance of each source, or, in some cases, what pathway was followed to enter the Great Lakes. Analysis of contaminant loads in urban runoff is also hindered by the high cost of laboratory analyses, limiting available data (Tsanis et al. 1994).

There are also many new chemicals in the Great Lakes that scientists have yet to identify. As a recent IJC report noted, researchers extracting chlorinated hydrocarbon residue from Great Lakes fish and birds have only been able to identify 30 percent of their findings (IJC 2000: 15). A further complication is the potential for more reactive chemicals to bind with each other to form new, more potentially harmful mixtures. In addition, the release of pharmaceutical products into the Great Lakes environment is only now being noted as a potential public health concern.

Given the increased public attention being paid to pathogens, as a result of drinking water problems and beach closures, greater emphasis is being placed on researching their environmental and health consequences. But research is now just scratching the surface. Scientists have been able to identify several potential sources of bacteria, but there remain significant unknowns regarding their biology and pathways. Even the source of the bacteria in the 1993 Milwaukee outbreak has not been identified (Logan 2000). There are also methodological challenges to be solved: for example, sampling and microbiological testing procedures are not standardized throughout the Great

Lakes, and there are no government guidelines for testing viruses at public beaches (Edsall and Charlton 1997: 90). The database for pathogens in tributaries discharging into the Great Lakes is poor (Logan 2000: 26).

The Great Lakes Science Advisory Board has summarized these shortcomings and their implications:

> "Although we now have much better general information about the nature and importance of sources, most of this information is derived from inference and not from direct measurement. *In fact, we have few direct measurements of loads, especially the detailed chemistry (for instance of phosphorus species) that may be relevant in assessing the effectiveness of proposed controls*. As governments scale down their monitoring and surveillance efforts, these data are becoming scarcer and older. *Without strong data, we lack proof of cause and effect relationships, and therefore cannot make sound management decisions with confidence*…. The paucity of good data on nonpoint source loads and their impacts on environmental decisions has contributed to confusion about appropriate actions and endpoints, and is a major obstacle to further progress on commitments made in the Great Lakes Water Quality Agreement" (GLSAB 2000: 5-6; emphasis in original).

In response to these research needs the IJC has recommended a binational study of the effects of changes in land use on Great Lakes water quality (IJC 2000: 32).

The Heinz report also indicated the need for research on indicators of the effects of urban areas on water quality. Most of the seven indicators noted above need additional development, such as more specific definition, refined measuring methods, or better benchmarks for evaluating results (Heinz Center 2002).

2. Applying this Knowledge to reducing the impacts of urban development

There are several approaches to reducing the impacts of urban development, ranging from technologies applied at specific sites, to political innovations, such as smart growth, that may apply across an entire region. Each implies particular information and research needs.

Site management of impacts: Best Management Practices

Many techniques are available for managing nonpoint source pollutants, including storm water management practices that detain, retain, and treat pollutant-laden runoff: retention ponds, wetlands, filters and infiltration trenches, and open channels designed to replicate predevelopment stream hydrology and water quality (Schueler and Caraco 2000: 20). One challenge has been to find effective ways of controlling erosion from construction sites or roads. Measures such as erosion fences have proven effective, but scientists continue to examine other methods (Lampe et al. 1996). At best, stormwater management techniques can only remove up to 60 percent of phosphorus and 40 percent of nitrogen (GLSAB 2000: 4). Often they do much worse: many structural stormwater systems are now reaching the end of their useful lives, or are in any case poorly maintained, and so are unlikely to remove significant contaminants. More study is needed of the effectiveness of control technologies, particularly those, such as infiltration trenches and bioretention, for which little if any monitoring data exist (Schueler and Caraco 2000: 11). There is also a need to expand the tool kit of nonpoint source pollution control technologies, possibly through transfer of waste management technologies now used in municipal and industrial systems (GLSAB 2000: 10).

Schueler and Caraco (2000: 22) identify the following research needs for urban nonpoint control best management practices (BMPs):

- Modeling and monitoring to determine how to design stormwater BMPs to reduce or prevent downstream channel erosion

- Research to further track bacterial sources and long-term removal pathways

- Sub-watershed scale evaluations of the effectiveness of BMPs in reducing pollutants and protecting habitat

- In situ monitoring within stormwater ponds and wetlands to understand internal nutrient and bacterial cycling in ponds over time.

Dozens of innovative efforts in managing urban nonpoint source pollution, particularly sediment, are underway across the region, as a result of support from the Great Lakes Basin Program for Soil Erosion and Sediment Control (Great Lakes Commission 2002).

Protecting critical areas

Certain areas, such as wetlands, floodplains, steep slopes, mature forests, critical habitat areas, and shorelines are especially important in moderating the impact of urban nonpoint source pollution. Preventing development of these critical areas is an essential component of pollution control strategies. Buffer strips along streams are especially critical: a forested buffer provides shade, woody debris, leaf litter, streambank protection, and many other functions and services to the stream. However, a buffer alone cannot ensure effective water quality protection, since most runoff arrives at a stream by channel or drain pipe, effectively bypassing the buffer (Schueler and Caraco 2000: 19).

Watershed management plans

Pollution control strategies that rely on technology alone are inadequate. As has been noted, performance of these technologies will be compromised if they are poorly designed or maintained. They are also generally unable to prevent channel erosion, or remove bacteria effectively (Schueler and Caraco 2000: 15). Thus, they need to be placed within a broader context of watershed land use management. Several management strategies are available: reducing impervious surfaces, better site design, stream buffers, and protection of natural hydrologic features, such as wetlands. Effective regulatory actions include protection of floodplains and other natural features, as well as regulation for erosion and sediment control during subdivision development, and rules requiring maintenance and replacement of septic systems (IJC 2000: 31). Development plans that include a lower proportion of impervious land area, using smaller streets and fewer cul-de-sacs, are also important, as are cluster developments, in which housing is placed in close proximity on smaller lots, allowing a larger proportion of a subdivision to remain undeveloped (Kellogg 1997). All such efforts depend on considering the long-term impact of development on watershed streams during the planning process. Watershed plans also need to be produced on smaller scales, to ensure responsiveness to local conditions (Schueler and Caraco 2000: 22).

Public education

Many aspects of nonpoint source pollution control depend on initiatives by the public. This implies a need for effective dissemination of scientific information, on such matters as lawn care strategies that employ alternatives to pesticides, herbicides and fertilizers. Efforts to discourage toxic waste disposal down storm drains, or to encourage pet owners to clean up after their pets, also indicate a role for public education (Fortner et al. 1991). However, little is known about the effectiveness of public education in actually reducing pollutant loads (Schueler and Caraco 2000: 21).

An essential element in public education is providing information regarding not just impacts on the environment, but, more positively, about the contribution of effective watershed protection to human health and quality of life, and to the local economy, in the form of higher property values and a community that is more attractive to both residents and investors (Kellogg 1997). The objective would be to communicate a view of local environmental protection as an investment, not a cost.

Beyond disseminating information, public education should also encompass encouraging a role for the public in gathering information, through community-based environmental monitoring initiatives. Such initiatives can be important not only as sources of information, but in encouraging attitudes of local stewardship (see, for example, www.naturewatch.ca/english/).

Controlling sprawl

Ultimately, control of urban nonpoint source pollution requires addressing unsustainable land use patterns, as technological or managerial solutions alone are inadequate. Smart growth initiatives, fostering more efficient land use through higher density development, provide one illustration of possible directions. The need for such initiatives illustrates how progress on more complex environmental problems depends on moving beyond narrow regulatory approaches, towards more innovative, dynamic collaborations among governments, the private sector, citizens' groups, universities and other organizations, ultimately embracing what is often referred to as "civic environmentalism," in which environmental protection is the joint responsibility of all members of a community (Shutkin 2000).

While civic environmentalism, as expressed through, for example, the decision to adopt smart growth patterns of development, is a political, not a scientific matter, the contribution of science to such a decision can be significant. This complex topic is examined more closely in the case study of the Oak Ridges Moraine (see below).

IV. LINKING SCIENCE WITH LAND USE POLICY: CHALLENGES

It has often been noted (by the International Joint Commission, for example) that the major challenges involved in controlling nonpoint source pollution are not technical, but institutional. To put this another way: although there are uncertainties and information gaps, we know how to do more than we are actually doing. The challenge, then, is in connecting what needs to be done, and what we do. Achieving this depends on linking science and policy more effectively. Two aspects of this challenge will be discussed: the frequent lack of clear policy direction provided by science; and the challenge of communicating scientific information in a complex jurisdictional environment.

Lack of clear policy direction provided by science

Scientific uncertainties regarding nonpoint source pollution often lead to a classic problem of environmental policy making: how do we take action when many sources and/or effects of pollution are imperfectly understood? For example, science cannot offer clear direction regarding future policy regarding phosphorus inputs into the lakes. Some studies suggest that these inputs remain a problem (Schueler and Caraco 2000), while others argue that nutrient levels in the Great Lakes are now too low (Gaden 1998). It is unclear therefore whether governments should pursue further reductions, do nothing at all, or allow increases. More generally, insufficient knowledge on nonpoint urban pollution and its sources can itself be an obstacle to effective responses. As the IJC has noted, "...without strong data, we lack proof of cause and effect relationships, and therefore cannot make sound management decisions with confidence" (GLSAB 2000).

With additional research may come consensus regarding these uncertainties. Application of the precautionary principle may also aid in resolving questions regarding appropriate responses to urban nonpoint source pollution. But other challenges remain to incorporating scientific information in land use policy decisions. Such challenges are often political, but they must be recognized and addressed if nonpoint source pollution problems are to be resolved.

Communicating science in a complex political environment

Decision-making and policy implementation with respect to nonpoint source pollution is the responsibility of governments at several levels of jurisdiction: federal, state/provincial, municipal, and other levels. However, not all levels have equal influence, or equal access to information or other resources. Federal and state/provincial governments have participated most in nonpoint source pollution control initiatives. In contrast, the local level has been much less active, even though local land use decisions impact most directly on urban pollution sources. Local governments in both the United States and Canada have jurisdiction over city planning, sewage systems, roads and waste (Thorp et al. 1997: 85, 95) and all of these areas are crucial to addressing nonpoint pollution issues. These governments are also closest to both the sources and effects of pollution, and may have knowledge that their state/provincial or federal counterparts do not. However, the connection between these two levels of decision-making: the binational, in which federal and state/provincial governments are represented, and the local, is very weak. As the IJC has noted, there is no linkage between local development decisions and the provisions of Annex 13, and the transfer of responsibilities and programs from senior levels of government to local governments, as well as the increasing economic and political importance of cities, has made this linkage more difficult (IJC 2000: 31). As a result, policymakers with the most direct link to urban planning issues often do not have the information needed for informed decisions regarding nonpoint source pollution, nor the resources—financial and regulatory—with which to implement these decisions.

In response, the IJC has recommended a "guidance policy" be incorporated into land use planning policies and decision-making across the region. Such a policy would draw on scientific understanding of the urban environment, as well as recent policy innovations, such as "smart growth," for the benefit of decision-makers and land use managers (IJC 2000: 31-32). However, more than a "guidance policy" is needed to ensure effective use of science at the municipal level. Municipal governments often lack the fiscal and human resources needed to obtain scientific information on nonpoint pollution. If the information does not exist, policymakers will have to obtain it, either by using in-house staff or by contracting out the research. While municipalities have often done so, it is becoming more difficult. This has been especially true for urban areas in Ontario, where government funds have been cut and municipal responsibilities increased. A further difficulty is structural, in the form of a lack of connection between planning and regulation: land-use planning and pollution prevention still tend to be seen as separate activities within municipal governments.

Some municipalities do have access to extensive scientific information on land use impacts. For example, the City of Toronto produces periodic reports on the state of the environment. One of its most recent documents, entitled “Water: Strategic Directions” lists several ongoing problems related to nonpoint pollution, including combined sewer overflows, wastewater, and drinking-water quality, and suggests strategies to resolve these problems (Toronto 2000). But few cities in the Great Lakes region have Toronto's resources, and thus smaller municipalities need to find alternative methods for obtaining scientific information. They must also address questions regarding the authenticity of data, and skepticism regarding its sources.

There are also political obstacles to applying scientific information. These are evident in the frequent observation that while policymakers may have adequate access to information about the environmental impacts of urban development, they nevertheless fail to act effectively. Most obviously, while the environmental and economic costs of sprawl are often cited in policy documents, this continues to be the dominant urban development pattern. Clearly, obtaining scientific consensus is only the first step in incorporating Great Lakes science into policy: it is also necessary to mobilize governments and the public to act. This can be difficult with regard to pollution from land use activities, for three major reasons.

First, there can be great difficulty in coordinating responses to scientific information, both inside bureaucracies and between cities and regions. Within the Great Lakes region there are 250 Canadian and well over 1000 American municipal governments (Thorp et al. 2000). Each must deal with a range of federal and provincial/state regulations and agencies; many of these agencies pursue divergent interests, often on the basis of different scientific information. The international border can hinder communication: governments along it often have little contact with their American or Canadian counterparts, and little mandate to negotiate or share information. This proved to be an obstacle to progress in Remedial Action Plans along the St. Lawrence and Niagara rivers (Sproule-Jones 2002: 45).

Second, economic considerations are always important. As cities compete against each other to attract investment, decision-makers may choose to downplay environmental concerns in land use decisions. In general, environmental impacts are only one factor among many that city planners consider in making land use decisions. Under pressure from a property rights movement that advocates limits on government regulation of development, officials may also face legal action for the decisions they make (Thorp et al. 1997: 19). In Ontario, developers can appeal city land use decisions to the provincially appointed Ontario Municipal Board, which can overturn the decision if it determines that the decision was in error or unfair (Ontario Municipal Board 2000).

Third, changes in activities that affect water quality, such as applying herbicides and pesticides to lawns, require changes in individuals' behavior (Hirsch et al. 2001). This can also be politically difficult, particularly in the face of dominant aesthetic ideals relating to lawns. More generally, suburban development reflects, to some extent, consumer demand: many people want detached homes, suburban neighborhoods, and the accompanying resource-intensive lifestyle. A recent study in Canada suggests that 60 percent of all homes built in the next ten years will be single detached homes (Remax and Clayton Research 2001). Communities may also be reluctant to consider changes in urban form, such as narrower streets, even if the resulting reduction in impervious surfaces provides environmental benefits. Thus, a major challenge in addressing urban nonpoint source pollution control is motivating the public to consider the environmental impacts of both the suburban lifestyle generally, and more specific activities such as pesticide use.

Together, these factors will tend to encourage a high level of variability in water quality protection efforts across any given watershed. The outcome, as Kellogg (1997) notes, is that the benefits of a higher level of protection in one community can be minimized as the river runs through less protected areas elsewhere in the watershed.

V. CASE STUDY: THE OAK RIDGES MORAINE

Understanding how science can be communicated and applied effectively in controlling nonpoint source pollution requires close attention to the local context. Accordingly, a case study of the use of science in such a context is presented. The Oak Ridges Moraine case highlights several important issues relating to accelerated urbanization in the Great Lakes region and the role of science in land use decisions.

The Oak Ridges Moraine: Human and environmental context

The Oak Ridges Moraine is a still largely undeveloped belt of hills, fields, forests and streams, extending 160 kilometers across the northern edge of Toronto. Bulldozed into position by glaciers about 12,000 years ago, the moraine's gravel and sand collect rainwater and snow melt, which is then slowly filtered and transferred to over 65 rivers and streams draining into Lake Ontario and Lake Simcoe (Figure 2).

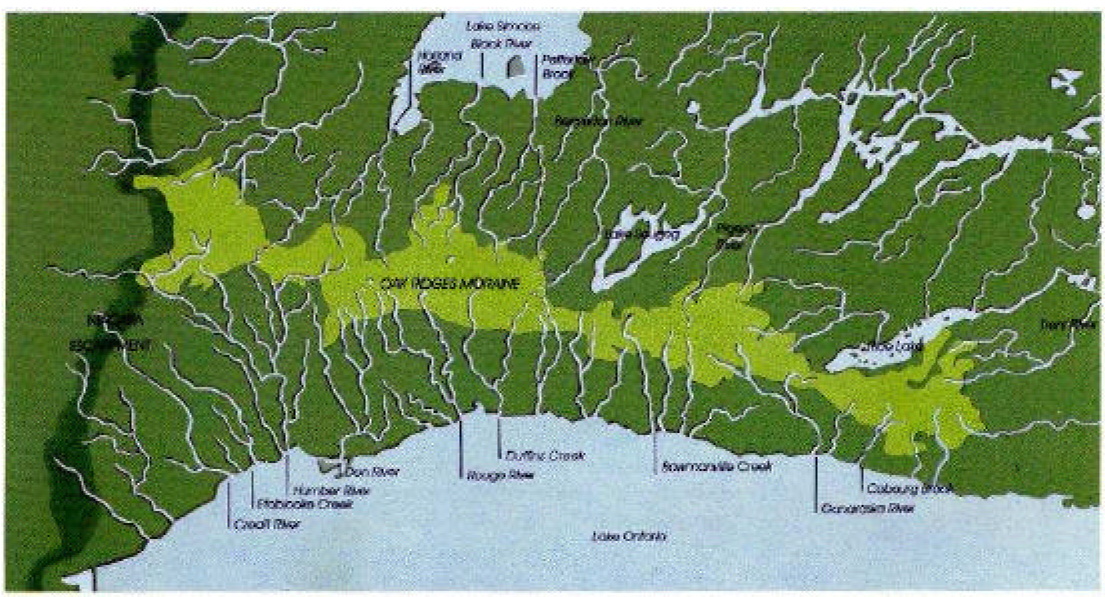

Figure 2: Location of the Oak Ridges Moraine
(Source: Save the Oak Ridges Moraine Coalition)

Preservation of the moraine was first urged sixty years ago – a suggestion repeated at intervals and in vain ever since. Nevertheless, the moraine has generally remained free of urban development. But over the past decade, as Toronto has expanded northwards, it has become exposed to increasing development pressures. Over the next twenty years the population of the Greater Toronto Area is expected to increase by about two million people, many of whom are expected to settle north of Toronto, where much of the moraine is located. The impending collision between this rural area and urban development, although shaped by local circumstances, is similar to processes occurring on the outskirts of many other cities in the Great Lakes region.

In June 1991 Ontario's Ministry of Natural Resources, Ministry of Environment and Minister of Municipal Affairs formed a technical committee to aid in creating a long-term development strategy for the moraine (Oak Ridges Moraine Technical Working Committee 1994). This strategy was intended to provide the basis for a regional approach to land use planning, coordinating the three regional governments and over a dozen municipalities on the moraine. The strategy was completed in 1994, but was then shelved, leaving land use decisions in the hands of local governments. These governments, in turn, welcomed developers' proposals for housing projects. From their perspective, these developments presented significant economic opportunities. The plans emphasized detached, single family homes, requiring substantial infrastructure, including an extensive road network and water and sewer facilities. As such, the communities would be typical of suburban development across North America.

But, beginning in 1999, moraine development became a highly politicized issue. Citing the ecological sensitivity of the region, and calling the moraine the "rain barrel of Ontario," environmental groups raised public awareness, eliciting mass opposition to development. Perhaps the fiercest battle occurred in Richmond Hill, where there were plans to house 100,000 people in subdivisions extending right across the moraine. The City of Toronto, although not on the moraine, also became involved. In 2000 the controversy moved to the Ontario Municipal Board. Developers appealed to the board to approve their plans, often over the opposition of local governments. In May 2001, with no resolution yet apparent, the Ontario government intervened, announcing a six-month moratorium on development, and the creation of a panel to prepare a land-use plan that would adhere to "smart growth" principles. The plan, released in October 2001, was welcomed by some as effective protection, but condemned by others as inadequate. It divides the moraine into four zones, with progressively tighter regulations on development in each. Most development would be restricted to "settlement areas," occupying eight percent of the moraine. The plan has now become the basis for provincial legislation, the Oak Ridges Moraine Conservation Act.

Science and the Oak Ridges Moraine

Research on the hydrology of the Oak Ridges Moraine had begun by 1970, with efforts to understand the significance of the aquifer as a recharge source for Lake Simcoe and Lake Ontario (Haefeli 1970). Only in the last decade, however, has there been a focus on the potential impact of urban development on the moraine, and ultimately on Great Lakes water quality. Much of the research on the moraine has taken place at two centers: the Geological Survey of Canada, and the University of Toronto Groundwater Research Group. Several consulting firms have also made significant contributions, including work for the Oak Ridges Moraine Technical Working Committee, or for private developers.

The basic facts regarding the moraine's geology and aquifer are well known (Figure 3), including the role of the moraine in recharging streams and rivers in the region (Desbarets et al. 2000). Despite a decade's research, however, many uncertainties remain in our knowledge of its hydrology, and its role in the regional ecosystem. For instance, lack of quantitative data on shallow local flow systems hinders estimation of flow from the aquifer into surface waterways (Grannemann 2000).

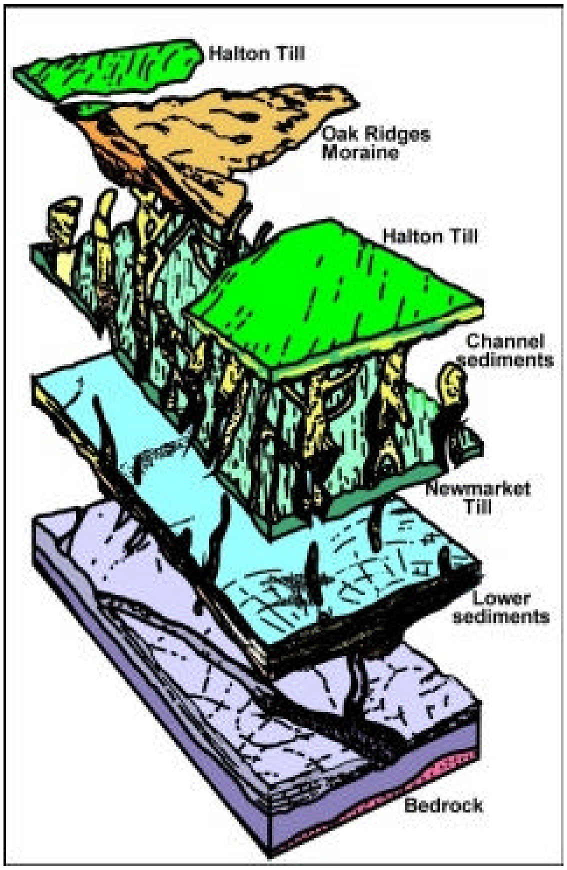

Figure 3: Geological structure of the Oak Ridges Moraine
(Source: Desbarets et al. 2000)

Even less is known about the potential impact of urban development on the moraine. There are several hypotheses regarding the relation of land use to moraine hydrology. Impervious surfaces such as roads and housing can reduce the amount of water available to the moraine for recharge, diverting it to urban storm systems, creating the potential for flooding (Grannemann 2000). Road salting in winter may lead to increased salinity in the moraine aquifer, and subsequently in downstream waterbodies, affecting fish habitat and even human health (Howard et al. 1993, Hunter et al. 1997). Other aspects of urban development, such as the effects of septic systems on well supplies, large-scale withdrawal of groundwater for consumption, and the effects of agrochemicals have been described as potentially affecting the moraine aquifer (Howard et al. 1995). However, no scientific study has determined conclusively whether urban land use will affect the aquifer. One reason is that because the aquifers release groundwater slowly, the effects of land use practices may not be noticed for years. It is likely that conclusive evidence of damage will only become available once the damage has been present for several years.

More generally, the Oak Ridges Moraine provides, inadvertently, a case study in the inaccessibility of scientific and monitoring information within a fragmented jurisdictional environment. As Hunter et al. (1997) summarized:

> "Environmental databases related to the Moraine are often not adequately maintained, integrated and cross referenced by source agencies. At present, historical long-term environmental monitoring data at best is virtually inaccessible and at worst has been lost by the administrative processes of the multi-jurisdictional agencies which operate within the Moraine. Many old monitoring records appear to have been lost, destroyed, redistributed with administrative

> mergers, lost on key employee retirement, or buried in archives. Often the only source of continuous long term monitoring information are the production wells and the existing large landfill sites. Comprehensive integrated environmental information management systems should continue to be implemented."

Science in the Oak Ridges Moraine Controversy

An especially significant feature of the controversy over development on the moraine was the extent to which both sides—environmentalists and developers—defined the issue in terms of science.

For environmentalists, science was a welcome ally. Geological accounts of its origins as an interlobate moraine (formed between two glaciers) reinforced its image as a distinctive landscape feature. Biologists noted the presence of more than 900 species (including several rare species), and the need to protect its ecological integrity. Most crucial was hydrogeologists' portrayal of the moraine as an essential aquifer. Studies had identified the risks of development: as Ken Howard, a University of Toronto hydrologist, explained in 1997, the moraine is a "nationally significant groundwater resource that has become increasingly threatened by urban growth. The results of the hydrochemical and hydrogeological studies confirm that urbanization represents a serious threat to local groundwater quality" (Swainson 2000). This account became the basis for describing the moraine as the "rain barrel" of southern Ontario, damage to which might be catastrophic for the drinking water of thousands. As a result, the issue became no longer about nature, but about something considered more urgent, especially in the aftermath of Walkerton: human health. As one activist noted: "We need to preserve this for our own health, not just the flora and fauna. It is so beneficial to us, our drinking water, our quality of life" (Hudson 1999).

Activists also set out to demonstrate a scientific consensus behind their position. Presenting a petition signed by 450 scientists, Gregor Beck of the Federation of Ontario Naturalists commented: "It's easy for politicians to say 'oh yeah it's just a bunch of environmentalists,' but now to get scientific specialists on board carries a lot more weight" (Immen 2000). Geological Survey of Canada scientists added their weight, pointing out that because of the moraine's many folds and cracks there was a great deal of uncertainty regarding the impact of development on the aquifer, and that therefore caution was needed.

Developers also saw the issue as a matter of science, particularly in presenting their case to the Ontario Municipal Board. Board hearings became seminars in geology, hydrology, soil studies and wildlife science, as experts piled up thousands of pages of testimony and exhibits. The purpose was to determine, using science, whether development posed unacceptable risks to the moraine environment. Developers spent millions on scientific studies to support their applications, and on lawyers to help present this information. Activists and local councils could not match these resources (although they received some help from the City of Toronto). As one environmentalist complained: "As of today, we have no lawyer, no planner and no expert witnesses, which means we will just be blown away… The public has virtually no place there… The decisions that will affect millions of people over 200 years are being made in a room where the admission ticket is $1-million" (Barber 2000).

Most crucially, the Board hearings gave developers a chance to present their own view of the moraine. They saw it not as a sensitive landform requiring protection, but as a resource that could, with appropriate management, be developed safely. This view also implied a different understanding of how decisions should be made in situations of uncertainty. While environmentalists argued for a precautionary approach, citing the possibility of aquifer contamination as reason enough to prohibit development, developers saw the lack of proof that such contamination would occur as reason enough to proceed.

This argument was supported by the developers' scientific consultants. As Ken Howard (the most prominent scientist hired by the developers) noted: "I've been working on groundwater for 25 years, and I believe development can take place in ways that minimize the impact on water quantity and quality. And I find that developers are actually listening". Lloyd Cherniak, a developer, and chair of the Urban Development Institute, echoed Howard's words: "The science is here to protect the moraine… And we have done extensive research. We believe we can build without hurting the environment" (Stein 1999).

Corporations active in fields that attract public concern, such as chemicals or biotechnology, often insist that regulatory decisions should be based on science. They do so both because they can outgun their opponents in the scientific arena, and because it places boundaries around an issue: by defining it as scientific, it avoids the need to consider difficult ethical or political issues. This pattern was perpetuated in the Oak Ridges Moraine controversy.

Oak Ridges Moraine Case Study: Conclusions

Several conclusions can be drawn regarding the contribution of science to this land use controversy, and to decisions relating to the environmental impacts of urban development, including nonpoint source pollution.

First, was the importance of science in placing the issue of suburban development on the political agenda, and in structuring the debate. In particular, knowledge of the hydrology of the moraine, including its importance as a regional aquifer, served as an essential resource in communicating the issue widely (although the description of the Moraine as the "rain barrel" of Ontario was also thought by at least one scientist to overstate its importance). This scientific characterization of the moraine also served to link this issue with more general concerns about water quality, especially prevalent in the aftermath of the Walkerton contaminated water tragedy. The uncertainty of the science, paradoxically, enhanced its political weight, by encouraging many citizens and environmental groups to adopt a precautionary approach to urban development.

However, science was not able to resolve the issue. In part this was because of the uncertainties inherent in the moraine's complex geology, that prevented definitive conclusions regarding the impact of development. Thus, while all parties tended to define the issue in terms of science, science could not provide a clear policy direction regarding whether development should be permitted. But beyond these uncertainties, science could not resolve the issue because there were basic differences between the parties not only regarding whether development should proceed, but regarding how science should be used in making such decisions. While environmentalists argued, as I have noted, for a precautionary approach, the developers expressed confidence in managerial and technological strategies to limit the potential impact of development.

This episode also demonstrated how local governments can lack the scientific capabilities to make effective decisions regarding development within a complex environment. Much of the information was provided by research conducted by senior governments—both federal and provincial—thereby illustrating the essential role of those levels of government in supporting local decisions. However, while the information provided by senior levels of government was produced through high quality, peer-reviewed science, it was not necessarily immediately relevant to decisions at the local level, in terms of providing, for example, answers regarding the likely effect of actual developments.

Instead, much of the most relevant information was provided by scientists employed by developers. But this raised an additional problem, of access to results: private interests, having greater resources, also had better access to the relevant science, and were thus better able to participate in the decision-making process. The ultimate outcome was a hindering of equitable participation by all interests in the land use policy decisions.

The need for equitable participation in these decisions, and in the land use process generally, is evident if we consider how the issue of "smart growth" emerged on the political agenda in the first place. While several studies of the moraine had been completed by the mid-1990s, it was only through citizen initiatives, shaped and focused by environmental groups, that serious debate, and eventual formation of a land use plan, took place. To put it another way, only significant political pressure was able to overcome the obstacles to sustainable land use planning: a development industry unaccustomed to controls, municipalities eager to encourage growth, a province reluctant to intervene. Science also played an essential role in creating this political environment for action, underlining thereby the importance of broad, equitable access to science. Thus, it demonstrates how science can contribute to broadening the basis for environmental protection, beyond managerial and technical approaches, by empowering communities to understand, and to protect their local environment, fostering a civic environmentalism.

Finally, this case study illustrates how science, far from encouraging agreement, can drive opposing parties further apart. There are, however, readily available alternative models for linking science and policy. In the broader Great Lakes regime, the

International Joint Commission, through its binational advisory boards and reference studies, has evolved a mechanism for joint fact-finding on contentious issues, allowing agreement on science, which can then form the basis for eventual agreement on action. Reference studies, for example, are guided by a study board with equal numbers of technical experts from each country to study the issues and recommend options for action (Valiante et al. 1997). This is a model that could well be adopted at the local level, with the parties within a watershed joining in developing a shared understanding of the watershed ecosystem.

VI. CONCLUSIONS AND RECOMMENDATIONS

1. Urban nonpoint source pollution constitutes one of the most complex—scientifically and politically—environmental challenges facing the Great Lakes community.

2. Some aspects of urban nonpoint source pollution can be ameliorated through managerial or technological strategies and practices. However the problem is also rooted in basic aspects of North American society, including dominant patterns of low-density suburban development. Therefore, political, as well as technical, solutions are required. Science can play a role in facilitating both kinds of solutions.

3. Effective management of urban nonpoint source pollution requires a variety of approaches to research: basic research to identify emerging problems (such as the input of pharmaceutical products into waterways); focused research on managerial and technological innovations, with a view to continual improvement of BMPs; research aimed at perfecting selected environmental indicators, particularly those that allow for comparison with national and international trends, as well as a steady, sustained commitment to monitoring; and public communication and involvement in science, including community monitoring activities.

4. Management of urban nonpoint source pollution is highly fragmented, discouraging ecosystem or watershed-based approaches. To be effective, solutions require coordination amongst a diverse array of agencies at the binational, federal, state/provincial and local levels. Efforts to improve scientific research and information dissemination must therefore be designed to encourage this coordination; ideally, science—through provision of an agreed-upon knowledge base—can provide a basis for interagency cooperation. The binational experience may be a useful source of models for cooperation at the local level on nonpoint source pollution.

5. There is an essential role for senior governments in the science of urban nonpoint source pollution, both in requiring better coordination and planning at the local level, and in facilitating this with appropriate assistance: by conducting research, enhancing the capabilities of local governments to do their own research, and disseminating research results more widely to local staff (e.g. through training) and to the general public.

6. Efforts to communicate scientific information to policymakers and other audiences should be informed by an understanding of the political and institutional contexts in which that information is applied, including the political and economic obstacles to effective environmental protection. These communication efforts should especially ensure that scientific information is available to all members of a community.

7. The assumptions that guide the application of scientific information to political and managerial decision-making—for example, regarding the appropriateness of the precautionary principle—must themselves be openly examined as an element of the decision-making process.

8. More research on the benefits, economic or otherwise, of nonpoint source pollution control would be beneficial, to contribute to political support for control initiatives.

9. To extend our understanding of the issues raised by this pilot study, and to further the objectives of the IAGLR/Joyce Foundation project on science and policy, IAGLR should consider partnerships with local agencies responsible for nonpoint source pollution. These partnerships—perhaps focused on two or three specific sites within the Great Lakes basin—would explore in more detail the factors that affect adoption of sustainable urban development patterns, and IAGLR's potential contribution to improving the effectiveness of science in the urban development process.

VII. ACKNOWLEDGEMENTS

A nonprofit organization with more than 700 members, the International Association for Great Lakes Research (IAGLR) was established to promote all aspects of research on the Great Lakes and other large lakes, and to disseminate research information through publications and meetings. This publication was prepared by Stephen Bocking, with research assistance from Matt Griem, under the auspices of a special committee struck by the IAGLR Board of Directors, with support from a grant from The Joyce Foundation to strengthen the science-policy linkage in the Great Lakes Basin. For more information contact Stephen Bocking (sbocking@trentu.ca).

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