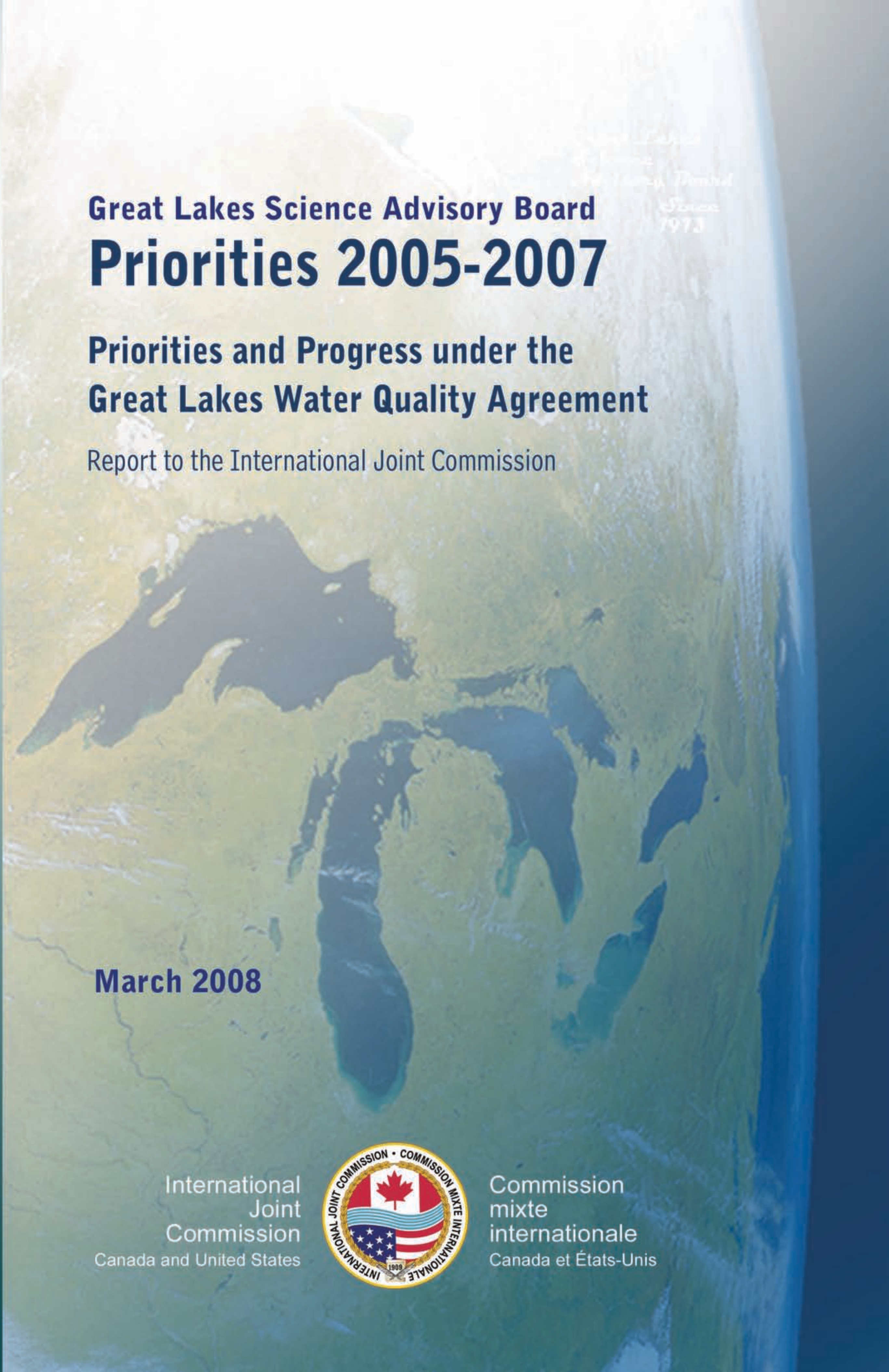
Priorities Report 2005-2007



Great Lakes Science Advisory Board

Priorities 2005-2007

Priorities and Progress under the Great Lakes Water Quality Agreement

Report to the International Joint Commission

March 2008

International Joint Commission
Canada and United States

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Canada et États-Unis

Great Lakes Science Advisory Board

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WINGSPREAD CONSULTATION ON STRENGTHENING SCIENCE UNDER A RENEWED AGREEMENT

On January 24-26, 2006, the Science Advisory Board's Work Group on Emerging Issues convened an Expert Consultation (details in Appendix 4) to explore means by which science might be strengthened within a renewed Great Lakes Water Quality Agreement. Of particular interest were institutional arrangements that would best promote the use and integration of science in decision making. On the basis of workshop discussions, the Work Group crafted a series of recommendations to help guide the Commission as it discusses revisions of the Agreement with the Parties with respect to the issue of how best to enhance science-based decision making applied to trans-boundary water resource management and governance in the Great Lakes Basin.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Agreement explicitly commits the Parties to decision making that includes three overarching principles: the precautionary principle, the principle of adaptive management, and the principle of robustness.**

These Principles should be defined in Article 1 of the Agreement.

- **A revised Agreement obligates the Parties to satisfy the existing requirement to review the Specific Objectives in Annex 1 at least every two years, and to report on the outcome of the review process. Moreover, the review should not be limited to the General or Specific Objectives in the Agreement.**
- **All revised objectives be at least as stringent as existing federal, provincial, or state water quality standards for the protection of aquatic life, and the revised objectives utilize the best scientific knowledge currently available about the impacts of pollutants on aquatic ecosystems and human health.**
- **The objectives be set to protect public health and be constructed, where possible, using a process-oriented framework – rather than a specific value – to provide for maximum flexibility in incorporating new science as it becomes available.**
- **Paragraph 3 of the Supplement to Annex 1 be revised to include a formal list of ecosystem health objectives and associated indicators for all lakes, as well as an explicit process by which these objectives and indicators will be revised.**
- **The revised Agreement includes a new annex that clearly and explicitly addresses the issue of accountability.**

This will ensure that all Agreement-related recommendations are responded to in a timely, substantive, and public manner. Specifically, the revised Agreement should require the Parties to establish a formal process to define: performance indicators with respect to both the ecological health of the ecosystem and program delivery, effectiveness, and outcomes; standards (benchmarks) against which performance is assessed; the agencies or organizations responsible for performance assessment; the format and schedules for performance assessment reports; provisions to communicate the results of performance assessment to the public; and the format and content of responses to the assessment reports.

- **The Parties commit to a level of support for research and monitoring commensurate with the principles of adaptive management.**

Toward that end, the Science Advisory Board (or similar body established under a revised Agreement) should be explicitly charged, in the Agreement, to undertake an ongoing assessment of research and monitoring needs, and to determine the costs required to ensure the full and timely implementation of Agreement provisions.

- **The Agreement should be amended to require a coherent, consistent, and accessible bi-national data management system that includes meta data.**
- **A revised Agreement to replace current Board arrangements with a single, Integrated Science and Policy Advisory Board, with an executive committee that regularly reports to the Commissioners.**
- **The Integrated Science and Policy Advisory Board be supported by a Bi-national Academy of Scientists that can be consulted, as needed, to provide expert advice on current and emerging Commission priorities.**

The Academy would be organized into issue-specific work groups, as needed, and prepare reports and recommendations for consideration by the Integrated Science and Policy Advisory Board and the Commissioners.

- **Board structure under the revised Agreement includes enhanced interaction with representatives of local government and the public.**

The revised Agreement should consider creation of a forum for local governments, ensuring the free and open sharing of data, facilitation of mechanisms to work with local coalitions, enhancement of local scientific capacity, facilitation of community volunteer initiatives and outreach to local planners, and facilitation of local public advisory councils.

PATHOGENS – THE UTILITY AND LIMITATIONS OF MICROBIAL SOURCE TRACKING TOWARD PROTECTION OF RECREATIONAL WATERS IN THE GREAT LAKES BASIN

The Science Advisory Board's Work Group on Ecosystem Health continued its investigation of waterborne microbial pathogens in the Great Lakes, building on previous work undertaken with regard to the Commission's 2003-2005 Human Health Priority (IJC, 2006). The Work Group invited an expert paper (Appendix 5) by Dr. Kate Field, Oregon State University, on the topic of microbial source tracking to address the current state of science using source tracking methods as an approach to improve management of surface water contamination.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **An inventory be undertaken of all microbial source tracking studies conducted to date for watersheds and water bodies in the Great Lakes.**

The inventory would include number of sites, number of samples, method, and results.

- **All Areas of Concern in the Great Lakes where recreational swimming is impaired be piloted to address the implementation of microbial source tracking studies using latest technology.**

A U.S. Environmental Protection Agency grant is presently funding a collaborative Gulf of Mexico project to determine the most useful currently available, library-independent microbial source tracking methods for detecting human fecal contamination at beaches and in shell fishing waters across Gulf Coast waters. The same should be done for the Great Lakes.

EVALUATION OF DAM REMOVALS – AN ECOSYSTEM APPROACH

On June 6, 2006, a consultation entitled An Ecosystem Approach to Dam Removals in the Great Lakes Basin was conducted in Windsor, Ontario, on behalf of the Science Advisory Board. Presentations addressed effects on fish communities, evaluating risks to wildlife, sedimentation, invasive species, energy considerations, and economic modeling. These formed the foundation for a roundtable discussion of the need for an ecosystem approach and a decision-making framework.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Parties, in collaboration with other partner institutions, develop guidelines and criteria, including analytic tools, to assess cumulative competing risks and benefits (including opportunity costs) of dam removal or retention in the Great Lakes Basin that can be embraced by relevant regulatory agencies.**

The tools should specifically allow for the assessment of competing risks and benefits at multiple spatial (local versus regional) and temporal (short-term versus longer-term) scales and for proactive local involvement in tool design and implementation, particularly the specification of valued ecosystem components.

- **The Parties facilitate the participation of all responsible and affected federal, state, provincial, and municipal agencies in an integrated plan for dam disposition in the Great Lakes Basin.**

Dam dispositions should be designed to maximize cumulative scientific value and information content regarding dam removals, and should be coordinated among all responsible and affected agencies. Each removal should be treated as a bona fide scientific experiment using the analytic tools developed as called for above.

- **The International Joint Commission explicitly take into account the issue of dam disposition in the development of the nearshore framework and in the development of its 2007-2009 priorities.**

The Science Advisory Board will continue to assist the Commission in this regard and will address dam disposition as an emerging issue during the 2007-2009 priority cycle.

HEALTH EFFECTS AND NEW CHEMICALS – OMEGA-3s AND FISH CONSUMPTION ADVISORIES

The question of benefits versus risk of fish consumption has been discussed within the Great Lakes public health community for many years and remains an important issue. As reflected in fish consumption advisories, the United States and Canada recognize fish as nutritious food. The general subject of fish consumption has been reviewed in an excellent report by the U.S. National Academy of Sciences (2006) entitled *Seafood Choices: Balancing Benefits and Risks*. The specific issue of benefits versus risk of Great Lakes fish consumption was reviewed by the Science Advisory Board and the Health Professionals Task Force at a one-day workshop held January 3, 2007. The issue was also the subject of a discussion paper prepared by the Task Force in January 2004 entitled *Great Lake Fish Consumption Advisories: The Public Health Benefits and Risks*. Rather than furthering an artificial controversy between nutrition and toxicology, it is recognized that some fish have excellent nutritional value and are comparatively low in pollutants.

Science to date clearly indicates that women of reproductive age and young children are especially vulnerable to contaminants. These groups should avoid and/or limit consumption of Great Lakes area fish to species, sizes, and frequency as specified in current advisories until such time as levels of persistent toxic substances in the Great Lakes region decline below concentrations that trigger fish consumption advisories for cancer and non-cancer health effects.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The states and provinces be advised to develop fish consumption advisories and communication messages which consider both contaminant levels and omega-3 fatty acid content of fish so that the benefits of fish consumption are maximized through the consumption of fish containing the lowest concentrations of contaminants and the highest concentrations of omega-3 fatty acids.**
- **Research, in particular involving First Nation populations, be conducted that specifically addresses the benefits of consumption of freshwater fish from the Great Lakes region in comparison to other food sources.**
- **Governmental monitoring of contaminants in freshwater fish also include additional evaluations of levels of omega-3 fatty acids in order to further evaluate risk and benefits of relative levels of contaminants and omega-3 fatty acids and to advise people on how to choose fish species that are the highest in omega-3 fatty acids and lowest in contaminants.**
- **Fish consumption advisories be continuously updated on the basis of new information about contaminants and health benefits.**
- **Women of reproductive age, children, and young girls be informed that the benefits to the developing fetus of obtaining omega-3s by eating fish can be achieved by eating uncontaminated ocean fish, or through a low-risk option of fish oil supplementation, or consumption of foods with added omega-3 fatty acids.**

THE STATUS OF GROUNDWATER IN THE GREAT LAKES BASIN

Groundwater is extremely important to both the quantity and quality of water in the Great Lakes. It is estimated that there is as much groundwater in the Great Lakes Basin as there is surface water in Lake Michigan. The groundwater contribution to the Great Lakes ranges from 48% in Lake Erie to 79% in Lake Michigan. Groundwater provides 82% of potable water needs for rural populations, 43% of agricultural water, and 14% (and escalating) of industrial water in the basin. Generally, the quality of groundwater resources in the Great Lakes Basin is very good. However, the quality is threatened in many parts of the basin, with worrisome implications for public health and economic development.

The Board's Work Group on Parties Implementation identified a range of issues that illustrate the breadth of groundwater concerns in the basin. The issues are summarized in Chapter 2, and the topic will be addressed in greater detail in a stand-alone report. That report will include recommendations developed by the collaborating partners.

THE IMPACT OF URBAN AREAS ON GREAT LAKES WATER QUALITY

The 2005-2007 biennial cycle marked the culmination of more than a decade of interest and study by the Board regarding the impacts of urban land use on Great Lakes water quality and the policy implications for sustainable land use. The Commission has a long history on this issue, dating back to the Pollution from Land Use Activities Reference Group studies of the 1970s. Article VI and Annex 13 of the Agreement address the issue and require the Parties to develop and implement programs and measures as well as to report to the Commission on their progress.

To emphasize a shift from delineating problems to searching for solutions, this priority was retitled "sustainable cities." The Science Advisory Board worked with other Commission boards and groups to develop findings and recommendations on how to move toward sustainable urban development in the Great Lakes Basin. This topic will be addressed in greater detail in a stand-alone report that also will include recommendations developed by the collaborating partners.

IMPACT OF CLIMATE CHANGE ON GREAT LAKES SURVEILLANCE AND MONITORING ACTIVITIES

Climate change has the potential to profoundly affect existing or proposed surveillance and monitoring programs and systems in the Great Lakes Basin, specifically the capacity of existing programs to provide sufficiently accurate and detailed information to assess progress – or lack thereof – under the Agreement, and to assess the effectiveness and efficiency of climate change mitigation and/or adaptation strategies as related to the integrity of Great Lakes waters. Moreover, scenario and model development as well as assessments all depend critically on the availability of comprehensive, unbiased, and informative surveillance and monitoring data.

Recommendation

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Parties develop a set of tools to evaluate the adequacy of existing surveillance and monitoring programs to inform sufficiently accurate assessments of progress on Agreement objectives, climate-related changes (both direct and indirect) on the integrity of Great Lakes waters, and the effectiveness and efficiency of climate change mitigation and adaptation strategies.**

Specifically, the tools should provide information on the adequacy of existing surveillance and monitoring programs with respect to: the suite of monitored indicators, especially those related to physical drivers of ecosystem dynamics in the Great Lakes Basin; spatial and temporal scales, including sampling resolution; potential – or likely – synergistic effects of climate change in combination with other anthropogenic stressors; ability to distinguish climate-change-related spatiotemporal signals from background fluctuations; and ability to distinguish local from regional effects, be these of climate change per se, mitigation measures, or adaptation strategies.

Once developed, these tools should be applied to existing surveillance and monitoring programs to evaluate current adequacy – or lack thereof – and to identify measures required to address existing inadequacies. Any proposed future surveillance and monitoring plans or programs also should be assessed using the evaluation tools and, if deemed inadequate, modified appropriately.

ENHANCING EVIDENCE-INFORMED DECISION MAKING IN THE GREAT LAKES BASIN

The stated purpose of the Parties to the Agreement is "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." Good science is critical to the success of this enterprise, which is why the Science Advisory Board is charged, under the Agreement, with responsibility for "developing recommendations … pertinent to the identification, evaluation, and resolution of current and anticipated problems related to Great Lakes water quality" (IJC, 1989). The accuracy of a prediction about the expected effect of some stressor – or mitigation thereof – depends on whether the underlying scientific hypotheses are indeed true. In the specific context of the Agreement, measures to restore the integrity of Great Lakes waters will only be effective if they are based on causal hypotheses that are – more or less – true.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The International Joint Commission, in collaboration with other partner institutions, develop, validate, and apply methodologies and tools for evaluating the weight of evidence associated with causal hypotheses about, for example, impacts of human activities in the Great Lakes Basin Ecosystem (and possibly beyond) on the chemical, physical, and biological integrity of the basin ecosystem, or the effectiveness or efficiency of potential mitigation interventions.**
- **Once validated, the Commission employ these tools to explicitly assess the weight of evidence underlying the Commission's candidate recommendations to the Parties.**
- **The Commission foster the dissemination and use of such tools and, particularly, encourage other actors under the Agreement to employ them in decision making.**

Partner institutions include, for example, the International Life Sciences Council and the Canadian Institute of Health Research.

EXPOSURE TO PERSISTENT ORGANIC POLLUTANTS AND RISK OF DIABETES

A number of adverse health effects have been associated with exposure to mercury and persistent organic pollutants (POPs). Cognitive impairment to infants whose mothers were exposed to mercury and POPs, such as PCBs, through consumption of fish and other seafood is well documented. Other adverse health effects from POPs include thyroid dysfunction and increased risk of cancer.

Recommendation

Because persistent organic pollutants remain major contaminants within the Great Lakes Basin, the Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **Additional studies be undertaken to further explore the potential relationships between exposure to persistent organic pollutants from consumption of contaminated fish (and other routes of exposure) with diabetes and other adverse health effects in populations within the Great Lakes Basin.**

Chapter 1

Introduction

The International Joint Commission's Great Lakes Science Advisory Board, a joint institution established by the Parties under the Great Lakes Water Quality Agreement, serves as the scientific advisor to the Commission and the Great Lakes Water Quality Board. To fulfill this role, the Science Advisory Board responds to Commission and Water Quality Board requests for advice. The Commission identifies and approves biennial priorities. This process establishes topics, assigns relevant deliverables, and commits available resources in support of the priorities. For the 2005-2007 biennial cycle, the Commission approved thirteen priorities:

- **Review of the Great Lakes Water Quality Agreement**
- **Sustainable Cities**
- **Annex 2 – Remedial Action Plans and Lakewide Management Plans**
- **Health Effects and New Chemical Issues**
- **Mercury Modeling**
- **Pathogens**
- **Evaluation of Dam Removals – An Ecosystem Approach**
- **Aquatic Invasive Species**
- **Groundwater**
- **Great Lakes Observing Systems**
- **Research Coordination**
- **Research Inventory**
- **Science Vessel Coordination**

The Science Advisory Board was involved in five of these priorities: Agreement review, sustainable cities, pathogens, evaluation of dam removals, and groundwater.

In terms of Agreement review, the Board's Work Group on Emerging Issues hosted an expert consultation at Wingspread, Wisconsin, in January 2006 to address ways to Strengthen Science Under a Renewed Great Lakes Water Quality Agreement. Approximately 30 people from the United States and Canada, with backgrounds in academia, government, and industry, participated. Discussions included:

- An Ecosystem Approach to International Law
- International Lessons in Transboundary Water Governance
- Mechanisms to Engage Local Government in Great Lakes Governance
- Horizontal Management in the Great Lakes Basin – Is There a Need for a Central Coordinating Body and Binational Surveillance and Monitoring?
- Great Lakes Water Quality Agreement Institutional Arrangements – Historical Context

The 2005-2007 biennial cycle marked the 5th iteration of Board work in relation to progress under Annexes 3 and 13 of the Agreement. Initially in 1998, the Board reviewed twenty years of progress since publication of the final report of the Pollution from Land Use Activities Reference Group, completed in 1978. During 2005-2007, this priority was a multi-Board effort; however, the Board's Work Group on Parties Implementation provided leadership by assisting in organizing two events: a Special Meeting held in Chicago on the occasion of the Board's 139th Meeting, December 1-2, 2005, and an Urbanization Symposium held September 25-26, 2006.

The Board's work on the pathogen priority, undertaken by its Work Group on Ecosystem Health, focused on review of the developing science of microbial source tracking. The Work Group also hosted an expert consultation, An Ecosystem Approach to Dam Removal, on June 6, 2006. Board advice was developed from the seven expert presentations and the discussion from the meeting.

The groundwater priority, addressed by the Board's Work Group on Parties Implementation and the Council of Great Lakes Research Managers, comprised a comprehensive effort to develop a report, State of the Groundwater in the Great Lakes Basin. To achieve a broad assessment perspective, the Work Group and the Council hosted three expert consultations in Lansing, Michigan (March 2006), Syracuse, New York (June 2006), and Milwaukee, Wisconsin (November 2006). The meetings addressed both science and policy issues and were well attended by groundwater experts in both Canada and the United States.

In addition to responding to specific requests for scientific advice, under its terms of reference, the Board is also responsible for "developing recommendations on all matters related to research and the development of scientific knowledge pertinent to the identification, evaluation, and resolution of current and anticipated problems related to Great Lakes water quality." This is the Board's Emerging Issues responsibility under its mandate. The Board exercises its independence to bring forward scientific matters identified by its members as pertinent to current and anticipated problems of Great Lakes water quality. For the 2005-2007 biennial cycle, three issues were identified:

- Impact of Climate Change on Great Lakes Surveillance and Monitoring Activities
- Enhancing Evidence-Informed Decision-Making in the Great Lakes Basin
- Exposure to Persistent Organic Pollutants and Risk of Diabetes

All Board meetings are open to the public and, in keeping with Commission policy, the Board posts its minutes on the Commission Web site www.ijc.org . Anyone interested in attending a Board meeting or in making a scientific presentation to the Board should contact the Board Secretary for more information about the meeting schedule and agendas.

Chapter 2

Scientific Advice Arising from Commission Priority Activities

WINGSPREAD CONSULTATION ON STRENGTHENING SCIENCE UNDER A RENEWED AGREEMENT

On January 24-26, 2006, the Science Advisory Board's Work Group on Emerging Issues convened an Expert Consultation (details in Appendix 4) to explore means by which science might be strengthened within a renewed Great Lakes Water Quality Agreement. Of particular interest were institutional arrangements that would best promote the use and integration of science in decision making. On the basis of workshop discussions, the Work Group crafted a series of recommendations to help guide the Commission as it discusses revisions of the Agreement with the Parties with respect to the issue of how best to enhance science-based decision making applied to trans-boundary water resource management and governance in the Great Lakes Basin.

Sustaining the ecological health of the Great Lakes Basin Ecosystem relies on the ability to ascertain both current and future ecosystem stresses, predict the outcome of the stresses on ecosystem sustainability, and implement effective treatment. Accurate diagnosis, prognosis, and treatment require an understanding of the ways in which human activities in the basin – and beyond – influence the ecological health of the ecosystem, and *vice versa.* Science – broadly construed – offers one primary mode of inquiry by which the causal structure of the ecosystem can be inferred. Thus, a commitment to sustaining the integrity of the ecosystem implies a commensurate commitment to Great Lakes science. This leads directly to the question of the extent to which current institutional arrangements under the Agreement are well designed for the effective and efficient conduct of Great Lakes science and the delivery of scientific information to stakeholders. As a corollary, if existing institutional arrangements are not well designed, what changes increase the likelihood of achieving these objectives?

The recommendations presented below are derived from four fundamental truths. First, a commitment to social justice (and intergenerational equity in particular) requires a commensurate commitment to ecologically sustainable development, not only by the Parties under the Agreement, but by all agencies in the basin in whom some measure of decision-making authority is vested. Second, because understanding of the causal structure of the ecosystem is – and will remain – incomplete, diagnoses, prognoses, and treatments are subject to uncertainty. Third, science is a necessary component of sustainable decision making with regard to ecosystem health. Fourth, while ecosystem ailments may be manifested at a variety of spatial scales, all treatments are inevitably implemented at a local level.

Accountability – or rather the lack thereof – was identified by consultation participants as the major hurdle to achieving the Objectives set out in the Agreement. Limited accountability is due, in part, to the failure of the Agreement to adequately sustain many of the science functions enumerated below. While this report focuses on issues of scientific accountability, the Board recognizes that there are non-scientific accountability issues that should be addressed in any contemplated revision to the Agreement, and that there are additional accountability issues that lie outside the scope of the Agreement but are nonetheless critical to sustaining the integrity of the ecosystem and, as such, must be resolved by the Parties.

The Board notes that revisions to the Agreement may take the forms of revisions to the Articles and revisions to the existing Annexes, which might include the addition of new Annexes or the modification or deletion of current Annexes. Because of the formidable procedural issues involved in amending the Agreement and, in particular, its Articles, the Work Group strongly recommends that, as much as possible, the recommendations below be implemented by means of revisions to the current Annexes rather than to the Articles proper.

THE FUNCTIONS OF SCIENCE UNDER A REVISED AGREEMENT

The Agreement defines the framework for sustainable Great Lakes science. As such, it must minimally sustain or preferably enhance:

- Systematic and coordinated monitoring and surveillance with respect to both known and suspected stressors, and ecosystem responses thereto
- Elaboration of the causal relationships between stressors and ecological responses through hypothesis testing, refutation, and refinement
- Effective and efficient decision making with respect to ecosystem protection, remediation, or restoration
- Timely and accurate evaluation of the current ecological status of the ecosystem and trends therein
- Data management, integration, analysis, inference, and interpretation (i.e., diagnosis, prognosis, and prescription)
- Identification of scientific data and information gaps and frontier/horizon issues
- Dissemination of scientific data and information to stakeholders in a form that is both interpretable and usable
- Evaluation and assessment of performance in achieving Agreement Objectives or targets, and the efficient and coherent reporting thereof
- Public education on the current state of the ecosystem, trends therein, and undertakings by the Parties to sustain the health of the ecosystem
- The development and support of local, community-based research and monitoring initiatives
- Collaborative research initiatives among government, industry, academe, and non-government organizations

FINDINGS AND RECOMMENDATIONS TO STRENGTHEN SCIENCE UNDER A REVISED AGREEMENT

The Great Lakes have witnessed many improvements since inception of the Agreement in 1972, and the lakes continue to improve as a result of amendments. The most dramatic examples are the reversal of eutrophication in the lower lakes as a result of reductions in phosphorus loading and the well-documented reductions in the concentrations of some banned toxic chemicals in fish. Nonetheless, while science has advanced understanding of the ecosystem, political will has not kept pace and many goals of the Agreement have not been met.

The Expert Consultation identified where improvements could be made to the Agreement to improve the incorporation and utilization of science into decision making to better achieve the goals of the Agreement. These are presented below as findings and are followed by specific recommendations from the Board to the Commission, to be considered as part of any revision of the Agreement.

FINDING: The core principles currently specified in the Agreement should be augmented to take into account new knowledge on decision making in light of uncertainty.

The precautionary principle gained wide acceptance and public awareness following the United Nations' 1992 Rio Declaration and, more recently, the Board's 1998 Wingspread Consensus Statement. Since then it has, in various forms, been incorporated into many international and national agreements, policies, and regulations. Principle 15 of the Rio Declaration states: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." The Wingspread Statement described the precautionary principle as "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically" (Raffensperger and Tickner, 1999). The various versions of this principle (Sandin, 1999; Wiener and Rogers, 2002) usually share two features:

- Where evidence exists of a risk of serious or potentially irreversible negative outcomes, rendered decisions may ("weak" precaution) or should ("strong" precaution) mitigate this risk even when strong scientific evidence of such risk is lacking.

- Reversal of burden of proof ("very strong" precaution), namely that, in rendering decisions, the decision maker assumes that serious or irreversible outcomes will occur unless substantive evidence is adduced that they will not.

The principle of adaptive management (Holling, 1978; Walters, 1986) begins with the premise that, at least at present, most systems whose behavior one is attempting to influence (i.e., "manage") are complex and poorly understood. As such, management decisions should be regarded as scientific experiments designed to provide increased understanding of the causal structure of the system and, ideally, to test hypotheses about system behavior. Consequently, management decisions ought to be designed to elicit specific system responses; the knowledge acquired from these responses is then used to inform future decision making. In the original formulation (Holling, 1978; Walters, 1986), learning by experimental decision making was considered to transcend the more usual learning by trial-and-error decision making or (the still more usual) anecdotal learning (Lee, 1999), although there is no reason in principle that the latter cannot be part of a (somewhat less efficient) adaptive framework.

Decisions predicated on the assumption that expected effects will indeed occur run the risk of turning out to be very poor decisions if the unexpected occurs. By contrast, robust decisions are those that result in satisfactory outcomes even if there is large scientific uncertainty concerning the causes of observed effects, and limited ability to control (putative) causal factors, that is, under conditions where predicted outcomes are quite likely not to materialize. Ludwig et al. (1993), Walters (1997), and Lee (1999) have all pointed out that this is the usual case in many – if not most – environmental decision-making domains. As such, science-based environment decision making should be robust (in the sense defined above) unless it can be demonstrated that the costs of such decisions are oppressively high.

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Agreement explicitly commit the Parties to decision making that includes three overarching principles: the precautionary principle, the principle of adaptive management, and the principle of robustness.**

These Principles should be defined in Article 1 of the Agreement.

FINDING: The Specific Objectives in Annex 1 of the Agreement are outdated and a process to revise them has not been implemented.

Since the 1987 Protocol amending the 1978 Agreement, understanding of the stresses on the ecosystem and their effects has increased substantially. This accumulated knowledge requires that both the General Objectives (Article III) and the Specific Objectives (Article IV, Annex 1) be revisited. Moreover, a commitment to adaptive management necessarily implies that objectives are periodically reviewed to ensure their appropriateness in light of existing scientific and other information.

Paragraph 2(a) of the Supplement to Annex 1 requires that the Specific Objectives be reviewed at least every two years. This requirement has not been met.

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **A revised Agreement obligate the Parties to satisfy the existing requirement to review the Specific Objectives in Annex 1 at least every two years, and to report on the outcome of the review process. Moreover, the review should not be limited to the General or Specific Objectives in the Agreement.**
- ***All revised objectives be at least as stringent as existing federal, provincial, or state water quality standards for the protection of aquatic life, and the revised objectives should utilize the best scientific knowledge currently available about the impacts of pollutants on aquatic ecosystems and human health.***
- **The objectives be set to protect public health and be constructed, where possible, using a process-oriented framework – rather than a specific value – to provide for maximum flexibility in incorporating new science as it becomes available.**
- **Paragraph 3 of the Supplement to Annex 1 be revised to include a formal list of ecosystem health objectives and associated indicators for all lakes, as well as an explicit process by which these objectives and indicators will be revised.**

FINDING: There is inadequate scientific accountability under the current Agreement.

Participants noted that the Great Lakes are not managed effectively in part because the governance structure is incoherent, with too many organizations, little vertical or horizontal integration, and no centralized decision-making body. This lack of structural coherence limits not only the conduct of science but also the ability of decision makers to make full use of existing science.

To ensure that all Agreement-related recommendations are responded to in a timely, substantive, and public manner, the Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The revised Agreement include a new annex that clearly and explicitly addresses the issue of accountability.**

Specifically, the revised Agreement should require the Parties to establish a formal process to define:

- Performance indicators with respect to both the ecological health of the ecosystem and program delivery, effectiveness, and outcomes
- Standards (benchmarks) against which performance is assessed
- The agencies or organizations responsible for performance assessment
- The format and schedules for performance assessment reports
- Provisions to communicate the results of performance assessment to the public
- The format and content of responses to the assessment reports

FINDING: Surveillance and monitoring as well as basic and applied research are ad hoc, piecemeal, and inadequately supported.

Adaptive management requires the continuous infusion of new science into the decision-making process. Science must be provided to stakeholders in a form that is both interpretable and useful. Workshop participants identified a number of existing barriers to the pursuit of ecosystem research and monitoring. Annex 17 notwithstanding, these include:

- Inadequate financial support
- Insufficient attention to hypothesis-driven research (versus surveillance and monitoring)
- Inconsistent approaches to data gathering, processing, and dissemination
- Inadequate provision of scientific capacity to local governments
- The absence of a formalized process to determine ecosystem research priorities
- Failure to provide scientific information to stakeholders in an interpretable and usable form

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Parties commit to a level of support for research and monitoring commensurate with the principles of adaptive management.**

Toward that end, the Science Advisory Board (or similar body established under a revised Agreement) should be explicitly charged, in the Agreement, to undertake an ongoing assessment of research and monitoring needs, and to determine the costs required to ensure the full and timely implementation of Agreement provisions.

FINDING: The lack of centralized data management, the lack of data dissemination, inconsistent formats of data handling and storage, and the lack of meta data all lead to incomplete use of existing scientific efforts.

Considerable scientific data and information currently exist for the Great Lakes and its ecosystem, and the Board has recommended further investments in science for the future. However, these data are only useful if they are properly managed and made accessible to users, including other scientists, resource managers, decision makers, and the public. Data currently reside in a plethora of unrelated forms, from hard-copy data sheets in filing cabinets to arcane databases developed and used by a single agency but not accessible by others. Data are collected using different procedures, preventing comparability of data. Meta data and quality assurance data are rarely reported and archived to provide context for future data users. For science to be used most effectively in decision making and management of the Great Lakes, it is imperative that investments in data management provide for accessibility, data quality, and comparability.

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Agreement be amended to require a coherent, consistent, and accessible bi-national data management system that includes meta data.**

FINDING: There is redundancy caused by the Board structure as constituted under the present Agreement, and the Boards do not adequately meet the advisory needs of the Commission.

The issues addressed and the activities of the Science Advisory Board and the Water Quality Board have increasingly overlapped. The Boards as constituted under the original Agreement have, over time, become too inflexible and static to meet the challenging needs of Great Lakes restoration. Revision is necessary.

There was widespread feeling among Consultation participants that the current board structure, as specified under the 1978 Agreement, is outdated. While the optimal structure depends on the scientific functions one is attempting to maximize, many participants were of the view that the current board structure does not optimize *any* of the required functions. Several models for a new board structure were discussed.

- **Dissolve the Water Quality Board, since its membership and mandate are redundant with the Parties' Bi-national Executive Committee. Expand the Science Advisory Board to approximately 30 to 40 members to include a broader array of scientists.**
- **Combine the two Boards into an Integrated Science and Policy Advisory Board, with an executive committee that reports to the Commissioners. Membership on this Board would include scientists and policy specialists.**
- **Create a Bi-national Academy of Scientists (on the order of hundreds) that can be called on to serve on ad hoc work groups that address specific issues of interest to the Commissioners (e.g., the National Research Council committees or the National Academy of Sciences in the U.S.). These ad hoc work groups would report to a standing executive committee (a smaller Science Advisory Board) that would report to the Commissioners.**

The lack of centralized data management, the lack of data dissemination, inconsistent formats of data handling and storage, and the lack of meta data all lead to incomplete use of existing scientific efforts.

The board structure under a new Agreement should enable an adaptive management approach. Specifically, any new board structure should:

- Be flexible to adapt to changing needs.
- Provide current, timely, and integrated scientific advice to the Commissioners.
- Address all relevant scientific issues.
- Possess broader representation of stakeholders.
- Access a larger pool of scientific expertise.

A public advisory panel which incorporates members from municipalities, non-government organizations, and the general public is regarded as an integral requirement for each of these possible board structures.

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **A revised Agreement replace current Board arrangements with a single, Integrated Science and Policy Advisory Board, with an executive committee that regularly reports to the Commissioners.**
- **The Integrated Science and Policy Advisory Board be supported by a Bi-national Academy of Scientists that can be consulted, as needed, to provide expert advice on current and emerging Commission priorities.**

The Academy would be organized into issue-specific work groups, as needed, and prepare reports and recommendations for consideration by the Integrated Science and Policy Advisory Board and the Commissioners.

FINDING: Local governments are primarily responsible for the activities requisite to achieving many of the objectives of the Agreement, but they are not adequately represented and engaged.

Local governments have limited capacity to engage in the conduct and interpretation of science, notwithstanding the fact that most of the implementation of science, e.g., restoration, is at the local level. While it is impractical for representatives of local units of government to be signatories to the Agreement, it is important to support scientific objectives and activities at the local level and to communicate these activities to the Boards and the Commission.

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **Board structure under the revised Agreement include enhanced interaction with representatives of local governments and the public.**

The revised Agreement should consider creation of a forum for local governments, ensuring the free and open sharing of data, facilitation of mechanisms to work with local coalitions, enhancement of local scientific capacity, facilitation of community volunteer initiatives and outreach to local planners, and facilitation of local public advisory councils.

PATHOGENS – THE UTILITY AND LIMITATIONS OF MICROBIAL SOURCE TRACKING TOWARD PROTECTION OF RECREATIONAL WATERS IN THE GREAT LAKES BASIN

The Science Advisory Board's Work Group on Ecosystem Health continued its investigation of waterborne microbial pathogens in the Great Lakes, building on previous work undertaken with regard to the Commission's 2003-2005 human health priority (IJC, 2006). The Work Group invited an expert paper (Appendix 5) by Dr. Kate Field, Oregon State University, on the topic of microbial source tracking (MST) to address the current state of science using source tracking methods as an approach to improve management of surface water contamination.

Fecal contamination of surface waters is widespread in the United States, Canada, and worldwide. The resulting illnesses, beach closures, environmental and habitat degradation, and contamination of fisheries have broad economic, health, and environmental impacts. Several severe waterborne disease outbreaks have underscored the importance of the problem. The 1993 outbreak of cryptosporidiosis in Milwaukee, Wisconsin, is estimated to have affected 400,000 people at an estimated cost of 96 million U.S. dollars. In 2000 in Walkerton, Ontario, 2,300 people became ill and seven died as a result of drinking water contaminated with *E. coli* O157:H7 from cow manure. The Put-In-Bay, South Bass Island, Ohio, outbreak in 2004 was a direct result of fecal contamination of the drinking water, causing severe economic damage to tourism for that year.

Since the public health concern is microbial disease, the most straightforward approach to protecting health would be to directly monitor microbial pathogens in water. Effective assays for many pathogens exist, such as the methods used for the required monitoring of *Cryptosporidium* and *Giardia* by the drinking water industry. However, some of the methods for other emerging and enteric pathogens are experimental, some are moderately expensive compared to indicator testing, availability of results may be 24 hours (e.g., real-time polymerase chain reaction (PCR)) or may take several weeks (cell culture methods), and some methods are technically complicated and would be available and used only in more modern water laboratories. In addition, studies on the application of the methods are needed, as well as good statistical approaches for temporal and spatial sampling. Otherwise, the sampling may not be adequately protective since it may miss pathogens that are rare and irregularly distributed, yet highly infectious even at low doses. Furthermore, a large number of assays for different pathogens would be required, and multiplexing methods are just now beginning to be tested. Feces from both humans and animals may contain as-yet-unidentified pathogens or pathogens for which no assays exist.

Because of these limitations, direct monitoring of pathogens has been limited to cultivatable viruses, *Cryptosporidium* and *Giardia*, for the U.S. Information Collection Rule, the Groundwater Rule, and the Enhanced Surface Water Treatment Rule. More often, particularly for ambient waters, standard practice has been to monitor fecal indicator bacteria (FIB) such as total and fecal coliforms. FIB are enumerated in water samples as indicators of possible fecal contamination; their presence in water is assumed to be due to fecal contamination. Exceedences of FIB-based water quality standards have occurred throughout the basin, at sites in all five Great Lakes. Some of the important related issues include beach closures, combined or sanitary sewer overflows, failing septic systems, agricultural and storm water runoff, pets at beaches, low water levels, extensive wildlife populations including Canada geese and gulls at beaches, fish kills, and algal blooms.

Although the use of FIB to assess water quality has certainly reduced human exposures to fecal microbes and, thus, human health risk, the current FIB approaches fall short. First, indicator bacteria do not identify the source of contamination. The fact that indicator counts lump together many different potential sources of fecal contamination, which may have wholly different associated pathogens, presents a problem from a risk assessment/risk management viewpoint.

A variety of warm-blooded, and even some cold-blooded, animals have FIB in their feces. The human risk from domestic and agricultural animal feces is usually assumed to be less than the risk from human feces, in part because viruses, which are the most common cause of human illnesses from exposure to fecal contamination in water, are highly host-specific.

Second, while it is generally assumed that disease risk to humans from fecal contamination by wild animals, such as gulls, is lower than that from human fecal sources, it should not be ignored. These risks are currently poorly understood. Although events are rare, it is known that when wild animal viruses do cross into humans, they may be deadly; HIV/AIDS and H1N5 bird flu are prominent examples. Certain waterborne bacterial and protozoan pathogens of wild animals have been documented to infect humans (e.g., *Campylobacater*, *Salmonella*, *Leptospira interrogans*, and *Giardia*).

However, an approach based on the simple presence of these organisms may be highly conservative. *Giardia* and *Cryptosporidium* widely infect wild animals, and mammalian cross-species infectivity has been well documented. Because these parasites appear structurally identical in animals and humans, wild animals have long been assumed to be reservoirs and important sources of human infection. In recent years, molecular evidence has made it clear that some of the genotypes of these parasites are host-adapted and cannot cross-infect among different host species. For example, some authors have concluded that although Canada geese feces contain cryptosporidia, Canada geese might only serve as accidental carriers of cryptosporidia infections to humans and probably play a minor role in the animal-to-human transmission cycle of the pathogen.

Thus, the presence of indicator species in water is not sufficient to determine the source of fecal contamination and therefore not sufficient to assess or manage risks to human health and may even be misleading. To manage water quality, the source of fecal contamination must be known, both to find and mitigate the problem and to estimate human health risk.

Since MST offers the promise of identifying the source or sources of the contamination, it could be of considerable benefit, if it could be implemented. From the point of view of regulators, the most important objective may be identification and elimination of the source or sources of FIB (not feces, not pathogens). A second objective is to identify particular pathogens in water. Certain sources of fecal pollution might be associated with particular pathogens (e.g., *E. coli* O157:H7 with ruminant feces). This is closely related to the third objective: to estimate the human health risk associated with exposure to contaminated water.

Unfortunately, as documented in the expert report in Appendix 5, a number of technical issues need to be solved before MST can live up to its promise. More than likely host-specific markers including those found in enterococci, bacteroides, and viruses will be most useful in determining sources in the future. More studies are needed on quantitative assessment and use of multiple targets. These need to be applied during rain events associated with non-point source pollution and applied directly to transport of these markers from point sources to exposure sites.

Water quality regulators are frequently in the situation where high bacterial counts are thought to be due primarily to wildlife. Even if microbial source tracking shows that fecal contamination is wholly animal-derived, current regulations do not usually allow for a higher permitted level of FIB. Hence, the benefits from microbial source tracking at the present time are only that it allows the source or sources of fecal contamination to be accurately assigned, located, and corrected. In some cases this could lead to a reduction in FIB. In others, where the source is primarily wildlife and there is no way to control the wildlife, no immediate water quality benefit from microbial source tracking will be seen. However, regulators must identify and eliminate all possible fecal sources; even when there is a lot of wildlife, human sewage, septage leaks, and agricultural runoff may still be identified.

The Science Advisory Board will continue to monitor the emerging science in this area as well as any pilot studies that may be undertaken, and inform the Commission concerning the status of MST methods and their applications.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **An inventory be undertaken of all microbial source tracking studies conducted to date for watersheds and water bodies in the Great Lakes.**

The inventory would include number of sites, number of samples, method, and results.

- **All Areas of Concern in the Great Lakes where recreational swimming is impaired be piloted to address the implementation of microbial source tracking studies using latest technology.**

A U.S. Environmental Protection Agency grant is presently funding a collaborative Gulf of Mexico project to determine the most useful currently available, library-independent microbial source tracking methods for detecting human fecal contamination at beaches and in shell fishing waters across Gulf Coast waters. The same should be done for the Great Lakes.

EVALUATION OF DAM REMOVALS – AN ECOSYSTEM APPROACH

On June 6, 2006, a consultation entitled An Ecosystem Approach to Dam Removals in the Great Lakes Basin was conducted in Windsor, Ontario, on behalf of the Science Advisory Board. Presentations addressed effects on fish communities, evaluating risks to wildlife, sedimentation, invasive species, energy considerations, and economic modeling. These formed the foundation for a roundtable discussion of the need for an ecosystem approach and a decision-making framework.

Dam removal has emerged as a major environmental management issue. Dam removal is sometimes promoted under the assumption that removal will be inherently beneficial because dam presence is considered detrimental to aquatic ecosystems. While removal can benefit many components of local ecosystems, it also may result in detrimental impacts. For example, sediment – especially contaminated sediment – released following dam removal may be harmful to downstream ecosystems. Other effects include the passage of contaminated fish to upstream areas where they are not currently impacting wildlife, loss of commercial value of real estate located along current impoundments, and the potential inland spread of Great Lakes invasive species. Whether such impacts are temporary or whether there will be significant long-term perturbations to already stressed ecosystems deserves increased attention and consideration. Because of the potential for both beneficial and detrimental effects, the appropriateness of dam removal projects to enhance habitat requires further evaluation. Little published environmental impact information has accompanied the removal of dams in the Great Lakes Basin. The lack of well-documented studies of short- and long-term impacts confirms the need to develop a suitable decision-making framework and to ensure the utilization of an ecosystem approach during the evaluation and completion of future dam removal projects.

Findings

A decision-making framework must be developed to meet the needs of decision makers who to this point have not been supplied with adequate criteria to make decisions. These criteria should be peer reviewed and adaptable to many different unique dam sites.

Additionally, no decision-making framework can be created without complete scientific data. Without coordinating and conducting scientific studies of dam sites before and after dam removal, no data will exist that could be used to justify removal. Once possible effects of a dam removal are known, a more complete scientific framework could be established to include a "big picture" outlook from the beginning to the end of the removal process.

Two major types of decision-making frameworks must be considered for dam removal along Great Lakes tributaries. The first would consider the effects of all dams located upstream of the lowest barrier dam. Such removals would not open the tributary to the Great Lakes aquatic ecosystem, including greater concentrations of persistent organic pollutants and invasive species. The second, different framework would only be used for removal decisions regarding the lowest barrier dam. Since such removal would open additional river miles or, possibly, the entire river system to the Great Lakes aquatic ecosystem, this second framework would need to include effects of fish as vectors of environmental pollutants and the availability and movement of invasive species.

Among other considerations for dam removal are the following:

- Alternative disposal methods for contaminated sediment should be developed through coordination with soil experts. This may lead to a reduction in the cost of dam removal where sediment plays an influential role and may have to be removed.
- There is a need to analyze the consequences of switching from a lacustrine environment back to a riverine environment after the removal.
- A long-term focus is required when choosing and coordinating projects.
- Because every dam site has different factors that will be affected by the removal, each site is unique and must be evaluated independently.
- A range of issues and values must be taken into account when considering dam removal. A "big picture" outlook must address current problems and, as well, future consequences must be understood and planned for as best as possible.
- An ecosystem approach must be adopted and combined with a strategic plan to do as much good as possible when faced with limited resources, understanding that every pressing issue will not be addressed immediately.
- A larger literature review or workshop may be able to combine research projects that, once compiled, may better address the diverse factors influencing dam removal.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Parties, in collaboration with other partner institutions, develop guidelines and criteria, including analytic tools, to assess cumulative competing risks and benefits (including opportunity costs) of dam removal or retention in the Great Lakes Basin that can be embraced by relevant regulatory agencies.**

The tools should specifically allow for the assessment of competing risks and benefits at multiple spatial (local versus regional) and temporal (short-term versus longer-term) scales and for proactive local involvement in tool design and implementation, particularly the specification of valued ecosystem components.

- **The Parties facilitate the participation of all responsible and affected federal, state, provincial, and municipal agencies in an integrated plan for dam disposition in the Great Lakes Basin.**

Dam dispositions should be designed to maximize cumulative scientific value and information content regarding dam removals, and should be coordinated among all responsible and affected agencies. Each removal should be treated as a bona fide scientific experiment using the analytic tools developed as called for above.

- **The International Joint Commission explicitly take account of the issue of dam disposition in the development of the nearshore framework and in the development of its 2007-2009 priorities.**

The Science Advisory Board will continue to assist the Commission in this regard and will address dam disposition as an emerging issue during the 2007-2009 priority cycle.

HEALTH EFFECTS AND NEW CHEMICALS – OMEGA-3s AND FISH CONSUMPTION ADVISORIES

Benefits versus Risk of Consumption of Great Lakes Fish

The question of benefits versus risk of fish consumption has been discussed within the Great Lakes public health community for many years and remains an important issue. As reflected in fish consumption advisories, the United States and Canada recognize fish as nutritious food. The general subject of fish consumption has been reviewed in an excellent report of the U.S. National Academy of Sciences (2006) entitled *Seafood Choices: Balancing Benefits and Risks*. The specific issue of benefits versus risk of Great Lakes fish consumption was reviewed by the Science Advisory Board and the Health Professionals Task Force at a one-day workshop held January 3, 2007. The issue was also the subject of a discussion paper prepared by the Task Force in January 2004 entitled *Great Lake Fish Consumption Advisories: The Public Health Benefits and Risks*. Rather than furthering an artificial controversy between nutrition and toxicology, it is recognized that some fish have excellent nutritional value and are comparatively low in pollutants.

The Benefits of Fish Consumption

Besides being a good source of protein, there is gathering evidence of health benefits associated with eating fatty ocean fish (e.g., salmon, herring, sardines), primarily from the presence of omega-3 fatty acids. Omega-3 fatty acids are a dietary essential for humans who cannot synthesize these at a rate sufficient to meet metabolic requirements. The major omega-3 fatty acids have 18, 20, or 22 carbons and have the first of 3 to 6 double bonds at the third carbon from the methyl end. The C18 omega-3 is linolenic acid, which is found in high concentrations in flaxseed, soy and canola oils, English walnuts and, at lower concentrations, in green leafy vegetables, corn oil, almonds, and hazelnuts (Connor, 1999). The major C20 (eicosapentaenoic acid, EPA, 20:5n-3) and C22 (docosapentaenoic acid, DPA, 22:5n-3 and docosahexaenoic acid, DHA, 22:6n-3) omega-3 fatty acids, in contrast, are found almost only in seafood and algal sources. These substances are synthesized by lower fungi, bacteria, and marine microalgae, then bioconcentrated in the marine food chain. They are not synthesized by fish. Omega-3 fatty acid levels are particularly high in fatty fish, but all seafood have some.

In addition to fish as a source of omega-3 fatty acids, food technologists have developed a wide variety of products to which algal-derived omega-3 fatty acids have been added (e.g., orange juice, pastas, cereals (Bourre, 2007; Kolanowski et al., 2001; Anthony, 2007; Tropicana, 2007; Conquer and Holub, 1996)). Such products can be a source of omega-3s to nonfish consumers and/or vegetarians.

Humans have limited ability to synthesize the longer-chain omega-3s from linolenic acid, and the rate of biosynthesis may not be adequate to meet physiological needs. The rate of endogenous biosynthesis of omega-3 fatty acids is generally about 15% in young adult males but varies substantially among individuals (Emken et al., 1994). Omega-6 fatty acids, also an important dietary constituent, are found in many foods including vegetable oils, meats, and fish. Most contemporary diets contain excessive amounts of omega-6 fatty acids, in contrast with omega-3 fatty acids. It has been suggested that, in hunter-gatherer humans of the past, the ratio of omega-6 to omega-3 fats in the diet was of the order of 1:1, whereas currently in developed countries it may be as high as 16:1 (Simopoulos, 2002).

Omega-3 fatty acids are major structural lipids in neuronal membranes and are important for fetal cerebral development. DHA comprises 30% to 40% of phospholipids in gray matter of the cerebral cortex and photoreceptor cells of the retina (Innis, 1991), and 10% to 20% of total brain lipid, while alpha linolenic acid, EPA, and DPA together comprise only about 1% of total serum lipids (Rosell et al., 2005; McNamara and Carlson, 2006). In human fetal brain, DHA accumulates at a rapid rate in the third trimester of pregnancy as part of specific phospholipids (especially in phosphatidylethanolamine and phosphatidylserine). Prolonged omega-3 deficiency in animals leads to learning deficits (Catalan et al., 2002).

In full-term infants, whether breast fed or not, there are conflicting reports as to whether there are cognitive benefits from fish consumption or omega-3 supplementation. Lucas et al. (1999) and Ghys et al. (2002) found no evidence of benefit of omega-3 supplementation, but others (Birch et al., 2005) have reported positive effects on vision and cognition. There is good evidence that premature infants who are not breast fed benefit from supplementation (Carlson et al., 2004). Because of the critical role that omega-3 fatty acids play in neuronal function, many advocate maternal fish consumption or omega-3 supplementation during pregnancy and in infant formula.

A new area of investigation relates to the possible benefit of omega-3 consumption on cognitive function in old age and in psychiatric diseases (Morris et al., 2005; Solfrizzi et al.., 2006). There is no evidence to support these conclusions from randomized clinical trials, and some conclude that there is little basis to conclude that omega-3 fatty acids improve depressed mood (Appleton et al., 2006). However, various reports have suggested that omega-3 consumption may reduce psychiatric diseases (Noaghiul and Hibbeln, 2003) including post-partum depression (De Vriese et al., 2003), hostility (Iribarrren et al.., 2003), attention deficit hyperactivity disorder (Joshi et al.., 2006), and Alzheimer's disease (Morris et al., 2003).

There is a significant body of evidence indicating that persons who eat seafood regularly have a lower incidence of cardiovascular disease. This suggestion dates from early studies that reported low rates of

Nearly all fish contain some methyl mercury, but levels are high especially in large, predatory fish living in water which has mercury in the sediments. Methyl mercury is sufficiently lipophilic that it is able to cross the blood-brain barrier in humans, and the major health concerns are central nervous system effects.

cardiovascular disease in Arctic natives in spite of a high rate of fat intake (Bang et al.., 1980). This conclusion has been questioned (Bjerregaard et al., 2003; Hooper et al.., 2006), but there are a number of studies in populations showing that omega-3 intake reduces risk of sudden cardiovascular death (see Psota et al., 2006).

The mechanisms whereby omega-3 fatty acids promote cardiovascular health benefits are incompletely known. It is thought that these lipids increase membrane fluidity which, in the case of heart muscle, may reduce the likelihood of a fatal arrhythmia following a heart attack (Leaf et al., 2005).

Although there are reports alleging a benefit of seafood consumption or omega-3 supplementation on reduced rates of other diseases (diabetes, hypertension, cancer, asthma), convincing evidence for this conclusion from randomized clinical trials is lacking. These benefits may be indirect in that people who frequently eat fish are simply eating less unhealthy foods.

There have apparently not been any studies that specifically address benefits of consumption of Great Lakes fish, and their comparison to other food sources in spite of the large number of studies addressing risks.

The Risks of Fish Consumption

The health risks from fish consumption and/or fish oil supplementation come from two sources: possible health hazards of excessive omega-3 fatty acids and adverse health effects resulting from the presence of chemical contaminants in fish and fish oils. The American Heart Association cautions against taking more than 3 grams of omega-3s from capsules per day, since some people (especially those on anti-coagulant therapy) have developed excessive bleeding with high intake of omega-3 fatty acids (Mortensen et al., 1983; Mueller et al., 1991; Rodgers and Levin, 1990; Harris et al., 1991; Schmidt et al., 1991; Tracy, 1999; and Jalli and Dehpour, 2007).

Concerns over high intakes of fish fall into two major groups: methyl mercury and persistent organic pollutants (POPs) such as PCBs, dioxins/furans, and chlorinated pesticides. Due to extensive mercury contamination of freshwater fish in the Great Lakes Basin, states and the Province of Ontario have issued extensive fish consumption advisories to women of child-bearing age to protect fetal neurological development, the developing child, and young children.

Methyl mercury is formed from inorganic mercury by sediment microorganisms. Inorganic mercury enters water bodies through atmospheric transport or run-off. Methyl mercury binds to the sulphhydryl groups of proteins in skeletal muscles and bioconcentrates in the food chain. Nearly all fish contain some methyl mercury, but levels are high especially in large, predatory fish living in water which has mercury in the sediments. Methyl mercury is sufficiently lipophilic that it is able to cross the blood-brain barrier in humans, and the major health concerns are central nervous system effects.

There is no question that high exposure to methyl mercury causes harm and even death, and that the fetus is much more vulnerable than adults. This is most clearly demonstrated by poisoning episodes in Japan and Iraq. There is, however, debate over what degree of exposure constitutes harm. There have been three large studies of children – in the Faroe Islands, the Seychelles, and New Zealand – and other studies near gold mining areas in the Amazon. In a review of these studies, the National Academy of Sciences (2000) issued a report that concluded that the data supported the conclusion that the fetus was at risk of neurobehavioral decrement if the umbilical cord blood exceeded about 58 mg/L (see Mahaffey, 2000). U.S. EPA supported this conclusion and used this concentration as the benchmark dose lower limit which is associated with a doubling of the prevalence of scores in the clinically abnormal range on tests of neurodevelopment. An uncertainty factor of 10 was applied to this lower limit benchmark dose calculation. With this uncertainty factor, data from the biomonitoring of U.S. citizens indicated that 8% to 10% of U.S. women of childbearing age have blood methyl mercury levels that the U.S. EPA considers to be unsafe (Schober et al., 2003). However, at the time this assessment was made, the concentration of methyl mercury across the placenta was not included in the assessment. A meta-analysis of 10 studies of mother-infant pairs concluded that, on average, the cord blood mercury concentration is 70% higher than maternal blood (Stern and Smith, 2003) making a cord blood of 58 ug/L and a maternal blood mercury concentration of ~35 ug/L approximately equal.

While neurobehavioral decrements are the major concern for methyl mercury, persistent organochlorine compounds such as PCBs not only cause similar decrements in IQ and behavior, but also are correlated with a number of other disease states, including cancer, suppressed immune system function, endocrine disruption of thyroid and sex steroids, diabetes, and cardiovascular disease. Furthermore, while methyl mercury in human blood is reduced by half in approximately 70 days, for organochlorines the time required to reduce by half is of the order of ten years. There is very strong evidence for decrements in IQ and adversely altered behavior in children whose mothers consumed contaminated Great Lakes fish before and during pregnancy (Jacobson and Jacobson, 1996; Stewart et al., 2003 and 2005; Newman et al., 2006). As well as methyl mercury, prenatal exposure appears to be more harmful than exposure later in life, but even adults who consume large amounts of contaminated fish demonstrate reduced memory function (Schantz et al., 2001). While there has been less study of other diseases in relation to organochlorine exposure, recent studies of Great Lakes populations demonstrate decrements in thyroid function (Schell et al., 2004) at serum concentrations of PCBs and pesticides that are not much higher than those found in the background North American populations.

Significant concern exists over another relatively uninvestigated contamination problem, the presence of new classes of persistent compounds, particularly the brominated flame retardants which are structurally related to PCBs, and perfluorinated organics used in teflon and water-repellant coatings. These chemicals are being found in high concentrations in fish and are toxic. While there is presently very incomplete information on health effects, the fact that these compounds are persistent and present throughout the ecosystem raises significant concern.

Finding the Right Balance Between Risks and Benefits

The above considerations lead to the conclusion that consumption of uncontaminated fish is nutritionally beneficial, but that the presence of contaminants may substantially decrease the beneficial effects of fish consumption and expose fish consumers to unhealthy levels of other contaminants. This is a particular problem for some Native Americans and some immigrant populations who traditionally catch fish for food, and for sports fisherpersons who often consume significant quantities of the fish they catch. Although there is clear evidence of potential harm at all ages, it is clear that the fetus is the most vulnerable. Thus there is a particular problem with consumption of contaminated fish by women during their reproductive years. A woman can substantially reduce her blood mercury concentrations if she avoids contaminated fish for one year prior to becoming pregnant. However, the long half life of the organochlorines indicates that even young girls risk future exposure of their fetus if they consume significant amounts of contaminated fish.

In the attempt to balance the risks and benefits of freshwater fish consumption, the Great Lakes states and the Province of Ontario provide advisories that discuss the benefits resulting from fish consumption. To maximize benefits, the advisories emphasize eating smaller fish and less predatory fish which have lower contaminant levels. In future evaluations the Science Advisory Board will discuss advisories and the risk and benefit messages they contain.

Science to date clearly indicates that women of reproductive age and young children are especially vulnerable to contaminants. These groups should avoid and/or limit consumption of Great Lakes area fish to species, sizes, and frequency as specified in current advisories until such time as levels of persistent toxic substances in the Great Lakes region decline below concentrations that trigger fish consumption advisories for cancer and non-cancer health effects.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The states and provinces be advised to develop fish consumption advisories and communication messages that consider both contaminant levels and omega-3 fatty acid content of fish so that the benefits of fish consumption are maximized through the consumption of fish containing the lowest concentrations of contaminants and the highest concentrations of omega-3 fatty acids.**
- **Research, in particular involving First Nation populations, be conducted that specifically addresses the benefits of consumption of freshwater fish from the Great Lakes region and in comparison to other food sources.**
- **Governmental monitoring of contaminants in freshwater fish also include additional evaluations of levels of omega-3 fatty acids in order to further evaluate risk and benefits of relative levels of contaminants and omega-3 fatty acids and to advise people on how to choose fish species that are the highest in omega-3 fatty acids and lowest in contaminants.**
- **Fish consumption advisories be continuously updated on the basis of new information about contaminants and about health benefits.**
- **Women of reproductive age, children, and young girls be informed that the benefits to the developing fetus of obtaining omega-3s by eating fish can be achieved by eating uncontaminated ocean fish, or through a low-risk option of fish oil supplementation, or consumption of foods with added omega-3 fatty acids.**

THE STATUS OF GROUNDWATER IN THE GREAT LAKES BASIN

The Commission's Investigations

The year 2007 marked the 20th anniversary of the incorporation of Annex 16 – Pollution from Contaminated Groundwater – into the Agreement. 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 will culminate in a stand-alone Commission report about the status of groundwater in the basin. That 2008 report, *State of the Great Lakes Basin Groundwater*, will contain findings and recommendations from the current effort. The report will expand and update the Commission's 1993 report as well as the Commission's 2000 report, *Protection of the Waters of the Great Lakes*. It also will provide information about emerging groundwater issues and concerns, linkages with other Commission priorities (e.g., urbanization and pathogens), and implications regarding water quantity issues contained in the Great Lakes Charter Annex 2001.

The 2005-2007 priority, under the leadership of the Science Advisory Board, was a collaborative effort with the Council of Great Lakes Research Managers. As work plans were developed, it became clear that human health expertise also would be valuable. Therefore, the Health Professionals Task Force joined the collaboration. The Council and the Task Force respectively identified contractors to prepare scholarly reports on groundwater research needs and human health implications of groundwater-borne pathogens and contaminants. Their insight and the advice provided was considered and incorporated into the 2008 report.

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

After the first consultation, it became clear that issues and concerns about groundwater in the Great Lakes Basin go far beyond the focus of Annex 16, that is, groundwater as a source of contaminants to the lakes. After the second consultation, the Commissioners specifically asked the collaborators for input, based on deliberations to that point, to assist in preparing Commission advice to the Parties regarding review of the Agreement. The co-chairs of the Board subsequently sent a letter to the Commissioners (see Appendix 3).

The Importance of Groundwater

Groundwater is extremely important to both the quantity and quality of water in the Great Lakes. It is estimated that there is as much groundwater in the Great Lakes Basin as there is surface water in Lake Michigan. The groundwater contribution to the Great Lakes ranges from 48% in Lake Erie to 79% in Lake Michigan. Groundwater provides 82% of potable water needs for rural populations, 43% of agricultural water, and 14% (and escalating) of industrial water in the basin. Generally, the quality of groundwater resources in the Great Lakes Basin is very good. However, the quality is threatened in many parts of the basin, with worrisome implications for public health and economic development. The following issues, selected by the Board's Work Group on Parties Implementation, illustrate the breadth of groundwater concerns in the basin.

Data Quality and Availability

Collaboration among the jurisdictions and their agencies is essential to establish an internally consistent, coherent, and seamless data and analysis system for groundwater in the Great Lakes Basin. However, the funding, instrumentation, and analytical capacity required to monitor basin groundwater quality and quantity has declined substantially in the last twenty years. Although modeling has improved and now offers impressive capability to inform decision makers about groundwater quality and quantity, the erosion in the collection of baseline hydrogeological data precludes meaningful model calibration or application in many parts of the basin. The most pressing scientific issues are:

- Better characterization of subsurface conditions, especially the hydraulic conductivity of geologic materials
- 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

To reverse past declines in data collection and monitoring, Ontario in 2000 restarted a province-wide 450-well monitoring program for groundwater with costs shared by the provincial government and local conservation authorities. With funding from a new carbon tax, Quebec will in 2008 re-establish 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.

Data Mapping and Modeling

The Geological Survey of Canada has developed an interactive Web-based geologic mapping tool that can be used for extensive characterization on a site-by-site basis The tool also helps communicate findings to the public. A user can actually "see" aquifer prospects at specific sites. For the Oak Ridges Moraine area near Toronto (10,000 km^2), geological content was collected over 10 years at a cost of $1 million per year.

Aquifer boundaries do not conform exactly to the surface water boundaries of the basin. The precise boundaries of the connected aquifers are imperfectly known in most locations.

The United States Geological Survey undertook detailed modeling of the groundwater system in southeastern Wisconsin, adjacent to Lake Michigan. Results established the major features of the groundwater system in the region and quantified the impact of municipal pumping from the complex system of aquifers in the area. Municipal pumping in Wisconsin and the adjacent area in Illinois have created a "world class drawdown cone" in this sandstone aquifer with water level declines of more than 250 meters. Pumping also has caused some deterioration in water quality; in particular, radium and radon concentrations are of considerable concern. Pumping has shifted the divide in the aquifer to the west, farther away from Lake Michigan. The amount of pumping from the aquifer is much larger than the natural flow of groundwater to Lake Michigan. The model will contribute to successful resolution of water management issues in this region.

Specific Groundwater Quality Issues and Contaminant Sources

Viruses

Viruses are common in groundwater, even groundwater from deep confined aquifers. Viruses travel farther and survive longer than bacteria in groundwater because of their small size and because they have the same electrical charge as soil and rock particles. Overall, 90% of waterborne pathogenic disease outbreaks are attributable to water systems supplied from groundwater, and more than half of these water-related illnesses may be due to viruses. The source of disease-causing viruses is human fecal waste from malfunctioning septic tank and seepage bed systems and leaking sanitary sewers. The occurrence of waterborne viral disease is correlated to density of septic systems. The causes of diarrhea in children under age five in central Wisconsin were reviewed. More than 20% of the cases were due to contamination of well water from failed septic systems. A critical observation is that the usual measures of sanitary quality based on bacteria do not correlate with viral contamination. The concerns associated with the on-site treatment of sanitary waste are discussed below.

Nutrients and Pesticides

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

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

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

On-Site Treatment of Human Waste

Inappropriate septage practices are of concern. Many small rural communities rely on aging individual septic systems or drain tile networks that discharge sewage directly to surface waters, even though direct discharge of untreated sewage is illegal. According to the Minnesota Pollution Control Agency, there are an estimated 64,000 septic systems posing an imminent threat to public health in the state. They estimate that it will cost $1.2 billion to fix all the septic system problems in Minnesota (Wallace et al., 2006).

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

Approximately 25,000 new or replacement on-site systems (OSSs) are installed annually in Ontario with similar numbers installed in each of the Great Lakes states each year. There has been little research to understand the extent of effects of OSSs on groundwater but, in addition to bacteria, viruses, and nutrients, pharmaceuticals and personal care products are a growing concern. Although there are 1.4 million OSSs in Michigan, there is no state-wide on-site system code. Most jurisdictions do not compile information on new or existing systems. Systems have a 30-year lifespan due to hardware issues and soil saturation, and 50% of the systems in the United States are older than 30 years.

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

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

Leaking Underground Storage Tanks

Leaking underground storage tanks (LUSTs) are a serious concern to groundwater quality in the basin (CESD, 2002). Although an accurate measure of total USTs in the United States and Canada is currently unknown, estimates place the number, for both countries combined, in the millions (Sierra Club, 2005). Many USTs are known to be leaking or have leaked at some point in the past. USTs frequently contain potentially dangerous and toxic substances including, but not limited to, oil, gasoline, diesel fuel, aviation fuel, other petroleum products, solvents, and waste/spent fluids (Sierra Club, 2005).

Every year hundreds of new LUST sites are discovered in both countries. Currently, the estimated United States national total of LUSTs backlogged for remediation is about 114,000; this number, however, only takes into account the known, 2.3 million USTs which are subject to federal regulations (U.S. EPA, 2006). Other sources indicate that there may be an additional 3.8 million non-federally regulated and orphan USTs in the United States (Sierra Club, 2005).

The U.S. federal Lust Trust Fund, established in 1986, provides a subsidy to regulate the actions of tank owners and operators and to clean up contaminated soil and groundwater. The fund is financed through a 0.1 cent per gallon tax on the sale of motor fuel (U.S. EPA, 2006). Fund assets are currently in excess of $2.6 billion (Government Accountability Office, 2007). Although total revenue to the fund in 2005 was $269 million, only $59 million was distributed among the 50 states and the District of Columbia.

Cleanup at one LUST site, a gasoline station in Utica, New York, cost over $2 million, which was equivalent to the total received by the state for its entire LUST program from the fund in 2006. In the Great Lake states, estimates of funding for necessary LUST remediation are over $3.3 billion (Sierra Club, 2005; U.S. EPA, 2006). Effective 2007, New York state authorities are now able to prevent deliveries to gasoline stations with known LUSTs. Ontario municipal officials have similar authority.

There are approximately 3,800 gasoline stations operating in Ontario, each with several USTs. Accurate numbers are not presently available for the total number of commercial, residential, institutional, and agricultural USTs in the province. However, recent assessments lead to a conservative estimate of at least 10,000 commercial USTs. Based on previous estimates that 5% to 35% of all tanks are leaking, it is believed that 500 to 3,500 are (MacRitchie et al., 1994). Estimates to clean up LUST sites in Ontario are therefore pegged at between $73.5 and $514.5 million.

Niagara River

Biomonitoring for contaminants discharging into the Niagara River began in 1975. Caged mussels, placed above and below targets, effectively detect sources and discharges of organic contaminants. Due to funding constraints, surveys are only run every two to three years at 30 to 35 sites and then only for three weeks at each site.

A large number of chemical sources remain along the Niagara River. As part of the Niagara River Toxics Management Plan, upstream and downstream monitoring is conducted to calculate a mass balance for the river. Monitoring is complicated by sediment

Petroleum refineries are also a significant source of groundwater contamination. At Whiting, Indiana, in the Grand Calumet Area of Concern, an estimated 60 million liters of petroleum light non-aqueous phase liquids are floating atop the water table

movement and volatilization of substances as they flow over Niagara Falls. However, contaminant levels appear to be declining in Lake Erie, but contributions from groundwater discharges in the Niagara region do not appear to be decreasing.

Also as part of the Plan, annual reporting on the loading of 18 priority toxic chemicals has been underway since 1998. Toxic loads were reduced by 93% from 1989 levels for 19 sites with remedial costs to date of $406 million. Estimates of future costs are $270 million. However, the quality of the original baseline study is uncertain, subsequent studies limited or highly debated, and some findings never released. Further, calculations are based not on actual measurements but on actions taken. In addition, many significantly contaminated sites in the area are not being addressed.

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

Other Sources of Groundwater Contamination

The significant frequency of spills and leaks from home and cottage heating oil tanks is another threat to groundwater quality; however, such tanks fall below regulatory volume limits. Petroleum refineries are also a significant source of groundwater contamination. At Whiting, Indiana, in the Grand Calumet Area of Concern, an estimated 60 million liters of petroleum light non-aqueous phase liquids are floating atop the water table (Indiana Water Resources Association, 1993; IJC, 1993).

Regulatory Issues and Groundwater Protection Initiatives

In most jurisdictions, ground and surface waters are regulated – if at all – under separate statutes, but there is little or no legal recognition of connections between surface and ground waters. Because of the separation of legal authorities, the limitations of riparian water law, and the embryonic state of law concerning subsurface water in most Great Lakes jurisdictions, there is little basis in statutory or common law to establish the duties of water users with respect to water withdrawals and impairments.

Great Lakes jurisdictions have undertaken several initiatives to protect groundwater that warrant broader examination and adoption.

"Point-of-Sale" On-Site Wastewater System Inspections

"Point-of-sale" on-site wastewater system inspections are essential to any comprehensive management program, and they offer a key opportunity to inventory OSS locations. "Point-of-sale" on-site regulations are controversial. Mandatory inspection regulations provide only a snapshot of the system's condition on the date of inspection, and there is a continued shortage of qualified inspectors. Regulations have been embraced in Wisconsin but have been aggressively opposed in Michigan by Realtor associations, home and cottage owners, and under-funded county health officials (Dietzmann, 2007). The Ohio Department of Environmental Quality implemented an inspection program in 2003, but some jurisdictions in the state found that the hefty cost of replacing a failed septic system causes some residents to abandon their property, which is then repossessed by the lender and may sit vacant for long periods of time.

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

Abandoned Wells

Abandoned wells in the Great Lakes Basin range from small-diameter geotechnical test holes to intercontinental ballistic missile silos. The Michigan Department of Environmental Quality estimates that there are two million abandoned wells in the state (Gilhouse, 2004), and Ontario has about 500,000 abandoned oil and gas wells. The lack of an inventory of wells and of mandatory reporting is problematic.

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

Groundwater Treatment to Protect Human Health

The U.S. EPA is promulgating a National Primary Drinking Water Regulation – the Ground Water Rule – to provide for increased protection against microbial pathogens in public water systems that use groundwater sources. Instead of requiring disinfection for all groundwater systems, the Ground Water Rule establishes a risk approach to target groundwater systems that are susceptible to fecal contamination. Full compliance is required by December 1, 2009. However, with the growing recognition that viruses in groundwater are a source of disease, coupled with the lack of correlation of viral pathogens with bacterial indicators, it is unclear whether the rule will be a fully adequate mechanism to protect human health.

Other Initiatives

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

THE IMPACT OF URBAN AREAS ON GREAT LAKES WATER QUALITY

The 2005-2007 biennial cycle marked the culmination of more than a decade of interest and study by the Board regarding the impacts of urban land use on Great Lakes water quality and the policy implications for sustainable land use. The Commission has a long history on this issue, dating back to the Pollution from Land Use Activities Reference Group studies of the 1970s. Article VI and Annex 13 of the Agreement address the issue and require the Parties to develop and implement programs and measures as well as to report to the Commission on their progress.

During the 2005-2007 cycle, to emphasize a shift in the Board's approach from delineating problems to searching for solutions, this priority was retitled "sustainable cities." Led by its Work Group on Parties Implementation, the Science Advisory Board worked with the Commission's Great Lakes Water Quality Board, Health Professionals Task Force, International Air Quality Advisory Board, and Council of Great Lakes Research Managers to develop findings and recommendations on how to move toward sustainable urban development in the Great Lakes Basin.

The major undertaking during this cycle was the drafting of a report to the Commission on the impact of urban areas on Great Lakes water quality. That report will be finalized and conveyed to the Commission under separate cover in 2008. To facilitate this work, the Science Advisory Board hosted a workshop in Chicago in December 2005 with expert presenters sharing experiences from within the region. In September 2006, the several boards hosted a two-day symposium in Chicago that brought together experts to discuss international experiences that could provide lessons for the Great Lakes Basin. Several discussion papers also were commissioned.

That work will be discussed in greater detail in the forthcoming report. Since that collaborative report is currently under preparation, it is premature to report findings and conclusions at this time. Although the Science Advisory Board had the lead for this activity during 2005-2007, recommendations will be developed in consultation with the Board's collaborators.

Chapter 3

Pertinent Scientific Knowledge to Identify, Evaluate, and Resolve Current and Anticipated Problems Related to Great Lakes Water Quality

IMPACT OF CLIMATE CHANGE ON GREAT LAKES SURVEILLANCE AND MONITORING ACTIVITIES

While climate change is no longer considered an "emerging issue," new developments require continued interest by the Board's Work Group on Emerging Issues. Key developments are contained in the *Fourth Assessment Report* released in stages by the Intergovernmental Panel on Climate Change (IPCC) throughout 2007. The Board highlights three components of that report.

In February 2007, the IPCC released a summary of the contribution of Working Group I titled *Climate Change 2007: The Physical Science Basis*. This most recent research concludes that global warming is "unequivocal" and that human activity is the main driver of this warming, asserting with near certainty – more than 90% confidence – that carbon dioxide and other heat-trapping greenhouse gases from human activities have been the main causes of warming since 1950.

In April 2007, the IPCC released the Working Group II Summary for Policymakers that evaluates *Climate Change Impacts, Adaptation and Vulnerability*. This report highlights the opportunity to limit the risks and costs of climate change through both emissions reductions and coping strategies to contend with the near-term impacts of unavoidable warming.

On May 4, 2007, the IPCC approved the Working Group III Summary for Policymakers that details strategies needed for the *Mitigation of Climate Change*. Many of the solutions presented focus on existing technologies such as switching from coal-fired power to renewable energy sources, improving energy efficiency in buildings, and introducing more effective economic incentives.

Policy Implications for the Great Lakes

These reports form a global science and policy foundation that informs discussions of climate change at numerous international, national, and regional conferences and other meetings, such as the National Summit on Coping with Climate Change, held at the University of Michigan in May 2007.

In 2003 the Water Quality Board provided a comprehensive analysis on the implications and impacts of climate change on Great Lakes water quality in its report, *Climate Change and Water Quality in the Great Lakes Basin*. In the report, the Board identified four elements for the Commission to consider in addressing the challenges that climate change will inevitably bring to the Great Lakes region:

- Development and implementation of an adaptation strategy
- Research on climate change impacts and adaptation, with a focus on the Great Lakes region
- Development of decision-making tools to enhance effective mitigation or adaptation efforts
- Communication and outreach

The Science Advisory Board's Work Group on Emerging Issues reviewed progress toward the implementation of the Water Quality Board advice since 2003 with a focus on identified research needs, including:

- Monitoring, surveillance, and analysis
- Scenario development
- Model development
- Vulnerability, impact, and adaptation assessments

Of these, the Work Group determined that monitoring, surveillance, and analysis should take top priority. Climate change has the potential to profoundly affect existing or proposed surveillance and monitoring programs and systems in the Great Lakes Basin, specifically, the capacity of existing programs to provide sufficiently accurate and detailed information to assess progress – or lack thereof – under the Agreement, and to assess the effectiveness and efficiency of climate change mitigation and/or adaptation strategies as related to the integrity of Great Lakes waters. Moreover, scenario and model development as well as assessments all depend critically on the availability of comprehensive, unbiased, and informative surveillance and monitoring data.

Some examples serve to illustrate the need for a critical assessment of surveillance and monitoring activities in the Great Lakes Basin. Even now, several Great Lakes are experiencing unprecedented drops in water levels. With lower water levels, the volume of the hypolimnion of the central basin of, for example, Lake Erie is reduced; historically, reduced hypolimnetic volume has correlated with increased hypolimnetic oxygen depletion. Moreover, because the date of stratification starts the clock for those processes involved in oxygen depletion, earlier stratification associated with increased spring temperatures will likely enhance oxygen depletion. Also, warmer fall temperatures may delay fall mixing of all the Great Lakes and their sub-basins. Consequently, greater oxygen depletion is expected prior to fall turnover. With lower hypolimnetic oxygen conditions and protracted periods of hot quiescent weather during the summer period, sediments will become sufficiently reduced to potentially generate large increases in internal phosphorus loading. This will be especially critical in the Western Basin of Lake Erie where such events are certainly linked to the unpredictable blooming of cyanobacteria.

Mercury represents another potential problem for existing monitoring activities. At present, surveillance focuses primarily on total mercury, but it is methyl mercury that accumulates in food chains. Methyl mercury formation has been linked to microbial activity, but details of the process have not been thoroughly resolved. While the drivers of mercury methylation are still imperfectly understood, increased bacterial activity associated with warmer temperatures could well enhance the rate of conversion, in which case assessments of human and ecological risks based on historical total-methyl correlations may be inaccurate. It is clear that even a modest warming of the region could result in increased methyl mercury production. This implies that more emphasis be placed on methyl mercury surveillance than has been the case historically.

Warmer temperatures will stimulate the growth and longer persistence of other bacteria. This will result in increased beach closings. As well, with warmer water, invasion is expected of exotic species that had previously been excluded due to colder water conditions.

It has been predicted that there will be little change in yearly precipitation but that there will be an increase in extreme storm events. This would contribute to increased soil erosion, increased nutrient loading and, generally, the persistence of more turbid conditions in the nearshore region.

In headwater regions, there has been a decline in the export of dissolved organic carbon. This substance has been called the master variable in controlling lake ecosystem processes since it is responsible for transporting metals, nutrients, and organic contaminants as well as for the attenuation of visible and ultraviolet radiation. This could already be a factor in the desertification of the waters of the main lakes, where the water is clearer and there are lower nutrient concentrations and less plankton biomass.

Altogether these observations clearly support the above conclusion for more monitoring and surveillance activities. Also, a thorough analysis of the data collected should be made in light of the above concerns. One way to handle the possible interactions is through model development.

Assessment of Surveillance and Monitoring Programs

The Work Group developed a preliminary list of specific assessments that will inform the general question of the impacts of climate change on monitoring and surveillance activities in the Great Lakes Basin. These include:

- Critical assessments of current monitoring programs, especially with respect to the extent to which inferences may be confounded by climate-induced changes and the adequacy of existing deployments (e.g., sampling locations, protocols, and methods) to distinguish climate-related from non-climate-related signals.
- Assessment of the adequacy of existing historical and ongoing surveillance and monitoring data for the evaluation of climatic, hydrological, water quality, and ecosystem variability and trends.
- Development of sensitive and efficient indicators of climate change, ecosystem impacts therefrom, or the effectiveness of impact mitigation and adaptation measures.

- Monitoring and analysis to corroborate climate change impacts (duration of effects, spatial extent, changes in species composition).
- Monitoring and assessment of water use, consumption, and withdrawal rates, including groundwater.
- Evaluation of SOLEC indicators for applicability to climate change.
- Monitoring effectiveness of adaptation strategies that have been implemented.

Recommendation

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The Parties develop a set of tools to evaluate the adequacy of existing surveillance and monitoring programs to inform sufficiently accurate assessments of progress on Agreement objectives, climate-related changes (both direct and indirect) on the integrity of Great Lakes waters, and the effectiveness and efficiency of climate change mitigation and adaptation strategies.**

Specifically, the tools should provide information on the adequacy of existing surveillance and monitoring programs with respect to:

- The suite of monitored indicators, especially those related to physical drivers of ecosystem dynamics in the Great Lakes Basin
- Spatial and temporal scales, including sampling resolution
- Potential – or likely – synergistic effects of climate change in combination with other anthropogenic stressors
- Ability to distinguish climate-change-related spatiotemporal signals from background fluctuations
- Ability to distinguish local from regional effects, be these of climate change *per se*, mitigation measures, or adaptation strategies

Once developed, these tools should be applied to existing surveillance and monitoring programs to evaluate current adequacy – or lack thereof – and to identify measures required to address existing inadequacies. Any proposed future surveillance and monitoring plans or programs also should be assessed using the evaluation tools and, if deemed inadequate, modified appropriately.

ENHANCING EVIDENCE-INFORMED DECISION MAKING IN THE GREAT LAKES BASIN

Introduction

The stated purpose of the Parties to the Agreement is "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." Good science is critical to the success of this enterprise, which is why the Science Advisory Board is charged, under the Agreement, with responsibility for "developing recommendations … pertinent to the identification, evaluation, and resolution of current and anticipated problems related to Great Lakes water quality" (IJC, 1989). Discharging this responsibility means, in effect, that the Board is concerned with characterizing the causal relationships between anthropogenic activities ("stressors") in the greater Great Lakes ecosystem (and conceivably beyond) on the one hand, and unsalutary ecosystem responses to these activities on the other. These putative causal relationships are, formally, scientific hypotheses.

The central tenet of rational, evidence-based or, more generally, evidence-informed decision making is that the causal hypotheses linking decision choices with expected outcomes are indeed true. Thus, the accuracy of a prediction about the expected effect of some stressor – or mitigation thereof – depends on whether the underlying scientific hypotheses are indeed true.

In the specific context of the Agreement, measures to restore the integrity of Great Lakes waters will only be effective if they are based on causal hypotheses that are – more or less – true. Suppose, for example, that fish in a region are found to have comparatively high mercury levels, giving rise to concern about the health impacts of mercury exposure through fish consumption. One potential solution is to issue a consumption advisory, say, that certain segments of the population (e.g., pregnant women) should consume no more than X grams of fish species Y per week. The logic of the argument is straightforward: If a fish consumption advisory is issued, then health of the target subpopulation(s) will improve. However, the empirical validity of this statement depends on the validity of two underlying scientific hypotheses:

- In making decisions about fish consumption, members of the target population are actually influenced by advisories.
- Above some level of fish consumption (as defined by the advisory), the net health effect of additional consumption is negative, i.e., the health benefits of increased protein consumption are outweighed by the negative health effects of increased mercury exposure.

If either of these hypotheses is false, the predicted salutary effects of a fish consumption advisory will not materialize.

Weight of Evidence

Although the concept of "weight" or "strength" of evidence is intuitively easy to understand, its operationalization is quite another story. Weed (2005) notes that weight of evidence has three general uses in the scientific literature:

- As a metaphor, hence, completely non-operational
- To refer to specific analytic or interpretative methods (e.g., meta-analysis, the premises of Bayesian statistical analysis, or summary narratives) that attempt to take into account all evidence (a premise which is itself operationally problematic)
- As a "conceptual framework" for inferring causality based on, for example, legal notions of evidentiary relevance, reliability, sufficiency, and standards of proof (Walker, 1996)

Particularly in clinical medicine, several different schemes have been developed for evaluating, grading and rating weight of evidence, including the Third United States Preventative Services Task Force system (Harris et al., 2002) and the GRADE system (Atkins et al., 2004; Guyatt et al., 2006), as well as a more recent attempt (Treadwell et al., 2006) based on the twin concepts of evidentiary strength (for qualitative conclusions) and evidentiary stability (for quantitative conclusions). The problem with all these approaches is that, in clinical medicine, the range of possible experimental designs, and the sources of evidence, are much more circumscribed than the set of study designs, results, and evidence sources that have – at least in principle – some bearing on the issue of the causal factors influencing the integrity of Great Lakes waters. As such, some method is required for assessing weight of evidence that can accommodate the full range of evidence that could be brought to bear on these issues.

Weight of Evidence and the Commission

In the decision-making context, evidence is usually sought to demonstrate a need for policy or regulatory action, or to demonstrate effectiveness or efficiency of candidate interventions (Bower, 2005). Recommendations to the Parties under the Agreement are of three types:

- Recommendations concerning stressor mitigation which, if implemented, are expected to result in improved physical, chemical, or biological integrity of the Great Lakes Basin.
- Recommendations concerning surveillance and monitoring which, if implemented, are expected to provide information on the spatiotemporal distribution of stressors or their effects on ecosystem or human health.
- Recommendations concerning governance structure or function which, if implemented, are expected to result in improved decision making.

Each recommendation is respectively based on scientific (that is, testable) hypotheses about the effect of particular stressors on integrity; comprehensiveness of scientific data and the design, structure, and implementation of environmental surveillance systems; and governance structure and function and the quality of rendered decisions. As such, weight of evidence is directly relevant to all three classes of recommendations.

This was recognized by the Commission 15 years ago. In 1992, the Commission's *Sixth Biennial Report on Great Lakes Water Quality* recommended the application of a "weight of evidence" approach to identify and virtually eliminate persistent toxic substances (IJC, 1992). The issue was briefly revisited in the 1994 *Seventh Biennial Report* (IJC, 1994a), but it was clear at that time that formal operationalization of weight-of-evidence decision making was hampered by a lack of consensus on what it meant in practice and how weight of evidence was to be evaluated. At least partially for this reason, in 1993, the Commission convened an expert panel (IJC, 1994b) to explore the issue of weight of evidence. Although most participants supported, at least in principle, a weight-of-evidence approach to Commission recommendations, there was extensive discussion on what, precisely, this meant, what it implied, and how weight of evidence should be assessed. Indeed, the Commission's U.S. Co-Chair, Gordon Durnil, concluded the workshop by commenting that in the next biennial cycle, the Commission would be "wrestling with weight of evidence as one of our priorities" (IJC, 1994b).

Accordingly, as part of its report on *1993-1995 Priorities and Progress under the Great Lakes Water Quality Agreement* (IJC, 1995), the Science Advisory Board addressed Weight of Evidence: Approaches to Decision Making in the Face of Uncertainty (IJC, 1995). In the context of a risk management approach to decision making in the Great Lakes Basin Ecosystem, the Board recommended that:

- Commission weight-of-evidence decisions be clear as to evidence used, assumptions, values, uncertainties, and consequences involved.
- The level of proof required (beyond a reasonable doubt, or more likely than not) be clearly stated.
- The risk of non-action be included in deliberations on risk management.
- Commission recommendations and decisions based on weight of evidence include parallel decisions on reasonable monitoring needed to serve as a measure of progress toward the desired goal or, conversely, as an indicator of a wrong decision.
- Commission recommendations and decisions based on weight of evidence, because tentative, incorporate clear strategies for ongoing cooperation between scientists and managers.

These recommendations have generally not been followed and, as such, the potential contribution of the Commission to the development and implementation of rigorous weight-of-evidence assessment methods – and their application – has not been realized.

Recommendations

The Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **The International Joint Commission, in collaboration with other partner institutions, develop, validate, and apply methodologies and tools for evaluating the weight of evidence associated with causal hypotheses about, for example, impacts of human activities in the Great Lakes Basin Ecosystem (and possibly beyond) on the chemical, physical, and biological integrity of the basin ecosystem, or the effectiveness or efficiency of potential mitigation interventions.**
- **Once validated, the Commission employ these tools to explicitly assess the weight of evidence underlying the Commission's candidate recommendations to the Parties.**
- **The Commission foster the dissemination and use of such tools and, particularly, encourage other actors under the Agreement to employ them in decision-making.**

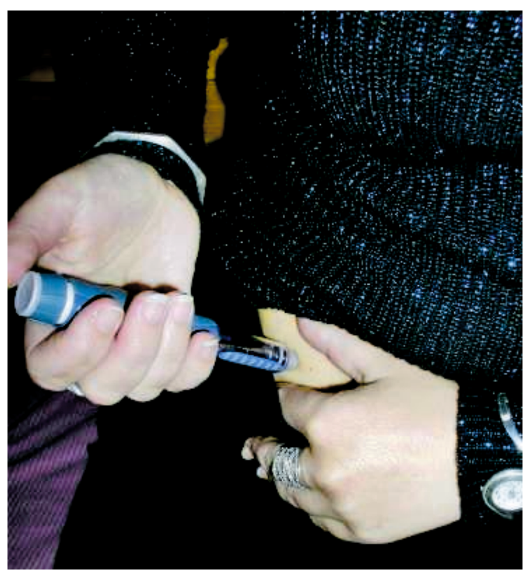
Partner institutions include, for example, the International Life Sciences Council and the Canadian Institute of Health Research.

EXPOSURE TO PERSISTENT ORGANIC POLLUTANTS AND RISK OF DIABETES

A number of adverse health effects have been associated with exposure to mercury and persistent organic pollutants (POPs). Cognitive impairment to infants whose mothers were exposed to mercury and POPs, such as PCBs, through consumption of fish and other seafood is well documented (U.S. Department of Health and Human Services, 1999 and 2000). Other adverse health effects from POPs include thyroid dysfunction and increased risk of cancer (U.S. Department of Health and Human Services, 1996).

Recent research provides evidence that exposure to POPs, including dioxins, furans, PCBs, and chlorinated pesticides, may increase the risk of diabetes. This is important since these chemicals are found at high levels in many Great Lakes fish and suggests that consumption of Great Lakes fish is associated with an increased risk of diabetes.

There has been suggestive (but not definitive) evidence of an association between exposure to POPs and diabetes for some time. In the 1998 Health Canada reports on diseases occurring at elevated frequency in the Canadian Areas of Concern, diabetes was found to be significantly elevated in 10 of the 17 areas. The National Academy of Sciences' Institute of Medicine reviewed studies of chemical workers, residents exposed to dioxin from the Seveso incident, and military exposure in Vietnam (Institute of Medicine, 2000). The Institute concluded that there was limited, but suggestive evidence that U.S. Air Force veterans who



In the 1998 Health Canada reports on diseases occurring at elevated frequency in the Canadian Areas of Concern, diabetes was found to be significantly elevated in 10 of the 17 areas.

sprayed Agent Orange in Vietnam had an increased risk of Type II diabetes. Other studies have not detected such an association between POPs exposure and diabetes. Steenland et al. (2001) did not detect an increased risk of diabetes upon combining the Operation Ranch Hand and NIOSH dioxin registry data.

A recent study indicated that POPs were associated with an increased risk of diabetes (Lee et al., 2006). Using data from the U.S. National Health and Examination Survey of 1999-2002, in which blood samples were taken from a random sample of 2,016 U.S. adults examined the relationship between diabetes prevalence and levels of six different POPs (two dioxins, one PCB, three chlorinated pesticides) and found that levels of all six were significantly related to diabetes. When participants were classified according to the sum of the six POPs, the adjusted odds ratios were 1.0, 14.0, 14.7, 38.3, and 37.7 (p for trend < 0.001). The report of odds ratios as high as 38 (which means a 38-fold increase in risk) suggests that exposure to POPs is a major risk factor for diabetes.

Associations with PCB blood levels and diabetes were also reported by Vasiliu et al. (2006). Interpretations have been offered that such findings might be the result of other factors, so further evaluation of associations in carefully designed studies is warranted (Longnecker, 2006). A recent paper on Mohawk Indians exposed to PCBs, DDE, and hexachlorobenzene through fish consumption from the St. Lawrence River found significant associations with serum levels of these chemicals and diabetes (Codru et al., 2007). In this particular study, the statistical analyses performed adjusted for confounding factors such as smoking, sex, body mass index, and gender as well as lipid-standardized concentration values for the chemicals.

Recommendation

Because persistent organic pollutants remain major contaminants within the Great Lakes Basin, the Great Lakes Science Advisory Board recommends that the International Joint Commission recommend to the Parties that:

- **Additional studies be undertaken to further explore the potential relationships between exposure to persistent organic pollutants from consumption of contaminated fish (and other routes of exposure) with diabetes and other adverse health effects in populations within the Great Lakes Basin.**

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Note: The scientific and technical references for this section are contained in Dr. Field's invited paper presented in Appendix 5.

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Appendices

Disclaimer:

The appendices contain pertinent information that was considered by the Science Advisory Board in the development of its advice to the International Joint Commission. Appendices 2 and 5 are provided for background only and have not been approved by the Board. Their information and content do not necessarily represent the views of the Science Advisory Board or its Work Groups.

Appendix 1

Acknowledgements, Activities and Meetings, Membership

ACKNOWLEDGEMENTS

The capacity of the Science Advisory Board to address priority issues and stay abreast of the latest scientific information is only possible through the dedication of its members, the involvement of the wider Great Lakes scientific community, and the participation of interested citizens and agency officials. The Board also routinely seeks outside expert advice to ensure that the most current scientific understanding is available to inform proceedings. The Board wishes to express its gratitude and appreciation for the assistance that all of these individuals have contributed throughout 2005-2007: Henry Anderson, John Bartholic, Matt Becker, Mark Borchardt, Riina Bray, Richard Brazell, Monica Campbell, John Carey, William Clune, Mary Jane Conboy, Deborah Conrod, Marie Pierre Dagenais, Gary Dawson, Joe Deal, John Dellinger, Christie Deloria, Tija Dirks, Dave Eckhardt, Ric Farlardeau, Doug Farr, Daniel Feinstein, Kate Field, Gary Foley, Joel Freehling, Emil Frind, Harold Garabedian, Boyd Gibbons, John Gladki, Hugh Gorman, Norm Grannemann, Bert Guindon, Gary Gulezian, Noah Hall, Stephen Hamilton, Marc Hinton, Joseph Janczy, Doug Joy, Bill Kappel, Bradley Karkkainen, Gerritt Knapp, Sandra Kok, Shari Kolak, Ashi Kumar, Charles Lamontagne, Kate Lauzon, Russ Lopez, Francine MacDonald, Richard Mariner, John Marseilles, Jiri Marselak, Craig Mathur, James McEwan, Ann McMillan, Jessica Mistak, Linda Mortsch, Miroslav Nastev, Bob Newport, Jim Nicholas, Kent Novakowski, Christie Olson, Jim Patchett, Aline Philbert, Tom Price, Cindy Rachol, Howard Reeves, Neville Reid, Rich Reynolds, Mark Richardson, Pete Richardson, Lisa Richman, Neil Rogers, Bill Rustem, Mark Servos, Kevin Shafer, David Sharpe, Brenda Sharpe, Harvey Shear, Judy Sheeshka, Ellen Shubert, Enid Slack, Webb Smathers, William Sullivan, William Testa, Ron Thomas, Robert Thompson, James Van der Kloot, James Wescoat, and Robert Whitesides.

ACTIVITIES AND MEETINGS OF THE GREAT LAKES SCIENCE ADVISORY BOARD FOR THE 2005-2007 BIENNIAL CYCLE

138th Meeting of the Great Lakes Science Advisory Board

September 29-30, 2005

Radisson Plaza Hotel at Kalamazoo Center, Michigan

Special Presenters

- Robert Whitesides: Kalamazoo River Watershed Council
- Shari Kolak: U.S. Environmental Protection Agency, Remedial Project Manager, Kalamazoo River Superfund Site
- Stephen K. Hamilton: Nutrients in Waters of the Kalamazoo River System

Multi-Board Urbanization Priority Discussion Meeting

November 9, 2005

Toronto, Ontario

Special Presenters

- Hugh Whiteley: Urban Issues and Water Quality in the Great Lakes Basin
- John Carey: Water Quality – What Should We Expect in Coming Years?
- Gary Foley, Ann McMillan, Harold Garabedian, and John McDonald: Urbanization, Sprawl, and Smart Growth in the Great Lakes Region
- Bert Guindon and Ying Zhang: Linking Remote Sensing Science to Energy-Related Policy Initiatives – A Case Study in Urban Energy Initiatives
- Neville Reid: Urbanization and Air Quality

139th Meeting of the Great Lakes Science Advisory Board

December 1-2, 2005

Illini Center, Chicago, Illinois

Special Presenters

- William Sullivan: Illinois-Indiana Sea Grant
- Isobel Heathcote: Urbanization Priority
- Jim Patchett: Urban Land Use Issues in the Great Lakes Basin
- Bob Newport: Issues and Initiatives Related to Cities, Stormwater and Sustainability
- Ron Thomas: Regional Public Involvement and Smart Growth Initiatives
- Robert Thompson: Land Use Planning, Regional Planning and Transportation Systems
- Richard Mariner: Sustainable Development Principles as Adopted by Chicago Wilderness
- James Wescoat: Linking Urban Ecological Design and Water Quality Management
- John Braden: Downstream Economic Benefits of Low-Impact Development
- James Van der Kloot: Sustainable Redevelopment of Brownfield and RCRA Sites
- Doug Farr: Leadership in Energy and Environmental Design – Neighborhood Development in the Great Lakes Basin

Strengthening Science under a Renewed Great Lakes Water Quality Agreement

January 24-26, 2006

Wingspread Conference Center, Milwaukee, Wisconsin

Special Presenters

- Bradley Karkkainen: The Ecosystem Approach in International Law
- Rick Findlay: International Lessons in Trans-boundary Water Governance
- Mark Richardson: Mechanisms to Engage Local Governments in Great Lakes Governance
- Mark Sproule-Jones: Horizontal Management in the Great Lakes Basin – Is There a Need for a Central Coordinating Body and Bi-national Surveillance and Monitoring?
- Jim Bruce: Great Lakes Water Quality Agreement Institutional Arrangements: Historical Context

140th Meeting of the Great Lakes Science Advisory Board

February 23-24, 2006

Great Lakes Regional Office, Windsor, Ontario

The State of Groundwater in the Great Lakes Basin

March 8-9, 2006

Holiday Inn South Convention Center, Lansing, Michigan

Special Presenters

- Jim Nicholas: Hydrogeological Cycle/Consumptive Use Estimates
- Marc Hinton: Groundwater Recharge and Baseflow in the Basin
- Howard Reeves: Michigan Groundwater Monitoring/Mapping
- Deborah Conrod: Ontario Groundwater Monitoring and Mapping
- Bill Rustem: Michigan Groundwater Economics
- Joan Rose: Groundwater Pathogens
- Ric Falardeau: On-site Wastewater Systems
- James McEwan: Abandoned Wells
- Bill Kappel: New York, Niagara/Onondaga 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

Work Group on Ecosystem Health Expert Consultation on an Ecosystem Approach to Dam Removal in the Great Lakes Basin

June 6, 2006

Great Lakes Regional Office, Windsor, Ontario

Special Presenters

- Jessica Mistak: Fisheries Benefits Due to Dam Removal
- Cyndi Rachol: U.S. Geological Survey Views
- Webb Smathers: Model of Pros and Cons of Dam Removal
- Bill Bowerman: Toxics in Fish and Effects in Wildlife
- Francine MacDonald: Ontario Federation of Anglers and Hunters Concerns Regarding Invasive Species Issues
- Gary Dawson: Consumers Energy-Hydro Considerations
- Christie Deloria: U.S. Fish and Wildlife Service Views

141st Meeting of the Great Lakes Science Advisory Board

June 7, 2006

Great Lakes Regional Office, Windsor, Ontario

The State of Groundwater in the Great Lakes Basin

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: Groundwater Policies
- Mary Jane Conboy: Ontario Regulations, Abandoned Wells
- Kent Novakowski: Sustainable Wells
- Bill Kappel: Hydrogeology of the Onondaga Trough

Urbanization Symposium

September 25-26, 2006

Chicago, Illinois

Special Presenters

- Jiri Marsalek: Urban Impacts on Water Quality
- Harold Garabedian: Urban Impacts on Air Quality
- John Gladki: Forecast and Analysis of Urban Development in the Great Lakes Basin
- William Testa: Industrial Growth in Great Lakes Economy
- William Clune: Implementing Sustainable Stormwater Management Strategies
- Gerritt Knapp: The Chesapeake Bay and Maryland – A Case Study in Water Resources Protection
- Bert Guindon: Development of the Great Lakes Urban Survey
- Sandra Kok: Tools and Other Experiences from the Canadian Great Lakes Program
- Kevin Shafer: Milwaukee's Water Quality Initiative – A Sustainable Approach
- Russ Lopez: Promoting Healthy Cities
- Riina Bray: Urban Sprawl and Public Health in Ontario
- Monica Campbell: Catalyst for Change
- Eric Laschever: Overview of the Growth Management Act
- Ronan Uhel: Europe's Environment – What Have We Learned?
- Andre Sorensen: Urban Growth, Land Management and Water Quality in Japan
- Peter Newman: Best Practice Sustainability Down Under
- Ron Thomas: Planning for a Shared Future
- Tija Dirks: Planning for Growth in the Greater Golden Horseshoe
- Neil Rogers: Towards Urban Sustainability – Enduring Balance, Prosperity and Public Expectations
- Enid Slack: The Impact of Municipal Finance and Governance on Urban Sprawl
- Joel Freehling: Shorebank

142nd Meeting of the Great Lakes Science Advisory Board

October 4-5, 2006

Great Lakes Regional Office, Windsor, Ontario

Special Presenter

- John Braden: Submerged Treasure

SOLEC Urban Groundwater Workshop

November 3, 2006

Milwaukee, Wisconsin

Special Presenters

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

Consultation on Omega-3 Fatty Acids and Fish Consumption Advisories

January 3, 2007

Great Lakes Regional Office, Windsor, Ontario

Special Presenters

- Henry Anderson: Comparison of 1994 and 2003 U.S. Basin-wide Consumption and Advisory
- Aline Philbert: Omega-3 Fatty Acid Levels in Humans Resulting from Consumption of St. Lawrence River and Abitibi Lakes Fish and their Effects on Human Health
- John Dellinger: Omega-3 Levels in Wisconsin Fish Species
- Judy Sheeshka: Reported Dietary Intakes of Great Lakes Fish and Blood Chemistry Analysis of Certain High Fish Consumers in Selected Canadian Areas of Concern

143rd Meeting of the Great Lakes Science Advisory Board

January 4-5, 2007

Great Lakes Regional Office, Windsor, Ontario

Special Presenter

- Linda Mortsch: Climate Change

144th Meeting of the Great Lakes Science Advisory Board

February 27-28, 2007

Great Lakes Regional Office, Windsor, Ontario

Special Presenter

- C. Scott Findlay: Inferential Strength, Weight of Evidence and Evidence-Formed Decision Making

145th Meeting of the Great Lakes Science Advisory Board

June 6-8, 2007

International Joint Commission

Great Lakes Biennial Meeting and Conference

Sustainable Cities, Healthy Watersheds

University of Illinois at Chicago

Chicago, Illinois

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③ Work Group on Emerging Issues
④ Work Group on Parties Implementation

Appendix 2

Enhancing Evidence-informed Decision Making in the Great Lakes Basin

INTRODUCTION

Under the GLWQA, the Parties are obliged to maintain and restore the chemical, physical, and biological integrity of the Great Lakes Basin Ecosystem. Good science is critical to the success of this enterprise, which is why the Great Lakes Science Advisory Board is charged, under the agreement, with the responsibility of "developing recommendations …pertinent to the identification, evaluation, and resolution of current and anticipated problems" (GLSAB Terms of Reference, GLWQA pp. 62-63). Discharging this responsibility means, in effect, that the SAB is concerned with characterizing the causal relationships between anthropogenic activities ("stressors") in the GGLE (and, conceivably, beyond) on the one hand, and unsalutary ecosystem responses to these activities on the other. These putative causal relationships are, formally, scientific hypotheses. Thus when we make a prediction about the expected effect of some stressor – or mitigation thereof – the accuracy of the prediction depends on whether the underlying scientific hypotheses are indeed true.

Suppose, for example, that fish in a region are found to have comparatively high mercury levels, giving rise to concern about the health impacts of mercury exposure through fish consumption. One potential solution is to issue a consumption advisory, say, that certain segments of the population (e.g., pregnant women) should consume no more than X grams of fish species Y per week. The logic of the argument is straightforward: If (a fish consumption advisory is issued), then (health of the target subpopulation(s) will improve). Note, however, that the empirical validity of this statement depends on the validity of two underlying scientific hypotheses: (1) that in making decisions about fish consumption, members of the target population are actually influenced by advisories; and (2) that above some level of fish consumption (as defined by the advisory), the net health effect of additional consumption is negative (i.e., the health benefits of increased protein consumption are outweighed by the negative health effects of increased Hg exposure). If either of these hypotheses is false, the (predicted) salutary effects of a fish consumption advisory will not materialize. Rational decision making must take into account the likelihood that the set of causal hypotheses linking decision choices with expected outcomes are indeed true. This is the central tenet of evidence-based, or more generally evidence-informed, decision making.

INFERENTIAL STRENGTH AND WEIGHT OF EVIDENCE

Although the concept of "weight" or "strength" of evidence is intuitively easy to understand, how it is operationalized is quite another story. Weed (2005) notes that WOE has three general uses in the scientific literature, either as a metaphor (hence, completely non-operational), to refer to specific analytic or interpretative methods (e.g., meta-analysis, the premises of Bayesian statistical analysis, or summary narratives) that attempt to take into account all evidence (a premise which is itself operationally problematic), to WOE as a "conceptual framework" for inferring causality based on, for example, legal notions of evidentiary relevance, reliability, sufficiency, and standards of proof (Walker, 1996). Particularly in clinical medicine, several different schemes have been developed for evaluating, grading and rating weight of evidence, including the Third United States Preventative Services Task Force system (Harris *et al.* 2002) and the GRADE system (Atkins et al., 2004; Guyatt et al., 2006), as well as a more recent attempt (Treadwell et al., 2006) based on the twin concepts of evidentiary strength (for qualitative conclusions) and and evidentiary stability (for quantitative conclusions).

b.

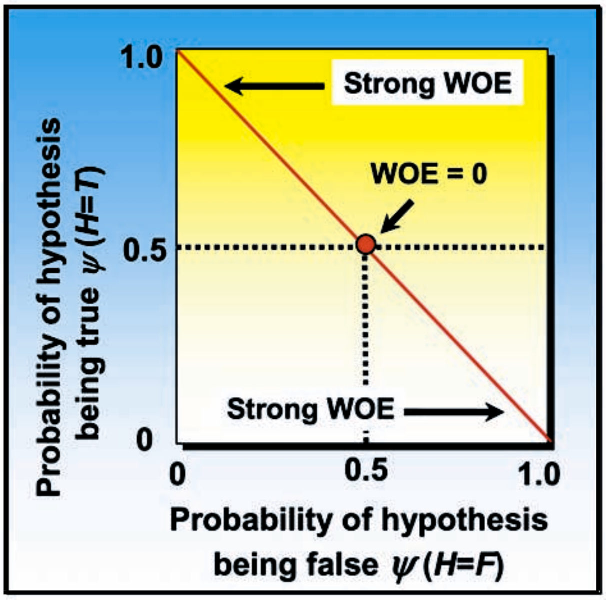

Fig. 1. The relationship between weight of evidence (WOE) and the probability of a hypothesis being true or false. Increasing WOE corresponds to an increasingly large absolute difference

$$|\psi(H=F)-\psi(H=T)| .$$

Despite their differences, all weight of evidence methodologies are based on the notion of the truth (or falsity) of scientific hypotheses. Scientific hypotheses are either true (T) or false (F), such that, if $\psi(H=T)$ is the probability of hypothesis H being true, then $\psi(H=F)=1-\psi(H=T)$ is the probability of it being false. In the absence of any evidence whatsoever, the probability of the hypothesis H being true is the same as it being false: $\psi(H=T)=\psi(H=F)=0.5$. Evidence supporting or refuting H implies deviations from equiprobability: Very strong evidence that H is false implies $\psi(H=F)\to 1, \psi(H=T)\to 0$, while very strong evidence that H is true implies $\psi(H=F)\to 0, \psi(H=T)\to 1$ (Fig. 1).

Scientific studies are designed to test hypotheses. On the basis of the obtained experimental results, the investigator draws an inference as to whether the hypothesis under consideration is corroborated or refuted: The greater the inferential strength of a study, the more likely it is that, given results (apparently) supporting hypothesis H, the hypothesis is indeed true (or, conversely, given results apparently refuting H, that indeed H is false – see Fig. 1) in the model system under investigation. Thus, inferential strength is a property of individual studies. By contrast, "weight of evidence" means the accumulated evidence from a collection of studies. Given an hypothesis (for example, that the trend of increasing surface temperatures in the northern hemisphere over the last few decades is a result of combustion of fossil fuels and the resulting "greenhouse" effect), at any time there will be a collection of studies whose results are relevant (that is, provide tests of) the hypothesis. The weight of evidence in support of the hypothesis is small if the collection includes only a small number of studies, all of which have low inferential strength, whereas if the collection includes a large number of studies, many of which have high inferential strength and which support the hypothesis, the corresponding weight of evidence is higher.

This distinction between inferential strength and weight of evidence also makes clear the difference between two superficially similar situations: (a) (strong) evidence of absence, i.e., the case where for some hypothesis H, there is strong evidence (based on a number of studies, each with comparatively high inferential strength) that in fact the hypothesis is false ($\psi(H=F)\to 1; \psi(H=T)\to 0$); versus (b) absence of evidence, i.e., the case where the hypothesis has yet to be subjected to any significant empirical testing, in which case $|\psi(H=F)-\psi(H=T)|\approx 0$. In the former case, scientific considerations are relevant, and, in particular, there is little scientific justification for a decision which is based on the (almost certainly false) assumption that H is true; in the latter case, considerations of scientific evidence are irrelevant.

WEIGHT OF EVIDENCE AND RECOMMENDATIONS TO THE PARTIES

In the decision-making context, evidence is usually sought to demonstrate a need for policy or regulatory action, or demonstrate effectiveness or efficiency of candidate interventions (Bowen, 2005). In the IJC context, SAB recommendations to the Parties under the Agreement are of three types: (1) recommendations concerning stressor mitigation which, if implemented, are expected to result in improved physical, chemical, or biological integrity of the GLB; (2) recommendations concerning surveillance and monitoring, which, if implemented, are expected to provide information on the spatiotemporal distribution of stressors or their effects on ecosystem or human health; and (3) recommendations concerning governance structure or function, which, if implemented, are expected to result in improved decision making. All are based on scientific (that is, testable) hypotheses about the effect of particular stressors on integrity (1); comprehensiveness of scientific data and the design, structure, and implementation of environmental surveillance systems (2); and governance structure/function and the quality of rendered decisions (3), respectively. As such, weight of evidence is directly relevant to all three classes of recommendations to the Parties under the GLWQA.

WEIGHT OF EVIDENCE AND GENERALIZED DECISION PRINCIPLES UNDER AN AMENDED GLWQA

Given a problem, decision makers must first define the set of candidate solutions. As noted above, each (putative) solution is based on a set of hypotheses, and the validity (i.e., truth or falsity) of these underlying hypotheses determines the likelihood that the expected outcome of a given decision choice will in fact materialize. So, as noted above, a fish consumption advisory will only produce the desired (and expected) effect if indeed members of the target population are actually influenced by advisories and the net health effect of consumption in excess of the advisory limit is negative. In the decision-making context then, there are two critical questions: (1) given a method for assessing weight of evidence, is there a threshold weight of evidence required to take a particular decision; and (2) if such a threshold exists, on what does it depend?

The issue of threshold weights of evidence for decision making has important implications to generalized decision principles under scientific uncertainty. In a recent report entitled "Findings of an Expert Consultation on Strengthening Science Under a Renewed Great Lakes Water Quality Agreement" [REF Wingspread 2006], the SAB recommended that an amended GLWQA should explicitly commit the Parties to decision making that is precautionary, adaptive, and robust, three properties intimately related to the notion of weight of evidence. For example, the precautionary principle asserts that when scientific uncertainty is high, and the potential for substantial (i.e., serious or irreversible) negative (but possibly unexpected) effects exists, administrative or regulatory decision making should err on the side of caution. As has been noted by a number of commentators (REFs), operationalizing the principle requires that one specify the circumstances under which the PP is triggered. If, as noted above, we equate weight of evidence with uncertainty regarding the truth of underlying scientific hypotheses, then weak weight of evidence

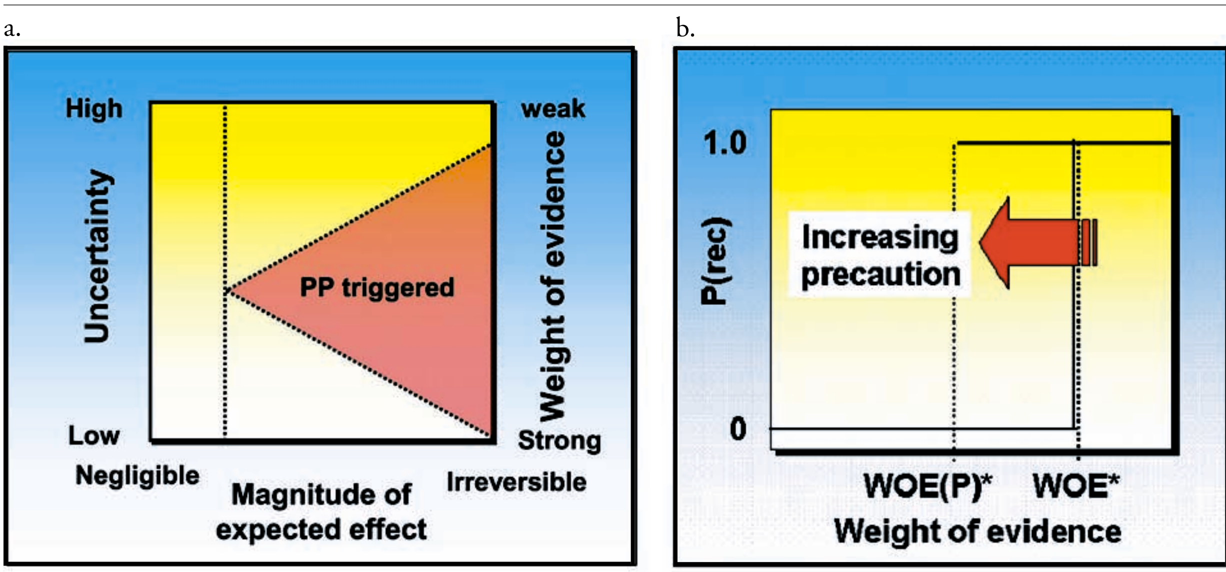

Fig. 2. (a) The precautionary principle (PP) trigger region. Because predicted effects are based on scientific hypotheses, uncertainty is inversely related to weight of evidence. As such, the potential exists for operationalizing the PP (that is, defining the trigger region) in terms of the weight of evidence associated with hypotheses which, if true, will result in increasingly large (negative) effects; (b) The probability of a recommendation for mitigation (P(rec)) in relation to the weight of evidence that the stressor in question is contributing substantially to impaired biological, chemical, or physical integrity. The effect of precautionary decision making is to lower the threshold weight of evidence (WOE(P)*) required for mitigation recommendations relative to that obtaining under a non-precautionary approach (WOE*).

corresponds to high uncertainty, strong weight of evidence low uncertainty. This suggests that in fact for a given maximum potential negative effect, whether the principle is triggered depends on the underlying weight of evidence: When the maximum potential effects are small, the principle is never invoked. However, as these effects increase, the range of weight of evidence compatible with PP invocation increases (Fig. 2a), so that decisions to mitigate can be made even when the weight of evidence is low (Fig. 2b).

Considerations of weight of evidence will also prompt decision makers to explicitly consider the normative ("value") and objective ("fact") dimensions of decision making. In risk-based decision making, for example, issues can – at least in principle - be ordinated along an axis ranging from "all fact, no value" (for example, the estimation of the probability distribution of effects with respect to a specified measurement endpoint under a given exposure scenario) to "all value, no fact", e.g., the determination of "acceptable risk." In the same manner, explicit consideration of weight of evidence prompts decision makers to differentiate between issues at either end of the scale (e.g., the determination of weight of evidence, given a tool for assessing same, on the one hand, and the specification of threshold WOE for triggering of the precautionary principle on the other).

RECOMMENDATIONS

That the Commission recommend to the Parties that:

- **The Parties take a leading role in the development of methodologies and tools for evaluating the weight of evidence associated with causal hypotheses about (a) the impacts of human activities in the GLBE (and possibly beyond) on the chemical, physical, and biological integrity of the GLBE and (b) the effectiveness or efficiency of potential mitigation interventions. In its most general from, this tool would allow each causal hypothesis to be assigned a qualitative WOE score (e.g., low, moderate, high) based on the existing scientific information.**
- **The IJC and its Advisory Boards explicitly use the WOE tool as part of the process of formulating recommendations to the Parties under the GLWQA, to score each hypothesis underlying candidate recommendations. This in turn requires that for any recommendation (a) the full set of underlying hypotheses be made explicit, (b) a WOE be assigned to each, and (c) the threshold WOE for recommendations be specified.**

Appendix 3

Transmittal Letter
Groundwater/Annex16 Recommendations

July 31, 2006

To: IJC Commissioners

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

Subject: Groundwater/Annex 16 Recommendations

Introduction

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

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

Preliminary SAB Recommendations on Groundwater Issues

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

1. Amend or extend Annex 16 in view of current scientific understandings, calling on the Parties to:
   a. Recognize and reflect the relationship between the quantity and the quality of groundwater and the interactions between groundwater and surface water in respect to both quality and quantity.
   b. Require systematic, ongoing, basin-scale collection of data following standardized protocols about quantity and quality trends in groundwater.
   c. Maintain water budgets for the basin that include major groundwater withdrawals and consumptive uses, and provide frequent reports concerning trends.
   d. Support research on spatial and temporal variation in recharge to groundwater, the status of groundwater resources, and the role of groundwater recharge, storage, and discharge in ecosystem functions of the Basin.
   e. Recognize the importance of groundwater as a source of drinking water in the Basin and, therefore, the high priority that should be given to protection of groundwater through monitoring, wellhead protection, well registration, and abandoned well closure programs to ensure protection of human health.
   f. Develop funding sources to support groundwater monitoring, the continued operation of programs for the protection and remediation of groundwater, and research activities.
2. Implement concrete plans to meet Party commitments under Annex 16, including:
   a. Designating lead agencies responsible for the implementation of Annex 16.
   b. Producing a public agreement between the Parties' lead agencies for standardization of mapping, sampling, and analytical protocols for use in monitoring contamination in groundwater of the Great Lakes Basin.
   c. Based on these protocols, reporting at regular intervals on the sources and quantities of contaminants entering groundwater and the Great Lakes through groundwater.

Previous Advice to IJC on Groundwater Issues

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

1993 Groundwater Report – (*Groundwater Contamination in the Great Lakes Basin,* IJC 1993.)

The Report concluded, in part, that:

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

Protection of the Waters of the Great Lakes – Particularly Recommendation VII, which is specific to groundwater and Annex 16 (*Protection of the Waters of the Great Lakes*, IJC, February 2000.) The August

2004 IJC review of this recommendation (*Protection of the Waters of the Great Lakes*, IJC, August 2004) also should be considered. The SAB finds the following quote from that document to capture many of the current issues with groundwater in the basin rather succinctly:

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

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

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

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

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

Conclusion

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

Michael Donahue
U.S. Co-Chair
IJC Science Advisory Board

Isobel Heathcote
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Appendix 4

Wingspread Consultation on Strengthening Science under a Renewed Agreement

The Consultation was held at the Wingspread Conference Center (operated by the Johnson Foundation) in Racine, Wisconsin. Participants (listed below) remained within the self-contained private grounds for the entire meeting time, and the warm and inviting atmosphere of the accommodations and meeting areas encouraged extensive interactions and frank discussion free of institutional representation or affiliation that is found at most professional meetings. Approximately 30 people from the U.S. and Canada attended or participated in the event, and came with backgrounds in academia, government (federal, state, and local), and industry. The Consultation program was structured in five sessions, each with a Convener and a Provocateur. The Convener, a member of the Workgroup, offered brief remarks to provide context for the session, introduced the Provocateur, and facilitated the discussion period. The Provocateur gave a 30-40 minute presentation, followed by lengthy discussion. The sessions were as follows:

- *The Ecosystem Approach to International Law*
  Provocateur: Bradley Karkkainen
- *International Lessons in Trans-boundary Water Governance*
  Provocateur: Rick Findlay
- *Mechanisms to Engage Local Government in Great Lakes Governance*
  Provocateur: Mark Richardson
- *Horizontal Management in the Great Lakes Basin: Is There a Need for a Central Coordinating Body and Bi-national Surveillance and Monitoring?*
  Provocateur: Mark Sproule-Jones
- *Great Lakes Water Quality Agreement Institutional Arrangements: Historical Context*
  Presenter: James P. Bruce

The final session of the Consultation consisted of small breakout groups that addressed two questions: (1) what changes to the current institutional arrangements might be made to enhance science-based decision-making? i.e., what functions should science have, and what forms (of institutional arrangements) will support these functions? and (2) to address accountability, what mechanisms might be recommended to assess the progress made by the Parties, and what consequences should there be if sufficient progress has not been made?

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Transmittal Letter

Science Advisory Board Findings from an Expert Consultation on Strengthening Science under a Renewed Great Lakes Water Quality Agreement

March 30, 2006

Lisa Bourget
Secretary
U.S. Section Office

Murray Clamen
Secretary
Canadian Section Office

Dear Secretary Bourget and Secretary Clamen:

On behalf of the Science Advisory Board (SAB), it is our pleasure to convey the SAB's "Findings of an Expert Consultation on Strengthening Science under a Renewed Great Lakes Water Quality Agreement" to you for use by the International Joint Commission (Commission). As you know from your participation in the Wingspread Workshop, these findings are based on discussions of invited guests at the January 24-26, 2006 Workshop. Since the SAB believes that the recommendations included in the attached document will be valuable to Commissioners during their development of advice to be provided to the Parties in the near future, we have taken steps to expedite the preparation of this document and its transmittal to you. In the future, we intend to request the Commission's approval to publish this document.

Sincerely,

Bruce A. Kirschner
Acting Secretary
Science Advisory Board
for
Isobel Heathcote
Michael Donahue
Co-Chairs of the SAB

Appendix 5

Microbial Source Tracking

Its Utility and Limitations toward the Protection of Recreational Waters in the Great Lakes Basin

Invited Expert Paper by Dr. Kate Field

Summary

Microbial source tracking is necessary because standard methods of measuring fecal contamination in water by enumerating fecal indicator bacteria (FIB) do not identify the source or sources of the contamination. Source tracking methods can be divided according to whether or not they require a library (a "host origin database" or set of bacterial isolates from fecal samples of known origin). Methods also can be divided by whether or not they use FIB and by whether or not they require cultivation of microbes. These variables all affect the cost, time required, and effectiveness of the methods.

Prominent library-dependent methods include antibiotic resistance analysis (phenotypic) and fingerprinting analyses (genotypic) such as ribotyping, REP-PCR, and PFGE. Library-depend methods are costly, time consuming, and have complex and sometimes poorly understood requirements for sample sizes and analyses. In addition, new libraries are needed for each geographical region. Prominent non-library-dependent methods include chemical markers (e.g., fecal sterols/stanols, caffeine, and laundry whiteners) and host-specific PCR (e.g., Bacteroidales molecular markers). Another set of techniques involves direct molecular monitoring of human viruses such as adenoviruses and enteroviruses. Viruses are important because they are not well correlated with FIB but are important pathogens.

All of these methods have been tested at the proof-of-concept level, but there have been few organized comparisons and proficiency tests with blind samples. In one such study, the SCCWRP study, host-specific PCR performed well, as did ribotyping and PFGE. Other comparative studies have found somewhat different results. All support the following conclusions: 1) No method is quantitative; 2) Results from the same method differ depending on the operator and on differences in experimental design and analysis. Few studies have followed up the results of fecal source tracking to quantify resulting gains in water quality.

The best evidence supports taking a multi-tiered approach to source tracking, moving from general to specific and from less to more expensive. The first step is intensive surveys using FIB to target sources spatially and temporally. Once "hot spots" are identified, then very directed source tracking can be done if needed, starting with less-expensive methods that identify human contamination, and continuing to more-expensive ones as needed to identify common species, or finally to identify all species.

Companies that offer source-tracking services should be provided with blind proficiency samples to assess their abilities and estimate possible benefits before they are hired.

Water quality standards were established based on epidemiological studies that measured human health outcomes following recreational exposure to human-derived fecal contamination. There are no similar studies for exposure to animal fecal contamination, although it is logical to assume that the risk from animal fecal contamination is lower. Thus even if microbial source tracking shows that fecal contamination is animal-derived, there is usually no way to allow for a higher permitted level of FIB. Hence the benefits from microbial source tracking at the present time are only that it allows the source or sources of fecal contamination to be accurately assigned, located, and corrected. In some cases this could lead to a reduction in FIB. In other cases where the source is primarily wildlife and there is no way to control the wildlife, no immediate water quality benefit from microbial source tracking will be seen. National environmental health agencies must take the responsibility to fund the required epidemiological studies so microbial source tracking can be properly applied to estimate human health risk.

INTRODUCTION

The problem: Fecal contamination of surface waters is widespread in the United States, Canada, and worldwide. The resulting illnesses, beach closures, environmental and habitat degradation, and contamination of fisheries have broad economic, health, and environmental impacts. The Great Lakes Basin, a major recreational site, presents many opportunities for human exposure to contaminated waters. Some of the important related issues in the Great Lakes Basin include beach closures, combined or sanitary sewer overflows, failing septic systems, agricultural and storm water runoff, pets at beaches, low water levels, extensive wildlife populations including Canada geese and gulls at beaches, fish kills, and algal blooms. Exceedances of bacterial water quality standards have occurred at sites in all five Great Lakes and throughout the Basin.

Several severe recent waterborne disease outbreaks have underscored the importance of the problem of fecal contamination. The 1993 outbreak of cryptosporidiosis in Milwaukee, Wisconsin, is estimated to have affected 400,000 people (74) at an estimated cost of 96 million dollars US (21). In 2000 in Walkerton, Ontario, 2,300 people became ill and 7 died as a result of drinking water contaminated with E. coli O157:H7 from cow manure (56).

Direct monitoring for pathogens. Since the public health concern is microbial disease, the most straightforward approach to protecting health would be to directly monitor microbial pathogens in water. However, although effective assays for many pathogens exist, currently these are often expensive, time consuming, and technically complicated. Pathogens may be rare, difficult to culture, and irregularly distributed, yet highly infectious even at low doses. Furthermore, a large number of assays for different pathogens would be required, and feces from both humans and animals may contain as-yet-unidentified pathogens or pathogens for which no assays exist. While microarrays to simultaneously assay numerous pathogens are under development (e.g., see (7, 69, 77, 118, 119), these still have numerous problems with sensitivity, specificity, and quantitation; it is likely to be awhile before they are ready for general use.

Fecal indicator bacteria. Because of these limits to direct monitoring of pathogens, it is standard practice to monitor fecal indicator bacteria (FIB) such as total and fecal coliforms, Escherichia coli, and fecal enterococci in water. FIB are easy-to-culture aerobic bacteria. Their presence in water is assumed to be due to fecal contamination; they are enumerated in water samples in order to quantitatively estimate the amount of the contamination.

Epidemiological studies have established human health standards based on exposure to FIB, and associated disease, in drinking, recreational, and shellfish waters (reviewed in (123)). Because the most serious threat to human health is thought to come from human, not animal, fecal contamination, these epidemiological studies took place at sites where the principal source of fecal contamination was human or human sewage. The reasoning was that this would best protect human health by avoiding setting bacterial standards too low.

Although the use of FIB to assess water quality has unequivocally reduced human health risk, the current FIB approaches fall short in several areas.

Indicator bacteria don't identify the source of contamination. To manage water quality, the source of fecal contamination must be known, both to find and mitigate the problem, and to estimate human health risk. A variety of warm-blooded, and even some cold-blooded, animals contain FIB in their feces (e.g., see (50)). Thus, the presence of indicator species in water is not sufficient to determine the source of fecal contamination; standard methods of measuring fecal contamination by growing public health indicator bacteria do not identify the source of the contamination.

Relative risks from human and animal fecal contamination. Indicator counts lump together many different potential sources of fecal contamination, which may have wholly different associated pathogens. Human and animal feces both pose threats to human health. The health threat from human fecal contamination is well documented. For example, human feces are commonly associated with the spread of Salmonella enterica serovar typhi, Shigella spp., hepatitis A virus, and noroviruses. Indeed, until recently, the focus of concern for water-related illness, and associated research, has been contamination by human effluent (reviewed in (121)).

The human risk from domestic and agricultural animal feces is usually assumed to be less than the risk from human feces, in part because viruses, which are the most common cause of human illnesses from exposure to fecal contamination in water, are highly host-specific. Domestic/agricultural animals spread many pathogens, including, for example, Salmonella, E. coli O157:H7, Campylobacter jejuni, Giardia spp., Cryptosporidium spp., and hepatitis E virus (reviewed in (22). Nevertheless, few studies have been carried out on the risk of animal feces as a source of waterborne zoonotic infections (121). In a Hong Kong study, illness rates for two marine beaches impacted by animal (pig) wastes were lower than for seven other beaches (20, 54). In a New Zealand study carried out at seven populous marine beaches, no substantial differences in illness risks were found between the human and animal waste-impacted beaches, though both were markedly different from the control beaches (78).

The disease risk from fecal contamination of wild animals, such as gulls, is poorly understood. Rare events when wild animal viruses cross into humans may be deadly; HIV/AIDS and H1N5 bird flu are prominent examples. Certain waterborne bacterial and protozoan pathogens of wild animals have been documented to infect humans (e.g., Leptospira interrogans). Giardia and Cryptosporidium widely infect wild animals. Because these parasites appear morphometrically identical in animals and humans, wild animals have long been assumed to be reservoirs and important sources of human infection. However, molecular evidence has made it clear that most genotypes of these parasites are host-adapted and cannot cross-infect among different host species (e.g., see (4, 130)). For example, in Canada geese, Zhou and colleagues concluded that, "Canada geese might only serve as accidental carriers of cryptosporidia infectious to humans and probably play a minor role in the animal-to-human transmission cycle of the pathogen" (130). However, a significant number of emerging and re-emerging waterborne zoonotic pathogens have been recognized (9). Some of these pathogens may not be of recent origin; some may have been causing illness for a long time, but were not previously identified due to a lack of suitable isolation and identification methods. These include, for example, vesiviruses, Campylobacter jejuni, Yersinia enterocolitica, and Cryptosporidium spp. (93, 113, 121).

Water regulators frequently must estimate total maximum daily loading (TMDLs) of fecal bacteria based on indicator counts. Although the data are sometimes contradictory ... there seems to be agreement that different species contain both different numbers and different relative proportions of E. coli and enterococci in their feces, making it unclear how to estimate the E. coli or FIB contribution of different sources of feces in a watershed, even if the amount of fecal input from each is somehow known.

Amounts of indicator bacteria in different types of feces. Water regulators frequently must estimate total maximum daily loading (TMDLs) of fecal bacteria based on indicator counts. Although the data are sometimes contradictory (e.g., see (1, 29, 32, 33, 40, 124), there seems to be agreement that different species contain both different numbers and different relative proportions of E. coli and enterococci in their feces, making it unclear how to estimate the E. coli or FIB contribution of different sources of feces in a watershed, even if the amount of fecal input from each is somehow known.

Environmental survival of indicator bacteria. An adequate fecal indicator should not reproduce outside the animal host. Both E. coli and enterococci can survive and persist ubiquitously in natural environments such as fresh water lakes and streams, algal wrack, beach sand, and tropical soils (16, 37, 90, 99, 125).

Correlation of indicator bacteria with pathogens. An indicator should be correlated with the presence of pathogens; and it should have a survival profile similar to the survival profile of the pathogens whose presence it indicates. E. coli and enterococci are not well correlated with pathogenic Salmonella spp. (68), Campylobacter spp. (10, 55, 68, 72), Cryptosporidium spp. (10, 55, 68, 72), human enteroviruses (39, 55, 68), including adenoviruses (87), and coliphage (60). The poor correlation of bacterial indicators with viruses is of particular concern because of the low infectious dose of the viruses (36), their linkage with both acute and chronic disease (36), and the fact that they are considered the most frequent cause of swimmer-associated illnesses.

Microbial Source Tracking. Diagnosing the sources of fecal contamination in water is typically called bacterial source tracking (BST) or microbial source tracking (MST). These names are misleading, since they imply that microbes or bacteria don't normally occur in water and only come from fecal contamination. However, naturally occurring microbes are ubiquitous in surface waters, with bacteria occurring at an average density of 106 cells/ml and viruses at a higher density.

The assumptions that underlie fecal source tracking are that some characteristic in feces unequivocally identifies a particular feces type; and that this identifying trait can be detected in water. Furthermore, many methods make the (usually untested) assumption that the relative proportion of identifying traits remains the same in water over time as the relative proportion in the original feces that entered the water; therefore, if the traits can be quantitatively detected, the quantitative contribution of each particular type of feces can be estimated.

As an example, an earlier method to distinguish human from non-human fecal contamination was based on estimating the ratio of fecal streptococci to fecal coliforms. But because strains of coliforms and streptococci have different survival rates, the ratio changes in complex ways over time, making it unreliable (111, 112).

There are several recent reviews of fecal source tracking (29, 80, 107, 110).

Why Microbial Source Tracking? There may be several reasons to do microbial source tracking. The first concern is frequently to investigate the source of high levels of FIB. From the point of view of regulators, identifying the source or sources of FIB (not feces, not pathogens) and eliminating them may be the only objective. A second objective is to identify particular pathogens in water. Certain sources of fecal pollution might be associated with particular pathogens (for example, E. coli O157:H7 with ruminant feces). This reason is closely related to the third reason, which is to estimate the human health risk associated with exposure to contaminated water.

The first objective is obtainable; the others may not be.

MICROBIAL SOURCE TRACKING: METHODS

A number of methods for fecal source identification are in use or under development. These can be divided into culture-based and culture-independent methods. Furthermore, some methods require a "library." In this context, a "library" is a set of bacterial isolates from fecal samples of known origin, tested using the method of source discrimination. It is also called a "host origin database." Most library methods are culture-based and require growing environmental isolates from water samples. Source identification occurs by a statistical comparison between test patterns from the library and the environmental isolates. Library-dependent methods include both phenotypic and genotypic tests. Culture-dependent, library-independent methods are based on growing source-specific viruses or bacteria. Library-independent, culture-independent methods include chemical and microbial (molecular) tests.

CULTURE-BASED, LIBRARY-DEPENDENT METHODS

It is logical to base fecal source identification methods on FIB, because throughout the U.S. and Canada, FIB are used to identify a water quality problem in the first place. Moreover, epidemiological studies correlating FIB with health risks have already been done, and water quality laboratories are expert at indicator assays. Thus library-based methods have typically started by growing E. coli or enterococci.

Library-based approaches are labor-intensive, requiring extensive sampling both to prepare the library and to test environmental isolates. All library-based methods have complex requirements for adequate sample size, representativeness, and geographic stability (52, 83, 128). Data on geographic stability suggest that for most methods, libraries are not cosmopolitan, and thus a separate library for each locale or watershed may be required (e.g., see (48, 94, 109, 114)).

Antibiotic resistance and other phenotypic methods. In the multiple antibiotic resistance (MAR) method, also called ARA (antibiotic resistance analysis) and ARP (antibiotic resistance profiling), isolates of E. coli or enterococci are tested against panels of antibiotics in order to discriminate among human and various animal sources of fecal pollution (e.g., see (26, 47, 51, 52, 95, 127)). The underlying assumption is that since humans, agricultural animals, and wildlife have been exposed to different antibiotic regimes, their fecal bacteria will differ in types and levels of antibiotic resistance.

Antibiotic resistance traits in bacteria are often borne on plasmids, are under strong selection, and change rapidly under the influence of host population exposure to antibiotics and other chemicals. Thus, antibiotic resistance is not geographically stable; libraries of strains from known sources must be constructed for each new geographic region being tested. However, the MAR/ARA method is inexpensive and low-tech, making it readily available to a broad variety of investigators.

Comparative studies that have assessed the effectiveness of antibiotic resistance methods for fecal source tracking have generally given them low ratings (e.g., see (52, 82)). In a blind study that compared a number of fecal source tracking methods using water samples containing feces (see below), the performance of antibiotic resistance-based methods of identifying the fecal sources was little different from random (45). There is some evidence that enterococci work better than E. coli for ARA (see (52, 82)).

Other phenotypic methods that have been tested include carbon-source utilization (CUP) and serotyping; the serotyping approach did not seem promising and was not extensively tested, and CUP did not perform well in a comparative study (45).

DNA fingerprinting: ribotyping, REP-PCR, and related methods. Genotypic library-based methods are usually based on DNA fingerprinting of bacterial isolates. Ribotyping, repetitive extragenic palindromic polymerase chain reaction (REP-PCR), amplified fragment length polymorphism (AFLP), pulsed-field gel electrophoresis (PFGE), random amplified DNA polymorphisms (RAPD), and denaturing gradient gel electrophoresis (DGGE) are fingerprinting techniques producing bar code-like patterns for each bacterial isolate.

Each of the fingerprinting methods depends on matching the fingerprint patterns of bacteria isolates from known sources of feces (the library) with fingerprint patterns from individual water isolates. Each fingerprinting assay is complex and different, requiring specialized equipment and training. For example, ribotyping involves growing indicator bacterial isolates, extracting DNA, amplifying 16S rRNA genes by PCR, and digesting amplification products with restriction enzymes. The "bar code" is usually created by separating fragments via electrophoresis, and detecting fragment patterns by hybridization with radioactive or fluorescent probes (e.g., see (19, 48, 83, 96, 104)). The resulting patterns can be very small, complex, and difficult to distinguish and interpret, either by eye or automatically.

For these methods, the size of the "library" is extremely important, as is the method of statistical analysis used (53, 61, 117). In addition, many studies have found that many or most environmental isolates cannot be matched to host isolates (e.g., see (53, 117). It is necessary to discard these unmatched isolates; identifying them based on similarity to known isolates results in incorrect classifications.

Ribotyping and PFGE are successfully used for epidemiology of food outbreaks to identify an outbreak and its source. However, source-tracking presents considerably more complex problems than matching outbreak genotypes. In a blind study that compared a number of fecal source tracking methods using water samples containing feces (see below), the performance of both ribotyping and PFGE was good (45, 83); REP-PCR was not as good, and the other fingerprinting methods were not tested. Several investigators have concluded that PFGE may be of too great resolution for source tracking (e.g., see (71)); however, commercial source tracking companies use it. A more recent comparison between ribotyping and antibiotic resistance profiling found that ribotyping only identified 27% of unknowns to the correct source category; E. coli ARA correctly identified 28%, and enterococci ARA correctly identified 45%.

Other genotypic library-based methods Ram and colleagues explored directly sequencing beta-glucoronidase genes from E. coli isolates, and comparing sequences to library sequences (103). They found 114 alleles (different sequences) in environmental isolates; different allele frequencies occurred at different sites. Of 82 alleles from fecal samples, a few were host-specific (2 in birds, 3 in humans), but the most common alleles were found in all of the hosts. Their "internal consistency" (ability to correctly assign isolates) was 60% to 75%.

LIBRARY-INDEPENDENT, CULTURE-DEPENDENT METHODS

Viral methods. Phage of Bacteroides fragilis can distinguish human and animal fecal pollution, since certain strains of B. fragilis will grow bacteriophages only from human sewage and others will support phage growth from both human and animal feces (102). However, these phages are more common in Europe, particularly southern Europe, and may not be useful in the U.S. and Canada (e.g., see (98)). Similarly, two serotypes of F+ RNA coliphages, Types II and III, are found in association with human fecal contamination, whereas Type IV is found in association with animal fecal contamination, and Type I occurs in both human and animal feces (38, 49). Growth of these coliphages in an appropriate cell culture, followed by serotyping, identifies human and non-human fecal contamination in water. Recently, serotyping has largely been replaced by molecular typing (57).

These viral methods are limited to discriminating between human and animal sources. Little is known about differential survival of the various types, which would affect the ability to discriminate over time. In addition, the markers appear to be irregularly distributed in populations and may work better in some geographic areas and when fecal sources comprise multiple individuals (such as from sewage) rather than single individuals (86). Culture-based viral detection methods are largely being replaced by molecular detection (see below).

Bacterial methods. Several microbial source tracking methods are based on culturing host-specific bacterial strains, such as Bifidobacterium adolescentis for humans (103)(11, 73) and Rhodococcus coprophilis for grazing animals (91, 106). They are isolated and detected with selective media and colony hybridization; molecular detection is coming into widespread use.

A recent revival of the ratio approach suggests that the bacterial ratio of atypical colonies to total coliform colonies (AC/TC) from a total coliform membrane filter assay could identify human fecal and agricultural impacts (12).

CULTURE-INDEPENDENT, LIBRARY-DEPENDENT METHODS

Community fingerprinting. This approach uses T-RFLP, a technique that digests community DNA with restriction enzymes then separates fluorescently labeled fragments according to size on a DNA automated sequencer. The pattern of fragments is then compared to patterns generated from known fecal DNAs. These known fecal patterns make up the "host origin database; like a library of bacterial isolates, they are unlikely to be geographically or temporally stable and likely to need to be re-done with relevant fecal samples for each new study. As well as demanding a DNA automated sequencer, equipment that a water quality lab would be unlikely to own, this technique did not perform well in a blind study that compared a number of fecal source tracking methods using water samples containing feces (see below) (30, 45).

A similar approach used cluster analysis to compare T-RFLP patterns from Bacteroides-Prevotella fecal DNAs derived from a number of species including chickens, cows, deer, pigs, dogs, geese, horses, humans, and gulls (34). The results were not promising. Using fecal DNAs, there was great overlap among species, and although cluster analyses separated the patterns obtained from single species, no species-specific diagnostic peaks were found. Even if a laboratory was equipped to carry out this analysis, it is unlikely that the technique could identify fecal sources mixed together in environmental samples.

CULTURE-INDEPENDENT, LIBRARY-INDEPENDENT METHODS

Chemical methods. Not being based on microbes, chemical methods are both "culture-independent" and "library-independent." Substances such as caffeine, fecal sterols and stanols, laundry brighteners, surfactants, fragrances, pesticides, and polycyclic aromatic hydrocarbons can be used to detect human and non-human fecal contamination and determine urban sources of fecal contamination (15, 27, 58, 67, 85, 100, 112, 115, 120). Standley and colleagues (115) compared several of these so-called "molecular tracers" and concluded that a combined index of caffeine and fragrance levels was an effective identifier for human sewage; a ratio between particular steroids made an effective identifier for agricultural input; and a different steroid ratio identified wildlife input. Similarly, profiling of seven sterols in South Australian metropolitan catchments suggested areas of human, dog, and bird fecal impact (120).

Although presence of chemical indicators and molecular tracers can identify recent fecal inputs, their spread, transport, and persistence in water may not be correlated with that of pathogens and FIB, which are cellular or particulate. Survival of indicators and pathogens in water is affected by factors such as settling, UV irradiation, and grazing (e.g., see (14)); these factors are likely to affect chemical indicators differently than cellular or particulate pathogens.

These methods have been tested in Australia and are in widespread use there. A recent study compared a suite of fecal steroids from the Santa Ana River in California and found that the steroid ratios were inconsistent with sewage; moreover, concentrations of FIB were correlated with occurrence of bird fecal steroids (89).

Molecular methods. This approach represents a large change in water quality monitoring, since in most cases the methods not only avoid culturing, but also may not use standard fecal indicators at all. In these methods, a genetic marker is assayed directly from a water sample or from DNA extracted from a water sample, without an intervening culture step. These methods assay specific genes by the polymerase chain reaction (PCR); this approach is also called "host-specific PCR." The approach speeds up the process of source tracking, and allows access to novel markers that would be difficult or impossible to grow. These methods can theoretically take as little as two or three hours from sampling to diagnosis.

PCR, a method of making many copies of a specific DNA sequence in a test tube, is routinely used in medical and food diagnostic labs, and has replaced many older diagnostic procedures that took weeks and required multiple differential media and biochemical tests. Thus although many water labs are not yet equipped for PCR, the technique is accessible, the equipment is not expensive (comparable to, say, an incubator, and far less than a centrifuge), and the technology is likely to be increasingly available.

The assumption that underlies this approach is that there are host-specific genetic markers in feces. These may be markers that are human-specific, to separate human from non-human fecal pollution, or markers that specifically identify individual host species. Although a single individual's fecal community may change over time and in relation to diet and age (although recent molecular data are challenging this assumption, see (76)), certain features persist and are diagnostic. However, host-specific markers may not be present in every individual, and individuals may have differing amounts of the markers. As a result, these methods usually work better when there is a "bulk" or community sample (such as sewage, for humans) rather than an individual or family sample.

Viral methods. A number of fecal viruses can be monitored directly in water, without culturing (reviewed in (35, 43). Examples include human adenoviruses, human enteroviruses, and bovine enteroviruses (36, 44, 59, 70, 87, 98, 122). The presence of human or bovine viruses indicates the presence of human or cattle fecal pollution. Monitoring for viruses typically requires larger water samples than the 100 ml samples used for water quality monitoring; concentration of such large samples can concentrate PCR-inhibitory substances as well, interfering with detection (59, 119). To increase sensitivity, investigators may use nested PCR, which makes it difficult or impossible to detect quantitatively (59). Real-time PCR assays have successfully quantified enteric viruses (8, 81). The viral methods are effective in detecting human sewage, although they may not detect feces from individuals or small groups of humans (86). These methods are particularly important because they directly detect viral pathogens, which are not well correlated with FIB.

Anaerobic bacterial targets. Some fecal anaerobic bacteria (for example, in the genera Bifidobacterium and Bacteroides) have host-specific distributions and can therefore identify particular sources of fecal contamination (e.g., see 2, 31, 64, 103). Fecal anaerobes make up the majority of bacterial cells in feces, and are present at much higher densities than coliforms and enterococci. However, because culturing anaerobes is far more complex that growing FIB, anaerobes were not generally adopted as indicators until a shift to molecular rather than culture-based methods for studying bacteria in natural populations spilled over into the public health arena.

This shift to molecular ecology of microbes led to the discovery that the vast majority of bacteria in all habitats, ranging from soil and water to the mouth and GI tract, have never been grown, and indeed cannot be cultivated using standard approaches. The importance of this discovery for source tracking is that "uncultivated" bacteria provide potential host-specific molecular markers. In fact, because the majority of bacteria in feces have never been grown, "uncultivated" targets are more common in feces that cultivated ones.

Ribosomal RNA genes are commonly used for molecular diversity studies of uncultivated bacteria, because these genes are present in all bacterial groups, allowing the use of published PCR primers; in addition, these genes contain sufficient sequence diversity to distinguish among specific strains, species, or genera. Most bacterial groups have multiple rRNA gene copies, increasing the ease of detection. Other good targets are rRNA gene spacers.

Bacteroides and related genera (Phylum and Class Bacteroidetes, Order Bacteroidales) comprise a large proportion of the fecal flora in warm-blooded animals, making them a relatively easy target for detection. In addition, they are genetically diverse, are limited to animal body cavities, are unlikely to survive long after release into receiving waters (because they are anaerobes), and show species- or group-specific host distributions (2, 31, 64). Bacteroidales host specific PCR primers and based on uncultivated microbes can specifically identify feces from ruminants, humans, dogs, pigs, horses, and elk (5, 23). Markers can be detected in fecally contaminated natural waters. Sensitivity of detection of host-specific markers in 100 ml water samples is comparable to the sensitivity of detection of E. coli by culture (5, 6, 13, 24). These assays appear to be geographically stable, and have been used successfully throughout the United States and Canada, northern Europe, Hawaii, and New Zealand.

In a blind study that compared a number of fecal source tracking methods using water samples containing feces (see below), host-specific PCR of Bacteroidales molecular markers performed well.

However, because there are many closely related Bacteroidales sequences in feces along with the host-specific sequences, and because even identical models of thermal cyclers vary significantly, it is important for each user to establish the specificity of the host-specific assays by testing them with fecal DNAs from the target species and other species. PCR conditions can usually be adjusted so that detection is specific.

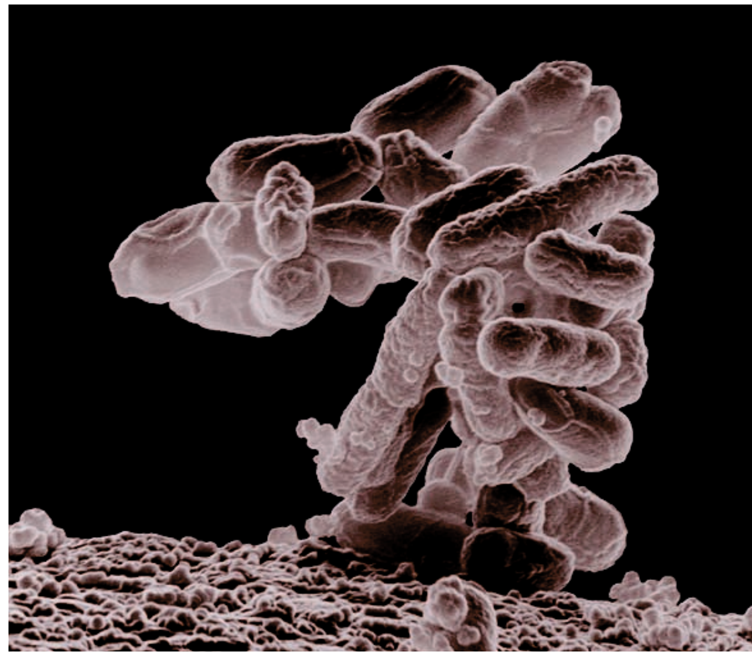
Not only do related hosts have closely related fecal Bacteroidales (for example, ruminants), suggesting co-evolution and adaptation, but horizontal transfer of fecal bacteria among species in close contact has also occurred (e.g., humans and their pets (23)). Sooner or later, therefore, it's likely that someone will find dogs, chickens, or gulls that bear the published "human specific" markers and so on. It is important to test host-specific primers each time they are used in a new locale.

A PCR ASSAY FOR B. THETAIOTAOMICRON DISTINGUISHES HUMAN AND DOG FECES FROM OTHER ANIMALS (18)

Similar approaches have targeted the genus Bifidobacterium. Nebra and co-workers (84) developed probes to distinguish B. dentium, a species thought to be limited to humans, and animal-specific Bifidobacterium species. Following amplification of Bifidobacterium 16S rDNAs using general primers, they used their probes to differentiate human and animal samples. There is some concern about survival of this group in water. Resnick and Levin (103) found that members of the genus Bifidobacterium could not be cultured after 5 h in fresh water or 10 h in salt water. Carillo and colleagues (17) also observed very low survival of B. adolescentis in a tropical environment and suggested that the genus could be used to detect only very recent fecal contamination. These cultivability problems may not matter for molecular detection.

Toxin/virulence genes. Host-specific toxin genes in E. coli make interesting targets for source detection, since they are not only related to standard fecal indicators, but also give information about pathogen status. A heat-stable enterotoxin from enterotoxigenic E. coli, the STIb toxin, is associated with human fecal waste; its gene is the target for PCR primers that detect human fecal pollution (92). Similarly, the STII toxin gene is associated with pig feces; specific primers can detect pig fecal contamination (63). The heat-labile enterotoxin, LTIIa, is associated with cattle fecal waste; its gene is the target of PCR primers to detect fecal pollution from cattle (62). These markers are generally specific (with occasional exceptions (30)), and are temporally and geographically stable. One drawback is that the target genes are relatively rare. In a blind study that compared a number of fecal source tracking methods using water samples containing feces (see below), host-specific PCR of toxin genes performed well, but it was necessary to enrich for E. coli from the 100-ml water samples before the toxin genes could be detected. This precludes quantitative detection, since the growth step introduces culture bias. Thus the method is not truly culture-independent, and will take longer than methods that directly sample genes in water without an intervening growth step.

Similarly, a virulence factor from Enterococcus faecium, the enterococcal surface protein (ent) is the target for a human-specific PCR assay (108). This assay is highly specific; 97% of human sewage and septage samples, but no livestock or bird samples, were positive for the marker. However, the assay is not very sensitive.



Escherichia coli

Like the E. coli toxin genes, the ent gene is rare; it is necessary to enrich for enterococci before the gene can be detected, precluding quantitative detection and increasing the time required.

Rhodococcus coprophilus. Culture-based detection of this bacterial indicator of fecal contamination from herbivores (cow, sheep, horse and deer) is slow. Detection by PCR and quantification by Q-PCR is specific and sensitive (106).

Host mitochondrial sequences. Martellini and colleagues developed PCR primers targeting host mitochondrial gene sequences (75). It is well known that hosts shed their own cells (e.g., blood cells, intestinal cells) in feces. It seems incontrovertible that these host cells make a better host-specific target for source tracking than bacteria, which may be found in multiple hosts and can spread among species. Mitochondrial DNA is more common than nuclear DNA, and is well known to be more variable. This approach appears extremely promising if the bugs can be worked out. The initial publication showed many unresolved problems with specificity and sensitivity.

CULTURE-INDEPENDENT VERSUS CULTURE-DEPENDENT METHODS

Advantages and disadvantages of culture-based methods. Culturing fecal indicator organisms is relatively inexpensive and low-tech, making it broadly available. However, this advantage is lost if the source identification method that is applied to the cultured isolates is high-tech and expensive (e.g., PFGE and AFLP). Another advantage of culturing is that it provides an enrichment step, increasing the numbers of target microorganisms and providing single strains in isolation. Finally, culture-based methods often use standard public health indicators such as E. coli or enterococci, for which at least some information about survival and transport is available.

Disadvantages are that these methods are limited to testing easily cultured microbes. Many pathogens, and even the most common fecal bacteria, are difficult to grow. In addition, the composition of microbial communities changes drastically when cultured (e.g., see (28)). This "culture bias" has virtually never been considered in culture-based fecal source identification.

Advantages and limitations of culture-independent molecular methods. These methods have the advantage of sampling the entire population present in the sample, with no culture bias. In addition, they are simpler and quicker than culture-based methods; they may require only a few hours to detect fecal pollution and identify its source. They do not require prior preparation of a "library," as the markers are in most cases universal or nearly so. They are not limited to easy-to-culture microbes, but may instead use difficult-to-grow but common fecal microbes or mine the uncultured genetic diversity in feces for source-specific markers.

A drawback of using any markers other than FIB is that their survival relative to, and correlation with, standard fecal indicators and pathogens are poorly known. Since regulations are currently based on FIB, any other markers must be correlated with public health bacteria in order for managers to use them.

PCR carries high risks of contamination. As a result, another disadvantage of these methods is the necessity of establishing stringent controls at all steps of the process, from physical separation of different stages of the research into different laboratories to inclusion of appropriate negative controls.

A further limitation of the culture-independent methods is that markers for only a few animal species are currently available; wildlife species especially are not represented. More and different gene targets are needed. Most of the culture-independent methods result in presence/absence of data on marker occurrence; quantitative assays are needed. Finally, for any of these markers, it is important to test their geographic range and temporal variability.

MICROBIAL SOURCE TRACKING USING COMBINED METHODS

Since no single source tracking method is ideal, some have suggested combining methods (45, 116), in order to enhance discrimination or provide confirmation of results. Boehm and colleagues used intensive testing for FIB to spatially locate areas of intense contamination and characterize variability in Catalina Bay (8). They followed this with targeted assays for human-specific Bacteroidales and enteroviruses to identify the source of the contamination. They concluded that there were multiple sources; the spatial component of their sampling allowed them to identify specific sources, including a leaking graywater pipe.

In a second study, intensive FIB sampling in a watershed emptying into Santa Monica Bay was combined with molecular detection of enterovirus, a human-specific Bacteroidales marker, and enterococcus. Finally, investigators sequenced amplified enterovirus sequences to confirm the presence of potential risks to human health. Although the entire creek had high FIB levels, high human-specific and viral indicators in specific areas indicated where mitigation would do the most good (89).

Genthner and colleagues combined REP-PCR fingerprinting with antibiotic resistance analysis of Enterococcus faecalis isolates, and concluded that the combination of the two increased their ability to assign beach/swash zone isolates as either human or gull-derived. Most isolates were identified as gull. It is striking that in this study there were no matches among isolates. Cluster analysis of REP-PCR patterns placed human, gull, and beach isolates in separate lineages; ARA also clustered beach isolates in a discrete lineage, with gull and human isolates intermingled in lineages. This study appears to support the existence of unique environmental lineages, rather than identifying them as human or gull-derived.

In New Zealand investigators combined identification of host-specific Bifidobacterium, Rhodococcus and Bacteroides with assays for fluorescent whitening agents and fecal sterols/stanols. They were able to identify human contamination, but found that animal input was more difficult (41).

MICROBIAL SOURCE TRACKING: IS IT QUANTITATIVE?

Because FIB are used quantitatively to estimate total fecal load, water quality practitioners accept without question, and in fact insist, that fecal source tracking methods should be quantitative. However, little is known about the comparative survival of the different kinds of source-specific markers, and what data there are indicate strongly that survival is not proportional. Many different studies have shown that populations of E. coli in fresh feces differ from strains sampled from diverse habitats such as dry feces, animal bedding, septic tanks, storage lagoons, and water samples (e.g., see (42, 79, 126)). The general trend in the environment outside the host, confirmed by several different measures of genetic variability, is dominance of environmental strains that differ from strains in the host. A study that used ribotyping to follow persistence and differential survival of E. coli genotypes, for example, showed that some strains were more persistent than others, and that the distribution of ribotypes in environmental mesocosms was different from their distribution in feces (3). Another study of diversity of E. coli in the environment versus in feces found that rivers and beaches were dominated by river and beach genotypes, which differed from fecal genotypes even when the environments in question were heavily fecally contaminated (79).

Under these circumstances, it is hard to imagine how fecal source tracking could be more than vaguely quantitative. If the proportions of the markers change as soon as they hit the water, and if the markers all show differential survival, and if fecal bacterial genotypes in water are dominated by unique environmentally adapted strains, then trying to make exact quantitative estimates of the contribution of different fecal sources doesn't make sense. This is particularly true for culture-based assays, where selection of readily cultivable strains leads to bias. However, used as presence-absence tests, microbial source tracking is useful both to identify fecal sources and to locate "hot spots" of contamination.

In a blind study that compared a number of fecal source tracking methods using water samples containing feces (see below), all methods failed to quantify fecal inputs in unknown samples (45).\

MICROBIAL SOURCE TRACKING: HOW SHOULD THE METHODS BE ASSESSED?

The field of microbial source tracking is still in early development in some ways. Many of the methods have only been tested against fecal samples in laboratory studies (proof of concept testing), or applied in field studies where the "real" answer is not known, so the real performance of the method cannot be assessed. Two kinds of testing are needed. The first is blind testing with proficiency samples; this could be done comparatively to rank methods and to better establish relative costs and strengths of each. The second is application of the source-tracking method in field studies, followed by measurement of the resulting improvement in water quality.

ARCC and other statistical tests. The average rate of correct classification (ARCC) has been used to judge how well library-based source tracking methods work. ARCC is a statistical estimate of the ability of a library to correctly classify isolates pulled from the library (not its ability to correctly classify environmental isolates or known-source isolates from outside the library). ARCCs reported in some studies have been quite high (e.g., see (25, 46)). However, the size of the library influences its ARCC. Small libraries have higher ARCCs than large libraries, but small libraries are not as representative and are therefore not as good at classifying novel isolates (from outside the library) as are large libraries (82, 128). Thus, ARCC may be better termed internal accuracy (82). It does not estimate the ability of the method to identify fecal sources, and can be misleading. Because many methods of fecal source tracking have been assessed only by calculating ARCCs, the ability to compare these methods is limited.

Comparative and Proficiency Studies. An ideal test of methods would supply practitioners with blind samples for source identification. The Southern California Coastal Water Research Project (SCCWRP) and the U.S. EPA sponsored such a study in 2003 (30, 45, 52, 83, 86). Study participants were asked to identify the fecal source(s) in identical sets of water samples containing human, cattle, dog, or gull feces, sewage, or a mixture. Along with unknown water samples, participants were supplied with samples of the feces used to create the unknowns. Study participants used coliphage and virus-based approaches, antibiotic resistance, carbon utilization profiling, ribotyping, REP-PCR, PFGE, community DNA profiling, and host-specific PCR of E. coli toxin genes and Bacteroidales molecular markers. Methods were assessed according to their ability to identify whether samples did or did not contain human feces, identify each fecal source, quantify fecal contributions, and handle both freshwater and saltwater samples and samples with humic acids.

Host-specific PCR (of E. coli toxin genes and Bacteroidales markers) was very accurate at identifying samples with human feces and sewage with no false positives, and was generally considered to perform the best of the methods. Ribotyping and PFGE also performed well, although results varied depending on what group did the analysis. Several of the others, including phenotypic methods and genotypic library-based methods, identified most or all samples with human input, but had false positives. The virus-based methods worked well at identifying samples with sewage but less well at identifying samples with human feces. None of the methods correctly identified all the sources in every sample. The host-specific PCR methods accurately identified the species for which they had markers, but did not have markers for all species. Many of the other methods had significant numbers of false positives. Several broad conclusions could be reached. First, the same approach did not perform equally well in the hands of different investigators, underlining the need for standardization. Second, the rate of false positives for culture-based, library-dependent methods was often very high. Third, no method was able to accurately quantify the sources. Fourth, each method had strengths and weaknesses, and no method performed perfectly. Methods that accurately identify human fecal contamination are useful when the principal question is the identification of human input. Methods that are rapid and accurate for some sources, but don't identify all sources, would be useful where the principal research objective is to identify the major sources of fecal contamination for rapid mitigation. Methods that are more time-consuming and less accurate, but identify all sources, would be appropriate where it was important to know all sources.

A second smaller study compared library-dependent methods using E. coli (117). Again, ribotyping and PFGE worked well. It was notable that ribotyping with EcoRI and PvuII approached 100% correct classification of unknown isolates, but only 6% of the isolates could be classified. This is the same pattern seen in studies cited above that compared genotypes of fecal and environmental strains; most environmental strains ("transients") differ from fecal strains. If someone doing microbial source tracking with a library-based genotypic method claims to be able to assign all the environmental isolates to host, they are either being deceptive or they don't understand the method.

A third study compared the performance of ribotyping with HindIII and antibiotic resistance testing (82). The study established libraries, measured internal consistency (rather low, as expected with large libraries), and used the libraries to attempt to classify blind proficiency samples. Twenty-eight per cent (by ARA) and 27% (by ribotyping) of the E. coli proficiency isolates were assigned to the correct source category. There was almost no overlap between isolates correctly classified by the two methods. This study concluded that "None of the methods performed well enough on the proficiency panel to be judged ready for application to environmental samples."

The difference in results reported in these and other comparative studies (105) may be due to study design and operator error, underlining the necessity of accurately establishing the correct parameters for each method.

Few or no studies have accurately measured water quality improvements that resulted from source tracking. These studies are necessary in order to analyze benefits and costs.

MICROBIAL SOURCE TRACKING: WHAT ARE THE BENEFITS?

Water quality standards were established based on the results of epidemiological studies that measured human health outcomes following recreational exposure to human-derived fecal contamination. There are no similar studies of health outcomes following exposure to animal fecal contamination, although it is logical to assume that the risk from animal fecal contamination is lower. A recent exposure study at Mission Bay, California (report available on the SCCWRP Web site), found a much lower level of human illnesses than expected considering the levels of FIB. In the next year, a follow-up study used two different methods of microbial source tracking and found that the primary source of the FIB at Mission Bay was non-human, most likely from water birds. These results underscore the need for larger epidemiological studies to measure human health risks from animal fecal contamination. National environmental health agencies must take the responsibility to fund the required epidemiological studies so microbial source tracking can be properly applied to estimate human health risk

Water quality regulators are frequently in the situation where high bacterial counts are thought to be due primarily to wildlife. Even if microbial source tracking shows that fecal contamination is wholly animal-derived, current regulations do not usually allow for a higher permitted level of FIB. Hence the benefits from microbial source tracking at the present time are only that it allows the source or sources of fecal contamination to be accurately assigned, located, and corrected. In some cases this could lead to a reduction in FIB. In others, where the source is primarily wildlife and there is no way to control the wildlife, no immediate water quality benefit from microbial source tracking will be seen. However, regulators must identify and eliminate all possible fecal sources; even when there is a lot of wildlife, human sewage, and septage leaks and agricultural runoff may still be identified.

MICROBIAL SOURCE TRACKING: HOW SHOULD IT BE DONE?

The best evidence supports taking a multi-tiered approach to source tracking (e.g., see (8, 65, 66, 89), moving from general to specific and from less to more expensive. After each step, progress should be assessed before deciding to move to the next one. The first step is intensive surveys using FIB to target sources spatially and temporally. Once "hot spots" are identified, their sources may become obvious even without any specific microbial source tracking (for example, leaky pipes or run-off from a particular farm). If not, then very directed source tracking can be done, starting with less-expensive methods that distinguish human contamination, continuing to more-expensive ones as needed, to identify common or likely targeted species, and finally identifying all species if needed. Appropriate methods to distinguish human contamination would be chemical methods (caffeine, laundry brighteners, and the like), host-specific PCR (for example, Bacteroidales molecular markers), and viral methods. The lowest tier of species identification also could be host-specific PCR, since it is quicker and less expensive than library-based methods and can identify common agricultural and domestic animals. The final tier, if needed, would be a library-based method to identify specific sources in more detail.

MICROBIAL SOURCE TRACKING: WHO SHOULD BE CHOSEN TO DO IT?

Since the need for microbial source tracking has arisen (in part driven by availability of methods), a number of commercial companies have started offering it as a service. Some are highly experienced; others are proposing to do it without any experience or even understanding of the issues. How should a group or municipality distinguish the two and decide who to hire?

If a municipality needs source tracking, it is important that they follow the tiered approach outlined above. Companies might want to sell them the most expensive "top tier" type of source tracking (a library-based approach that would attempt to identify all the species and perhaps quantify the input from each). This may not be needed, and should not be done unless the lower tiers have already been done.

Second, the municipality should provide the potential providers of source tracking services with blind proficiency samples, and assess each company's ability to correctly identify the sources of contamination in the samples (not to provide ARCCs). Several studies (e.g., see (45)) demonstrate how to approach providing proficiency samples. It is important to provide the same kinds of samples to all companies. It is also important to provide samples that mimic what the municipality would want analyzed; if water samples, then water samples with known sources of fecal contamination should be provided, not bacterial isolates. If a company cannot provide a level of improvement in source identification proportional to the amount it will be paid, a different approach or company should be considered.

An appropriate role for a central scientific advisory board or agency would be to either provide blind proficiency samples themselves, or to fund a reliable laboratory that could provide sets of identical samples, thus helping municipalities make good choices.

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Appendix 6

List of Acronyms

CESD	Commissioner of the Environment and Sustainable Development
DDE	dichlorodiphenyldichloroethylene
DHA	docosahexaenoic acid
DPA	docosapentaenoic acid
EPA	eicosapentaenoic acid
EPA	Environmental Protection Agency
FIB	fecal indicator bacteria
GRADE	Grading of Recommendation Assessment, Development and Evaluation
HIV/AIDS	human immunodeficiency virus / acquired immunodeficiency syndrome
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
IQ	Intelligence Quotient
LUST	leaking underground storage tank
MST	microbial source tracking
NIOSH	National Institute for Occupational Safety and Health
OSS	on-site system
PCB	polychlorinated biphenyl
PCR	polymerase chain reaction
POPs	persistent organic pollutants
SOLEC	State of the Lakes Ecosystem Conference
UST	underground storage tank