EXPERT CONSULTATION ON

EMERGING ISSUES OF THE GREAT LAKES IN THE 21ST CENTURY

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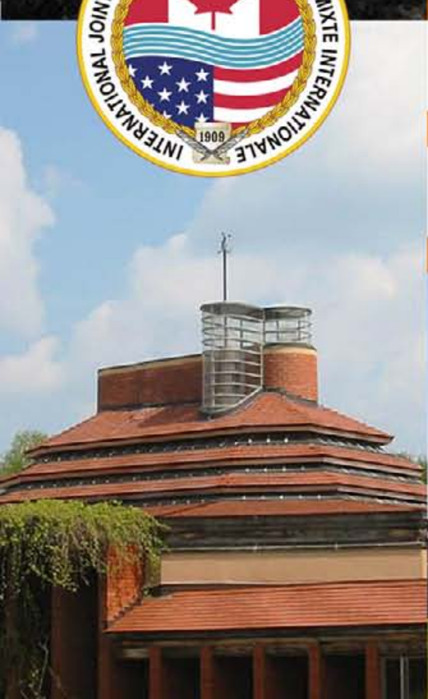

Expert Consultation on Emerging Issues of the Great Lakes in the 21st Century

Papers Submitted to the Expert Consultation on Emerging Issues of the Great Lakes in the 21st Century

Hosted by the International Joint Commission's
Great Lakes Science Advisory Board
at Wingspread, Racine, Wisconsin, February 5 - 7, 2003

Edited by Peter Boyer, Allan Jones and Deborah Swackhamer
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The expert papers presented at the Wingspread consultation February 5-7, 2003 represent the views of the authors and do not necessarily represent the views or position of the Great Lakes Science Advisory Board or the International Joint Commission.

Expert Consultation on Emerging Issues of the Great Lakes in the 21st Century: Overview and Synthesis

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Introduction

The International Joint Commission (IJC) of the United States and Canada was created under the Boundary Waters Treaty of 1909 to address issues related to the joint and separate interests of shared water along their boundaries, including the Laurentian Great Lakes (http://www.ijc.org/rel/agree/water.html). The IJC is composed of 3 U.S. and 3 Canadian Commissioners, and is advised by numerous volunteer boards made up of professionals representing state, provincial and federal agencies, academic institutions and the private sector. The IJC Science Advisory Board (SAB) provides scientific advice to the Commission and the Water Quality Board under the Great Lakes Water Quality Agreement (GLWQA/Agreement) (http://www.ijc.org/rel/agree/quality.html). Within its scientific mandate, the SAB also is charged with alerting the Commissioners to emerging issues that may fall outside their ongoing activities. This led the SAB to organize a specific work group in 1992 to address emerging issues.

As part of their priority activities for the 2001-2003 biennium, the Commissioners requested that the SAB host a meeting to address emerging issues in the Great Lakes. An explicit understanding was that this meeting would inclusively address chemical, biological and physical issues in an integrated fashion. The substantial interest of other IJC advisory groups led to a collaborative planning effort involving the Water Quality Board, the International Air Quality Advisory Board and the Council of Great Lakes Research Managers. The IJC boards then formed a partnership with Environment Canada, the U.S. EPA and the Johnson Foundation to convene what was termed an "Expert Consultation" at Wingspread, February 5 - 7, 2003.

The planning committee identified three principle objectives to be achieved in the consultation process:

- Conduct a scoping exercise to identify issues of importance for the Great Lakes over the next 25-year horizon
- Facilitate binational discourse on an interdisciplinary basis among eminent scientists and policymakers
- Identify specific initiatives that represent the most promising future opportunities for sustaining progress under the Great Lakes Water Quality Agreement.

The curiosity and desire to simply anticipate the future, based on the most current scientific knowledge and understanding, formed a further underlying motivation and challenge for the planning committee. In attempting to perceive the future, an integrative view of science and policy is needed to distinguish between change driven by factors that are not fully understood or managed, and thus are difficult to forecast, from those that are desirable and can be attained or influenced by human actions and can be readily predicted.

Format

The format chosen for the Expert Consultation was carefully crafted to maximize discussion and interaction. Six themes were selected to explore a range of future issues and challenges for the Great Lakes. The themes, described in greater detail below, included: (a) a vision for the future; (b) new non-chemical stressors; (c) new chemicals; (d) new effects; (e) changing ecology; and (f) new policies. A quarter of a day was devoted to each theme, and discussion was informed by a presentation given by a Lead Discussant and a Respondent. The Lead Discussant gave a 20-minute presentation on what he thought were the most important emerging issues within the theme, and the Respondent gave a 10-minute presentation on his viewpoint, highlighting points of agreement, disagreement or emphasis relative to the Discussant. The presentations were deliberately kept to a combined total of 30 minutes so there would be significant discussion time, which was managed by a professional facilitator.

The meeting was held at the Wingspread Conference Center in Racine, Wisconsin. This unique facility provides an elegant and isolated setting that is completely self-contained with a guest house, dining facilities and meeting rooms. This environment proved to be highly conducive for both informal and formal discourse, and allowed participants to more easily put aside any biases from their day-to-day environments. The facility is limited to 35 guests, thus further lending to an intimate setting. The participants were carefully chosen to provide diversity of both experience and expertise, and included scientists and decision makers from federal agencies, academia, industry, and consulting.

Themes. The six themes were initially chosen as departure points for the speakers, and to stimulate discussion. The Vision for the State of the Great Lakes in 2025 is focused on the redesign of urban space in the future through connections of built and natural environments (Greenberg). This represents a new development paradigm that will have a major positive impact for Great Lakes cities over the next 25 years and beyond. A new visioning of the management of the Great Lakes from a regulatory perspective also was presented (Wise). A range of ecological threats was addressed in the non-chemical stressor theme, including invasive species, climate variability, nutrient enrichment, habitat loss and food web dynamics, and the speakers offered perspectives on addressing future problems (Brandt, Shuter). Muir presented what is known about newly identified chemicals in the Great Lakes, and Walker discussed ways to get ahead of the curve in addressing potential chemical stressors before they occur. The session on emerging effects focused on what those effects are, and how changing concentrations of existing contaminants are producing an array of new effects in wildlife and fish in the Great Lakes (Fox, Brown). Moving to an more integrated perspective, the future changes in the ecology of the Great Lakes, and the difficulties of predicting such changes, was discussed (Koonce, Taylor). Finally, new policies needed to address the management of the lakes into the future were presented and discussed (Ogilvie, Carey).

Results and Discussion

The individual presentations by the Lead Discussants and Respondents were very useful for stimulating discussion, with each theme building upon the previous one. Each of them prepared individual papers on their presentations, and these are included in this publication. A series of crosscutting issues began to emerge from each theme after several sessions, which were identified by the participants and the meeting organizers through formal and informal integrative discussion periods. A professional facilitator assisted in focusing the formal discussions, and the Wingspread conference facilities greatly enhanced the opportunities for informal interaction. The remainder of this paper provides a synthesis and discussion of the discourse that surrounded and resulted from the presentations.

Future Challenges. One interesting outcome of the discussions was that no new, previously unidentified, threats to the Great Lakes were suggested. Rather, future problems of the Great Lakes will be continuations or permutations of those we are already aware of. This is primarily a result of our inability to adequately address these issues currently, or in the past. Such challenges include the following general categories:

- Chemical contaminants and their effects
- Excess nutrients
- Climate change
- Exotic species
- Changes to the biological community
- Shoreline development and suburban sprawl

While these topics are not new, there are some interesting "twists" to them that indeed make them important considerations for the future. For example, we need to be mindful that the list of contaminants in the Great Lakes is a dynamic one, and not simply the IJC Chemicals of Concern ("dirty dozen") or the Tier I and Tier II substances from the Binational Toxics

Strategy. Several new classes of chemicals have been identified by researchers, and include the brominated compounds (brominated diphenyl ethers, tetrabrominated bisphenol A), fluorinated compounds (polyfluorinated octanyl sulfanate, or PFOS), chlorinated paraffins, plasticizers (alkyl phenols and ethoxylates; phthalates). As commerce changes, so do the chemicals in our environment: so it is anticipated that we will continue to see new chemicals in the Great Lakes.

The present chemicals as well as these new chemicals exert new kinds of deleterious effects on fish, wildlife and potentially, humans. Researchers are reporting that many chemicals that were associated with the endpoints of mortality and population extirpations are now exhibiting sub-lethal effects that are more insidious and difficult to assess. For example, many compounds can impair or disrupt the endocrine system, interfering with proper development, reproduction and growth of certain species. Even more disconcerting is the fact that many of these effects do not exhibit a linear dose-response, so that declining concentrations of current chemicals may not always result in a decline of adverse effects. On the contrary, what is observed in some cases is the emergence of a new endpoint that was masked by a more evident effect caused by higher concentrations.

Inputs of nitrogen and phosphorus from point sources have been controlled for decades, but the loading of nutrients from non-point sources still results in excess concentrations. The dominant sources of these non-point inputs are agricultural operations, both crop-based and animal-based. Runoff and animal manure disposal and treatment are not well regulated or controlled. In addition, nutrient cycling is not fully understood, as evidenced by the recent hypoxia trends in the Lake Erie central basin.

Climate change is affecting chemical, biological and physical aspects of the Great Lakes. Future effects that have been identified include the impact on lake levels, which are predicted to decline even further than their current low levels. Another significant effect will be the impact of warming on biological community structure, including the fish communities and algal communities. Changes in either fish predator species or algal assemblages will further impact other trophic levels through top-down and bottom-up effects. Finally, warming of the Great Lakes will result in greater evaporation of semi-volatile compounds from the water column, which will cause sediment reservoirs to leach back to the water column. Thus rather than sequestering contaminants in sediments, they will reverse their movement and re-enter water and air.

The control of exotic species that have been introduced to the Great Lakes ecosystem has been and will continue to be a huge challenge to resource managers. The current efforts to prevent further introductions have not been effective, however, since the current rate of new introductions is about two species per year. These unknown introductions are a future threat, and present a unique blend of ecological, management and economic challenges.

Exotic species introductions often lead to changes in the biological community structure and changes within the entire foodweb. These changes cause instability in the overall ecosystem. Historically, changes in the biological community structure also have occurred as a result of fish stocking and management, over-harvesting of fish, nutrient inputs, disease etc. Some changes have no clear cause, such as the decline of *Diporeia* in the upper Great Lakes. Such stresses are anticipated in the future and may be due to combinations of stressors.

Finally, the impact of future increases in population and the growth of urban areas within the basin will inevitably lead to continued shoreline development, increased runoff, increased air pollution (from increased miles driven, energy demands etc.) and increased loss of fish and wildlife habitat and wetlands.

The discussions within each of the sessions were reviewed by the organizers, and a list of "findings" was developed. These findings reflect insights and important discussion points and capture any specific recommendations and initiatives that were made. The list is summarized below.

The Need for a New Vision

- It is necessary **to develop long-term objectives for recovery** to achieve future progress in restoring and maintaining the chemical, physical and biological integrity of the waters of the Great Lakes basin ecosystem. The GLWQA should be reexamined in light of these objectives. The reestablishment of some native species could be one such objective - recognizing that many native species will have to be introduced and that restoring the Great Lakes to an historical natural ecosystem will not be possible. One challenge will be to integrate resource management goals to achieve multiple long-term objectives related to (for example) fishery, nutrient and contaminant management. Another challenge will be to manage future demands for beneficial uses on a sustainable basis.

Improved Governance

- There is a need for **a renewed sense of shared purpose**, an image of the basin as a total system that people accept collectively and that has personal relevancy. No one vision of the Great Lakes may be attainable, or practical, because of the importance of this vast resource among many users. The challenge for the future will be to develop a process, or a forum, where shared values can be discussed and decisions made to protect and maintain the high natural amenities that sustain the use and enjoyment of the resource. If expressed as a key question, it is, "How do we organize ourselves to deliver an ecosystem approach?"
- **Greater institutional capacity** to coordinate and integrate roles, responsibilities and decision making to provide greater accountability among all levels of government is required. Policymaking in the future will increasingly depend upon a hierarchy of global, continental, national and local initiatives employing a wide variety of principles, instruments, methodologies and processes. Institutional effectiveness is impeded by a multitude of agencies and organizations fulfilling their own objectives with insufficient coordination, in the absence of shared long-term goals and strategies and according to disparate visions. For example, additional formal binational programs are necessary to contribute greater inter-operability to the institutional framework, building on examples such as International Air Deposition Network and the Binational Toxics Strategy (Canada and U.S., 1997).

Reinvestments in Science and Information Gathering

- Major reinvestments in scientific infrastructure for the basin are required to provide improved monitoring and, more important, to develop a **capability for ecosystem forecasting**. Decision making by individuals, industry, non-governmental organizations and multiple levels of government that impinge on Great Lakes water quality cannot be made wisely on the basis of current information especially its lack of integration. New technologies have the potential to attain forecasting capability through the innovation of continuous real-time monitoring employing integrated observation and monitoring systems. Such capabilities hold major promise for managers and decision makers to "get ahead of the problem curve" and to be truly proactive.

- Future policymaking will depend on **superior data management** to inform decision making and reduce scientific uncertainty of a decision. The model for this exists in Canada, in Statistics Canada, whose singular role is to provide high-quality information by maintaining confidentiality and interpreting the data for decision makers. This contrasts sharply with the many roles that environmental agencies fulfill through information gathering, regulatory oversight, enforcement, and environmental management and research. There is considerable merit in developing a binational institution to collect, store and manage high-quality Great Lakes information to support agency policies and programs as well as Agreement activities.
- The development of screening assessments using Quantitative Structure Activity Relationships, the use of release inventories to identify high-production volume chemicals and advancements in analytical methodology and equipment have resulted in **improved capabilities to identify new classes of chemicals of concern** in the Great Lakes. However, exposure assessment and aggressive monitoring is still needed to evaluate the significance in terms of Great Lakes water quality. Pharmaceuticals, hormones, phenolics and current-use pesticides still have the potential to surprise scientists with effects that are not predicted. For example, the following have been discovered by researchers in Great Lakes biotic and abiotic samples: polybrominated diphenyl ethers (PBDEs), perfluorosulfonates and carboxylates (PFOs and PFOA), chlorinated paraffins (C10-C17 chlorinated n-alkanes), chlorinated napthalenes, PPCPs, phenolics and about 20 current-use pesticides. Analytical method development needs to keep pace with the identification of new substances.
- **The identification of new effects requires greatly enhanced monitoring, data sharing and ecosystem forecasting**. As the system moves from a degradation phase to a recovery phase, population effects, such as declines and extirpations, have given way to various specific pathologies affecting organs and their systems. The capability of being able to anticipate new effects has the potential to be addressed through the interdisciplinary developments such as the field of toxicogenomics, QSARs and others in the field of toxicology.

Policies and Concepts

- There is an urban renaissance underway based, in part, on the value of the water resource to impart the qualities of the natural environment within the developed area. A fundamental tenet of that renaissance is creating the conditions for the natural environment to reestablish itself in harmony with the built environment. Developed waterfronts present unique opportunities for this to occur, and especially to bring natural amenities into the core of the city. Encouragement and innovation at the site level is evident through the **adoption of green design concepts**, such as the Leadership in Energy and Design (LEED) principles (LEED 1999), which could comprise further opportunities for extension into broader policy principles at the basin level.
- Three key Great Lakes policy challenges will be increasingly relevant over the next 25 years:
  - **Agricultural policy** will need to move beyond developing "farm nutrient management plans" to consider manure not as a nutrient, but rather as a waste;
  - **Waste water treatment** will need to reuse and recycle water
  - There must be better **integration of environmental and economic considerations into policy** decisions.

Toward Implementing an Ecosystem Approach

- **Broader ecosystem-based management strategies are needed** in order to manage resources such as the fishery, to maintain biodiversity and to support land use decision making. Centers of biological organization such as the Biodiversity Investment Areas identified by SOLEC, need to be vigorously protected and maintained. The fragmented landscapes and habitats in the Great Lakes basin, in contrast, provide opportunities for diseases, invasive species and exploitation that weaken or prevent long term recovery while at the same time requiring ever constant management effort to achieve what amounts to only limited success in achieving the purpose of the GLWQA.

  Greater access to data, better basin wide data management, and detailed basin-wide, **bi-national scientific assessments** are needed to interpret and coordinate effects-based research that encompasses an ecosystem approach. Despite slowly declining contaminant levels, some effects in fish and wildlife are still occurring, and in some areas, for some species, there is a concern that these effects may be increasing. For highly exposed species, such observations are viewed as critical sentinels for human health, and are important in terms of their possible implications for human health.
- It is theorized that **the future ecology of the Great Lakes may be unpredictable because it is unstable**, based on the scientific understanding that a well-functioning ecosystem hierarchy has few surprises. Biological integrity, and how to achieve it, is not scientifically well understood; however the importance of higher levels of organization to impart a stability and regulatory constraint on the entire system was further theorized. It was speculated that the loss of this attribute for the Great Lakes was a critical aspect of a lack of ecosystem integrity and stability.
- There is an urgency to develop better science and technology **to identify and treat pathways for introductions of alien invasive species**, such as ballast water, and to manage undesirable introduced species. Invasive species are a characteristic of disturbed systems, with accessible aquatic environments such as the Great Lakes most vulnerable. Once introduced, invaders can permanently change the ecosystem and defy management.

Recommendations

Our recommendations were sent to the Commissioners, and asked that they recommend that the United States EPA and Environment Canada (the "Parties"):

- ***Conduct a comprehensive review of the operation and effectiveness of the Agreement and seek public input, with a view to substantially revising the current Agreement to reflect a current vision of goals, priorities and institutional arrangements. Such a review also should consider greater accountability for implementation and for measuring progress, for example, including a schedule to accommodate those actions deemed most essential to achieve important goals.***
- ***Develop an ecosystem forecasting capability within the auspices of a bi-national monitoring, information and data management policy and infrastructure for the Great Lakes to inform management and decision makers, and to provide for greater public accountability in reporting progress.***

- ***Establish a bi-national Integrated Great Lakes Observing System as a key element of a major reinvestment in Great Lakes scientific infrastructure and to provide high-quality scientific information for policy decisions.***
- ***Establish an "International Field Year for Great Lakes Research" as a special five-year program to improve the knowledge and understanding of the Great Lakes basin ecosystem.***
- ***Ensure that:***
    - ***There are adequate bilateral mechanisms to identify and monitor previously undetected chemicals in the environment,***
    - ***We develop and implement strategies that use QSARs to identify chemicals of concern,***
    - ***The Parties increase their support of the development and validation of QSARs to promote cost-effective chemical testing resources; and***
    - ***We establish early notification processes between researchers and regulatory officials to minimize the possible injury to health and property as a result of the presence of new chemicals.***
- ***Further develop bi-national institutional mechanisms to enhance bilateral cooperation and coordination for air, land and water management in order to implement a truly ecosystem approach for water management that involves local, state/provincial and federal governments.***

In conclusion, the Expert Consultation successfully provided a stimulating discussion of emerging issues for the Great Lakes in the 21st century. This brainstorming led to a series of findings and recommendations to the IJC Commissioners, in anticipation of future action to address these issues and "get ahead of the curve" of emerging threats to the Great Lakes.

As a postscript, the consultation also led to two other related activities: the Science Advisory Board workshop held in Ann Arbor in February 2004 to review the GLWQA from a scientific perspective, and the subsequent Wingspread consultation on strengthening science under a renewed Great Lakes Water Quality Agreement held in January 2006. (IJC 2006, unpublished).

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Facilitating Dialogue to Foster Interdisciplinarity: The Role of Focused Conversation Method in the IJC Expert Consultation

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Introduction

In February 2003 the Science Advisory Board Workgroup on Emerging Issues of the International Joint Commission convened a consultation among experts from a broad cross-section of disciplines relevant to the ecosystem of the Great Lakes basin. The overarching goal of this meeting was to stimulate thinking about emerging issues of concern to the Commission and solicit comment on and insight into possible actions that would enable the Commission to position itself to effectively respond to the Parties and the public. The specific purpose, objectives and background leading to the consultation have been set out in the introductory paper of this volume.

The challenge confronting the Workgroup is captured by the comment of a sponsor of an initiative the author had previously facilitated. In 1997, the Curve Lake First Nation and the Trent-Severn Waterway convened a collaborative ecosystem management initiative to develop consensus on actions to manage the ecosystem of the Kawartha Lakes region in Central Ontario. Gary Williams, at the time the Chief of the Curve Lake First Nation, welcomed participants to the first meeting with this urging: “Remember, you are here to protect an ecosystem, not an ego system.”

The complexity of the Great Lakes ecosystem calls for an approach to ecosystem management and problem-solving that is, at the same time, interdisciplinary and innovative. The influence of ego is always a concern when convening individuals to address issues of mutual concern, and, fairly or unfairly, this is particularly so when those individuals are considered experts in the Western epistemological tradition. The challenge facing the Workgroup on Emerging Issues, therefore, was to create a forum for creative thinking, critical thought and a healthy and frank exchange of ideas while, at the same time, encouraging experts to embrace and contribute to interdisciplinarity. In that regard, the Workgroup retained the author to build on the format of the consultation (described below) and design a facilitation approach that would establish the conditions for successfully meeting that challenge.

This paper sets out the facilitation approach and its rationale. It will not comment in detail on the outcomes of the event since they are addressed separately (Boyer, Jones, Swackhamer, 2004)

The Facilitative Process

The format of the consultation was designed to focus attention on six thematic areas and facilitate a rich discussion among participant experts. The six themes were future vision, new non-chemical stressors, new chemicals, new effects, changing ecology and new policies. (Each theme is addressed in detail in the other contributions to this edition of the Journal.) Each theme was addressed by a lead discussant and then followed by a respondent who enlarged the frame of reference through underscoring or critically questioning key points raised by the lead. To maximize the time available for an exchange of views among the participant experts, efforts were made to limit each lead discussant and respondent to 20 and 10 minutes respectively.

Turning then to the structure of the facilitated discussion that was to follow the remarks by each lead and respondent, it was decided that the dialogue would be structured along the lines of a Focused Conversation (Stanfield, 2000). Although a number of facilitation strategies were available, this particular approach, described in detail below, was favored given its procedural fit with the overarching structure of the consultation as well as its suitability for creating a forum that would foster interdisciplinary exchanges. A Focused Conversation allows for dialogue about a subject to be comprehensively informed by different, yet complementary dimensions of focus (Stanfield, 2000). It was felt that the approach held the greatest potential for innovative thinking because it acknowledges ecologist Garrett Hardin's entreaty, in *Filters Against Folly*, for a panoramic view in place of tunnel vision (Hardin, 1985), as well as Edward de Bono's ideas on lateral thinking as a means of tapping and rearranging available information to generate insight (de Bono, 1970).

Given that the participant experts came from a broad cross-section of disciplines, it was important to ensure that the facilitation method provided the opportunity for and nurtured expanded thinking and critical reflection, and from that, hopefully, a cross-fertilization of ideas. The method draws inspiration from Hunter's counsel that, "The idea that one's view of reality is the only reality is the most dangerous of all delusions" (1983, p. 243). Indeed, the complexity of the Great Lakes ecosystem reveals multiple realities and the need to acknowledge those realities as the basis for informed action.

It was also critical to ensure that the process reflected strong participatory values (Kaner et al., 1996). It is indeed worth noting that over the two-and-one-half-day consultation every participant contributed at some point to the reflection on and exchange of ideas following each lead discussant and respondent.

Stanfield (2000) highlights a number of advantages of the Focused Conversation (FC) method, three of which are noted here and elaborated on given their relevance to the consultation. First, FC applies a structure to the reflecting and commenting process, and prevents conversation from drifting aimlessly. It recognizes that meaningful comment in such settings is borne of critical reflection and provides the flexibility for group deliberation to unfold in a constructive manner. Second, FC makes room for both critical and creative thinking, while encouraging inquiry in place of advocacy. Advocacy too often arrests interaction at the level of thesis/antithesis. This was clearly not the desire of the Workgroup given the objectives of the consultation. Inquiry, on the other hand, embraces as legitimate all views in the spirit of exploration and impliedly elevates interaction to the level of synthesis. Finally, FC fully taps the wisdom and experience of the participants, while making space for constructive diversity of thought.

A focused conversation employs questions along four dimensions to concentrate attention and participation. The dimensions—Objective, Reflective, Interpretive and Decisional—together represent an approach that recognizes and validates the unique history and amalgam of experiences held by each participant. Personal history and experience undergird ontology and epistemology, both of which are significant influences on expanded group thinking. Goldberg (1998) notes that questions imply relationships—between people, between different aspects of the person, between the person and information and data. She further notes;

> The importance of questions lies in their intrinsic contribution to creative and critical thinking, which renders them fundamental for problem solving and decision making. Furthermore, it is through questions that we operationalize curiosity into behaviour, and as such they are the foundation of any kind of learning, be it formal, informal or personal. (pp. 7-8).

The questions posed in a Focused Conversation are formulated to be open-ended, not too specific and, in the case of this consultation, related to the contexts established by the remarks of the lead discussants and respondents.

The first dimension, the Objective level, involves questions that get out external data, the facts relating to a lead discussant's paper and respondent's commentary. This allows a group to establish a shared image of what is to be discussed. It acknowledges that individuals will zone in on different aspects of a subject matter, and, therefore, its aim is to mentally situate participants on the 'same page of the hymn book and same verse of the hymn.'

The second dimension is the Reflective level. It is at this level that each participant begins establishing a personal relationship to the subject matter. Questions probe internal data, focus on how a participant feels about the topic and seek to tap intuition, memory, emotion and imagination—all important sources for creativity. Notwithstanding the seeming incongruity between the nature of such questions and the respective professional worlds and worldviews of the participant experts, internal data is important because it provides clues about and insight into the tacit assumptions that underpin and shape each participant's epistemology.

The third dimension, the Interpretive level, aims to get at how each participant makes meaning with the subject matter. Questions at this level focus on the significance that the subject matter has for each participant and the group, and the implications of the subject matter. This dimension also might be thought of as the hermeneutic level since it seeks to surface the manner by which each participant organizes and makes sense of his or her experience with the information presented by the lead discussant and respondent as well as that shared by other participants.

The final dimension is the Decisional level. The purpose here is to bring some kind of closure to the participants' consideration of the subject matter, some kind of decision about what might be done so that participants are not left feeling that their efforts have been a waste of time, energy and emotion. In the context of this consultation, the focus of this level was not on consensus about substantive issues. It did, however, provide an opportunity for dialogue about what next steps might look like and laid a foundation for synthesizing the insights offered by participants into key findings and recommendations to the Commissioners.

Conclusion

It is important to acknowledge in this writing the commitment of each participant expert to the consultation and the value of their contributions, both individually and as a group. Each participant worked enthusiastically within the parameters established by the Focused Conversation approach and must be applauded for their willingness to embrace an approach that was new to many of them. As their facilitator, the author was certainly appreciative. It is not the place of this paper to review the key findings and recommendations emerging from the consultation. The spirit of collaboration that emerged over the course of the consultation is but one measure of the value of the Focused Conversation approach for fostering interdisciplinarity. As for the merit of the Focused Conversation approach for structuring the interaction and dialogue and rendering the consultation a worthwhile experience, that determination is reserved for the expert participants. As for the efficacy of the Focused Conversation approach in producing outcomes upon which the Commission may build and act, that determination is reserved for the Workgroup and, ultimately, the Commissioners.

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A Land Based Vision on the State of the Great Lakes — Retreat of the Industrial Glacier

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Waterfronts — seafronts, lakefronts and riverfronts — have become the new frontier for cities with the potential for re-use of vast tracts of obsolescent port, industrial, railway and warehousing lands. Typically these are places from which the cities derived their prosperity and vitality and notwithstanding their past degraded condition, they have become a locus of renewed vitality and potential.

In the mid 1990s, the author first used the phrase "retreat of the industrial glacier" as a metaphor to describe two key concepts of urban renewal: First, it is a long, slow process and second, it exhibits a certain inevitability. As the industrial glacier recedes, it reveals an extraordinary terrain of availability and a host of new possibilities. While there are enormous differences from place to place, there appear to be a number of common characteristics. There is an almost universal psychological desire to be near water. The powerful allure of these great natural features draws people to them, wanting to live, work and recreate there. They offer respite from the pressures of city life, a boundless or expanded horizon. Because of the centrality of these places, relating to the reasons the cities were founded there in the first place, they offer a great possibility for compact and more 'sustainable' development, putting housing closer to workplaces with reduced travel times. For many city dwellers, the new waterfronts become the 'resort' *in situ* for leisure in close proximity.

There are many examples that illustrate some of the dimensions of this process of cyclical transformation. Many of the obsolescent areas of cities were actually created in the middle of the 19th century when the railways established themselves, connecting to ports around the world in low-lying areas near bodies of water. A particular aspect that warrants recognition is the dissolution of the false dichotomy, both professional and conceptual, that divided the city from the natural world. Like many powerful and timely impulses, this reconciliation has had many sources: scientific, cultural, aesthetic. It is significant as an example of simultaneous discovery that also was necessitated by a sense of crisis as the environmental movement called attention to appalling degradation and its impact on people. Powerful symbols, such as the Cuyahoga River fire, created further awareness of the need for urgent action at all levels.

The change in consciousness also has been fostered by inspired practitioners and writers including Ian McHarg, *Design with Nature,* Anne Spirn, *The Granite Garden,* and Michael Hough, *City Form and Natural Process*. These three landscape architects devoted much of their work to the presence of nature in city form. Their ideas have opened possibilities for a new way of thinking beyond conventional mitigation and management of impacts to one based on new possibilities for creative synthesis. It is also based on the acknowledgment that humans are part of nature. Two relatively recent anthologies *Uncommon Ground*, edited by William Cronan, and *Reinventing Nature*, edited by Michael Soule and Gary Lease, raise the question: What is nature and wilderness when it exists without influence or control by human society? To an extent, nature everywhere on the planet has become a built environment which has been deeply altered by human interaction with it. In order to develop a vision of the future, it is necessary to understand the nature of the city and how it functions as a home for the vast majority of people who live as urban dwellers.

Two quotes from Anne Spirn illustrate the need for understanding the relationship between the natural and built environments: *"We need to move away from the persistent, common perception of the city as a degraded environment and wilderness as a pristine place untainted by human presence." …." We have to deal with cities as systems in which cultural processes create an environment that's decidedly different from undisturbed nature, yet united to it through the common flow of natural process."* These ideas also are reflected in Jane Jacobs' most recent book and great synthesis of natural systems and economics, *The Nature of Economies.*

The enhanced recognition of natural systems and great natural features like the Great Lakes is integral to a renewed understanding of the urban setting. While this renewal is still in its inception, it is already producing forms of development that are inherently more environmentally friendly. It also is producing a cultural predisposition to a new form of co-existence, the intertwining of city and nature and an altered sense of place. As Betsy Barlow Rogers, the former Executive Director of the Central Park Conservancy states *"As the city becomes more park-like, the park becomes more city-like."* An interesting contrast is Frederick Law Olmstead describing his own work in 1870: *"We want a ground to which people may go easily after their day's work is done…where they may stroll for an hour, seeing, hearing and feeling nothing of the bustle and jar of the streets, where they shall find the greatest possible contrast with the restraining and confining conditions of the town, those conditions which compel us to walk circumspectly, watchfully, jealously, which compel us to look upon others without sympathy."*

The environmental theme has developed a broad popular appeal, establishing new common ground which often cuts across class, cultural and political lines. This appeal is often out ahead of political perceptions and existing policies. It also encourages interesting new ethical questions, challenges and opportunities such as the emergence of 'Green Principles' and evaluation systems like the LEED [Leadership in Energy and Environmental Design] rating system developed by the American Institute of Architects which deals with impacts on ground, water, air, use of energy, materials, and the treatment of waste. [U.S. Green Building Council, www.usgbc.org/LEED/LEED_main.asp]. There also are efforts underway to create a similar kind of rating system for landscape architecture.

How is practice of urban design, architecture and landscape architecture on urban waterfronts affected in a world where this new perception of nature is emerging? Several examples illustrate the current state of the art including many of the urban places surrounding the Great Lakes where significant remediation efforts are currently underway. These cities and their unique relationship to the lakes offer a source of great promise and potential. To quote

Jane Jacobs, "Cities are the 'crucible' where solutions are found to problems that are otherwise quite intractable."

1. *Saint Paul on the Mississippi – Development Framework*

   Beginning in the 19th century, the City of St. Paul exploited the advantages of the Mississippi River while securing and developing its urban area by displacing the natural landscape. However, in the early 1990s a new appreciation of the river emerged based on "Great River Park" and ecosystem concepts designed to re-establish the relationship of the river and the city. This led to a development framework in 1994-95 to incorporate a new vision of the community through urban design elements and most important, the reconnection of the city with the river by restoring the historic landscape and creating, ultimately, an urban forest within the city.

2. *Brooklyn Bridge Park Master Plan*

   Initiated by the Brooklyn Park Local Development Corporation, this project demonstrates the opportunity created by revival of a historic waterfront. It is one element of restoration within a larger pattern of parks, green spaces and redevelopment of New York Harbor, which includes the creation of selected areas of natural shoreline and new green edges.

3. *Boston Harbor*

   Two new private developments, Fan Pier, Boston and Kendall Square, Cambridge illustrate the commercial opportunities for green development, especially in collaboration with a public realm plan based on small-scale green spaces within the urban area. The series of new public places: Courthouse Park, Tidal Park, Fishing Pier, the Cove, the Public Green and the Institute for Contemporary Art provided a larger context involving six new city blocks and two new squares. One project, the Behnisch and Behnisch building received a platinum rating under LEED certification, one of the highest achieved in the U.S.

4. *Toronto Portlands Initiative*

   The earliest plans for settlement at the mouth of the Don River date from 1815; however major harbour improvements are more recent since 1915. The current site reflects its industrial heritage. However, the plan is to restore the natural integrity of the Don River as part of a long-term plan to develop interconnected greenways and a natural landscape to the harbour environment on the east and the Humber River on the west.

Conclusion

Without exaggerating the importance of these examples, they give rise to some cautious optimism about the potential for future re-development of the Great Lakes shoreline. They reflect a new shared vision which suggests a profoundly different sense of opportunity as well as aesthetic appreciation. On the basis of this new vision, one can look forward to a change in the image and use of urban places, a greater integration with natural settings, and in-built environments where a greater mix and complexity of uses contributes to an improved urban lifestyle and culture. As this new urban growth and succession occurs, there is also evolving a more mature aesthetic sense that appreciates that development, as in nature, is a messy process which is perpetually unfinished.

The perception of new 'green' characteristics also is leading to changes in design approaches at the level of city plans and of individual buildings and landscapes. New places reflecting these approaches will become more rooted and specific, with the underlying layers of the natural setting revealed and better understood. To work in this way, clearly new kinds of professional alliances will be needed including Urban Designers, Planners, Architects, Landscape Architects, Engineers and Environmentalists.

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Changing Climate and Its Impact on the Great Lakes

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The Intergovernmental Panel on Climate Change (IPCC) has sponsored the use of global atmospheric circulation models to forecast the likely impacts of future increases in atmospheric CO_2 on regional climates around the world (eg Houghton et al. 1996). Several studies (eg. Magnuson et al., 1977; Lofgren et al., 2002; Winkler et al., 2002; Sousounis et al., 2002; Kling et al., 2003) have used such projections of climate change for the Great Lakes region to assess likely impacts on the physical, biological and social systems of the Great Lakes. Climate projections for the next 50 and 100 years describe trends that seem to be already underway. Systematic changes in climate are demonstrated by long-term, temporal trends in annual weather data. However, weather data is highly variable and the demonstration of a long-term trend requires the presence of monitoring programs that have been consistently operated for a very long time. Reconstructions of Great Lakes weather data for the period 1900-2001 exhibit trends that are consistent with the trends expected from CO_2-based climate warming. A recent study is reviewed that looked in detail at the changes in Great Lakes climate to be expected from CO_2-based climate warming and the likely consequences of those changes for the aquatic systems of the Great Lakes Basin and the social systems that depend on them.

Recent Trends in Meteorological and Limnological Data from Lake Erie

There are several weather stations along the south shore of Lake Erie that have been operated continuously since at least 1900. (Five rural sites are identified (Fredonia, Lockport, Hiram, Oberlin, Franklin) that have reported annual air temperature data over this entire time period and the average monthly air temperature means for each sites was calculated to arrive at a regional measure of monthly air temperature for each year for the period 1900 to 2001. The aquatic laboratory at Put-In-Bay, Ohio reported daily surface water temperatures for the western basin of Lake Erie continuously for the period 1918 through 1992 (McCormick 1997). A site close to Leamington, Ontario reported similar data from 1960 through 2001. Both sites operated concurrently for the period 1960-92 and over this period the data from both sites were strongly correlated. Therefore, the data from the Ontario site could be used to extend the data from the Put-In-Bay site for/ward to 2001. Following McCormick and Fahnenstiel (1999), a small set of annual summary statistics from both the air temperature data and the water temperature data were generated for each year:

(i) winter-length, air temperature data: the number of days in the period that begins with the last day in fall where the air temperature is greater than 0°C and ends with the last day in spring where the air temperature is less that 0°C

(ii) winter-length, water temperature data: the number of days in the period that begins with the last day in fall where the water temperature is greater than 4°C and ends with the last day in spring where the water temperature is less that 4°C.

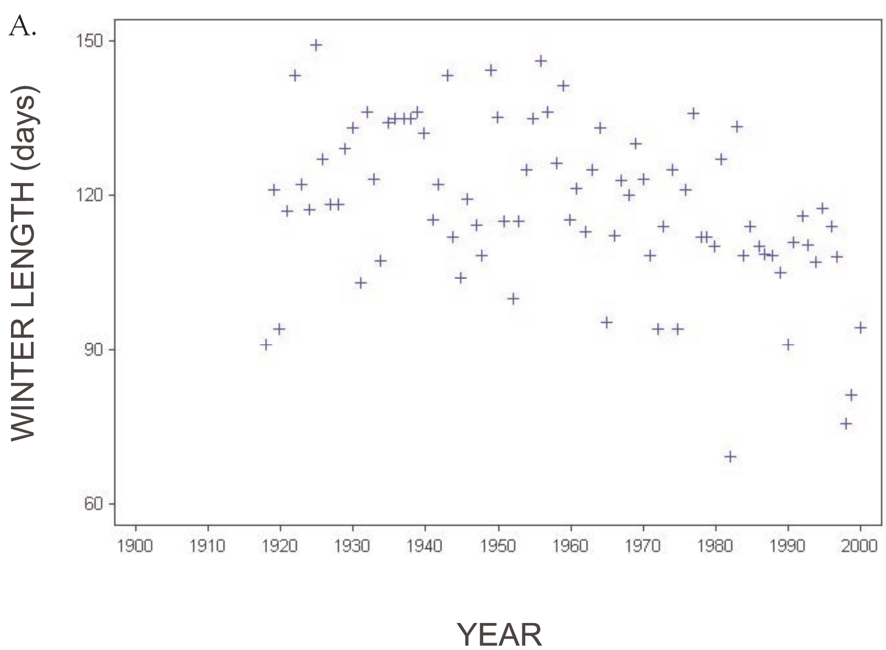
(iii) summer-warmth, air temperature data: July mean air temperature

(iv) summer-warmth, water temperature data: average water temperature over the last week of July and first week of August

The air and water temperature versions of both indices were highly correlated and thus the air temperature indices to extend the water temperature indices back to 1900 could be used. The winter-length data are summarized in Figure 1(a) and (b). The annual data is highly variable (Figure 1a), but there is some suggestion of a recent decline in the index. However upon 'smoothing' out some of the short-term variation using a five-year running average, a recent trend toward shorter winters clearly emerges. The smoothed summer-warmth index also indicates the presence of a recent trend toward warmer summers (Figure 2).

Figure 1. Variation in length of winter – index values derived from surface water temperatures in the western basin of Lake Erie. A. Annual Variation. B. Smoothed variation, derived by applying a 5-year running average to annual values.

1 A.



1 B.

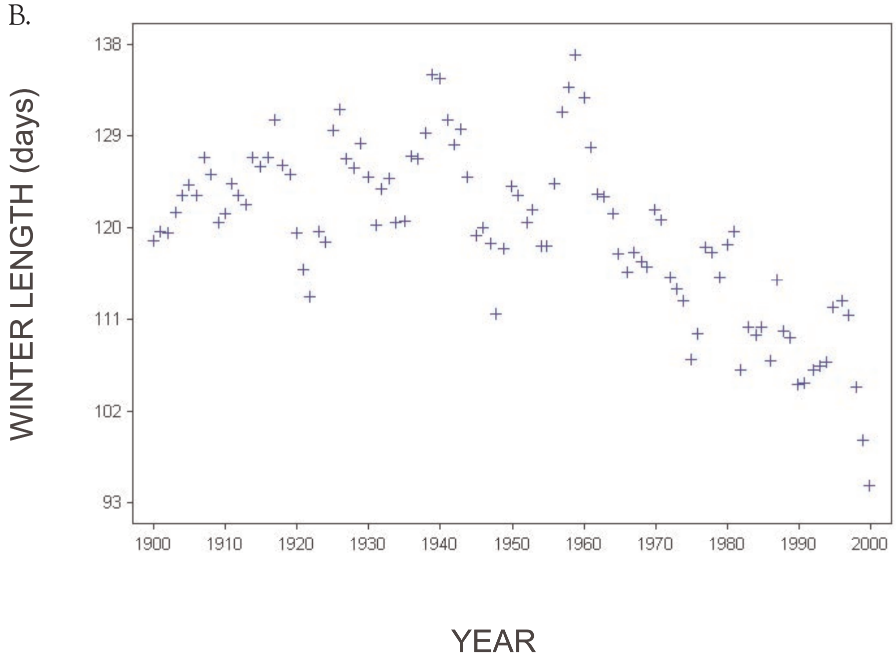
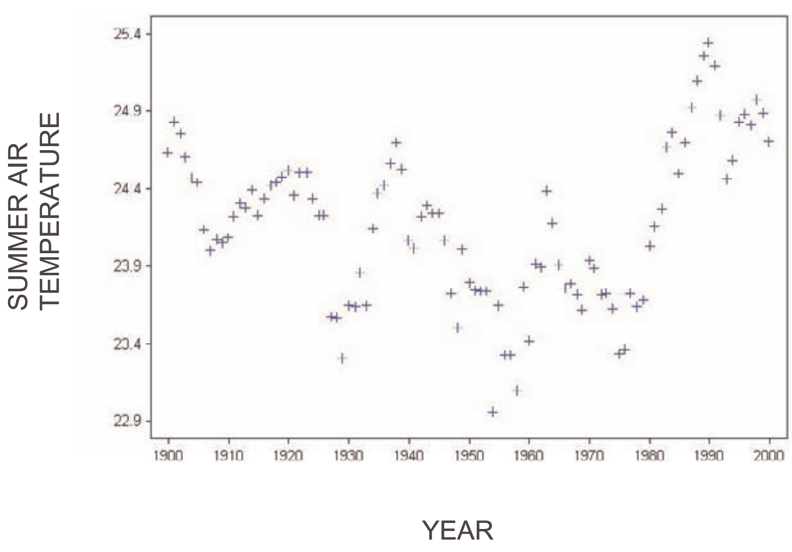


Figure 2. Variation in warmth of summer – index values derived from surface water temperatures in the western basin of Lake Erie. Plotted values derived by applying a 5 year running average to annual values.



This analysis demonstrates several important points. On the methodological side, it demonstrates that consistent, long-term monitoring programs are an essential component of the science needed to assess both the reality of climate change and the consequences of that reality. On the question of the presence/absence of evidence for climate change, the analysis strongly supports the contention that the climate of the Great Lakes region is already changing in the direction predicted by the general circulation models and that a new climate, quite distinct from that present at the turn of the century, is already in place.

The Changing Climate of the Great Lakes Basin: Consequences for Aquatic Ecosystems and the Social Systems that Depend on Them

Over the last 15 years, there have been many projections of future changes in climate, given continued increases in atmospheric CO_2. A brief overview of the conclusions presented by Kling et al. (2003) in their report on the consequences of CO_2-based climate warming for the Great Lakes Basin follows.

Future Trends in Great Lakes Climate

In general, the climate of the Great Lakes region will grow warmer and drier, with summer and winter temperatures anywhere from 2-4^{o}C warmer. Nighttime temperatures will warm more than daytime temperatures. Periods of extreme heat and periods of extreme rainfall will increase. However, the increases in evaporation arising from warming, will more than compensate for any increase in precipitation. Thus, the region will become drier, resulting in lower surface and groundwater levels and drier soils. By mid-century, a summer in Illinois will feel like a summer in Oklahoma today.

Consequences for Lakes and Streams

A warmer drier climate will produce many changes in lakes and streams. For lakes, water levels will decline, the winter ice-cover period will shorten and the summer stratification period will lengthen. Longer stratification periods will promote hypolimnetic oxygen depletion in summer with negative consequences for water quality and for resident biota. For streams, earlier ice break-up and earlier peaks in spring runoff will change the timing of stream flows, and severe summer rainstorms will cause more frequent flooding. Reduced summer water levels will diminish the recharge of groundwater supplies, cause drying of small streams and reduce both the extent of wetlands and the quality of the water in the wetlands that remain. River flooding will become more frequent and extreme, resulting in increased erosion and water pollution from nutrients, pesticides and other contaminants in runoff.

Consequences for Aquatic Ecosystems

For aquatic systems generally, the spatial distributions of many fish and other organisms will change, with coldwater species such as lake trout and brook trout declining in the southern parts of the region and cool and warmwater species such as walleye and smallmouth bass expanding in the central and northern parts of the region. Invasions by native species currently found just to the south of the region will be common and invasions of warmwater exotic species such as common carp will be more likely. Many fish species can grow faster in warmer waters but it is uncertain whether these potential increases will be realized because productivity at the base of the food chain may not increase to the degree necessary to meet these new demands. Lower water levels must lead to overall reductions in habitat for aquatic organisms. They also can exacerbate damage from ultraviolet radiation to aquatic life generally and, in concert with warmer temperatures, can accelerate the accumulation of mercury and other contaminants in aquatic food chains.

In shallow lakes, reductions in winter ice will reduce the frequency of winter kill. In lakes generally, reductions in winter ice will have a myriad of negative and positive effects among individual species, depending on whether the species requires the presence of ice or is constrained by its presence. In all lakes, duration of summer stratification will increase, adding to the risk of oxygen depletion and formation of deep water "dead zones" for fish and other organisms.

In streams, reduced summer water levels will likely diminish the recharge of groundwater supplies, cause drying of small streams and reduce the area of wetlands, resulting in poorer water quality and less habitat for wildlife. Changes in timing and severity of flood pulses will reduce safe breeding sites, especially for amphibians, migratory shorebirds and waterfowl, and may cause many northern migratory species such as Canada geese to winter farther north.

Consequences for Social Systems

Shorter, warmer winters and a longer ice-free season will increase the length of the shipping season but will result in losses in winter recreation such as skiing, ice fishing and snowmobiling. However, the season for warm-weather recreation will lengthen. Changes in recreational fishing, hunting and wildlife viewing will occur as the distributions of fish and wildlife species shift across the region.

Lower lake levels will increase shipping costs in the Great Lakes, as well as the costs of dredging harbors and channels and making other necessary infrastructure adjustments. By 2050, lower water levels could reduce hydropower generation in the region by as much as 15%. This reduction in supply will be coupled with increases in demand arising from increases in the need for air conditioning in summer to combat rising health risks associated with extreme heat exposure.

Of primary importance is the impact that a drier Great Lakes Basin will have on the competing demands for basin water, both within and outside the region. Water withdrawals from the Great Lakes are already the subject of contentious debate, and pressures for increased water for irrigation, drinking and other human uses will intensify these conflicts as water levels drop.

Summary

A reconstruction of weather trends in the region around Lake Erie for the period 1900-2001 and data from the latter half of the century exhibit strong trends that are consistent with those expected from CO_2-driven climate warming. This suggests that a new climate, quite distinct from that present at the turn of the century, is already in place. This climate is characterized by shorter winters, warmer summers and very likely by drier watersheds. These changes will have many significant impacts on the physical, biological and social systems of the Great Lakes region. Of primary importance is the fact that the expected decline in water supply will occur in parallel with continued increases in water demand, driven largely by population increases within the basin and agricultural demands outside the basin.

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Identifying Potential and Emerging Chemical Contaminants in the Great Lakes

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Abstract

The past five years has seen a major expansion of measurements of new chemicals in the Great Lakes environment that are not on lists developed by the Great Lakes Water Quality Agreement and the Great Lakes Bi-national Toxics Strategy (GLBNS). These chemicals include brominated diphenyl ether flame retardants, fluorinated surfactants, estrogenic substances, pharmaceutical drugs, personal care products such as synthetic musks, and current use pesticides. However, the list of chemicals measured represents only a tiny fraction of the chemicals in commerce or of even high-production volume chemicals (HPVCs) used within the basin. Quantitative Structure Activity Relationships (QSAR) are being extensively applied to screen chemicals for persistence, bioaccumulation and toxicity characteristics in the US and Canada and one outcome will be priority lists of additional chemicals that will be candidates for future measurements. Many of the recent measurements of new chemicals have been driven by advances in analytical methodology especially in the case of fluorinated organics and pharmaceutical drugs. There are presently no trace analytical methods for determining the vast majority of HPVC organic chemicals identified as potentially bioaccumulative and persistent by QSARs. Surveys of pharmaceuticals, endocrine disrupting phenolic compounds and current-use pesticides in the Great Lakes regions have shown that these substances are highest near sewage treatment plants (STPs) and river mouths and generally decline to non-detectable concentrations in the open lake. Nevertheless these compounds may be important from the point of view of effects on aquatic biota in waters adjacent to STP outfalls as well as in agricultural and urban tributaries. To routinely assess these effects there is a need for water quality criteria for a much wider range of substances than are available at present.

Introduction

In 1986 the Great Lakes Water Quality Agreement (GLWQA) committed the US and Canada to "virtually eliminate" a set of persistent toxic substances comprised of 11 chemicals. These were intentionally produced chemicals (PCB, DDT, dieldrin, toxaphene, mirex), production byproducts (hexachlorobenzene, TCDD, TCDF, benzo(a)pyrene); and metals (lead, mercury), whose availability had been enhanced by human activity. Chlordane, cadmium, arsenic, and octachlorostyrene were subsequent additions to the Critical 11. The GLBNS identified the above 13 "level 1" substances plus about 14 other "level 2" substances (depending on how they are classified) for action within the Great Lakes region (EC/EPA 1997). Great progress has been made in tracking sources and reducing emissions of all level 1 substances and some "level 2" substances as well, as a result of national, provincial and state initiatives. For the highly bioaccumulative compounds such as PCBs this is readily demonstrated by temporal trend studies using lake trout and herring gull eggs (US EPA 2002).

The GLBNS/GLWQA lists reflect chemicals first identified as persistent and toxic in the 1970s (or earlier) and are also a reflection of the prevailing measurement technology of the 1970s and 1980s. The GLBNS does include a protocol for nominating new chemicals; however, none have been added since 1997. The lists also do not include current use pesticides which are exempted on the grounds that they are regulated by other legislation. Most research and routine monitoring has focused on the "Critical 11" to the present day.

Environmental chemists have continued to slowly add to the list of chemicals detectable in the Great Lakes and indeed in air, surface waters and sediments globally. Over the past five years there has been an explosion of new information on brominated flame retardants (BFRs), perfluorinated compounds, pharmaceuticals and personal care products (PPCPs), and a decline in papers on "legacy" persistent organics such as PCBs. For example, a search of *Environmental Science and Technology*'s titles and abstracts reveals that, in 1996, only two dealt with alkyl phenols and estrogenic compounds and none with PPCPs or BFRs, while in 2002 there were, respectively, 14, 5 and 8 papers on these topics. As is discussed in more detail below, the reasons for this shift are numerous and include public pressure to study endocrine disrupting chemicals as a result of books like *Our Stolen Future* (Colborn et al., 1996) and *Toxic Ignorance* (Roe et al., 1997), new analytical methodology, and new government legislative and regulatory initiatives to classify and assess chemicals in commerce.

The purpose of this paper is to consider "new chemicals" in the Great Lakes context and what factors must be considered to assess their potential for harm to ecosystems in the basin. To do this the ongoing categorization and assessments on chemicals in commerce being conducted by government environment agencies worldwide (Walker et al., 2002) will be briefly reviewed because this process may identify new chemicals of concern in terms of persistence, bioaccumulation and toxicity. The second approach will be a brief review of recent studies of "new" chemicals in the Great Lakes especially temporal trend studies. Finally, factors to be considered in identifying and assessing these new chemicals in the Great Lakes context will be discussed.

Tracking, Categorizing and Assessing Chemicals in Commerce

The ongoing chemicals evaluation activities conducted by government environment agencies in the United States, Canada, the European Union and other environment agencies are potentially a major source of information from which to develop future "priority" lists for chemical contaminants in the Great Lakes. The Organization for Economic Cooperation and Development (OECD), the USA and the EU maintain lists of High Production Volume Chemicals (HPVCs). High production volume is one characteristic of chemicals on the current POPs list (e.g., global PCB use has been estimated at 1.2 $x10^6$ tonnes; Brevik et al., 2002). Production volume is assumed to be a surrogate for occupational, consumer and environmental exposure (OECD, 2000) and therefore is a good place to start in any priorization process. While the majority of HPVCs are probably not a concern with regard to their environmental persistence, bioaccumulation and toxicity (PB&T) characteristics, the chemical industry has recognized that data is lacking for many of these chemicals (OECD, 2000).

The US HPVC list includes 2,863 organic chemicals produced or imported at ≥ 450 tonnes/yr ($1x10^6$ lbs). In the European Union, the European Inventory of Existing Commercial Chemical Substances (EINECS) lists 100,195 "existing chemicals," i.e., in commerce as of 1981, of which about 2704 are considered high production volume (HPVC) based on production of >1000 tonnes/yr and 7842 low volume production chemicals (10-1000 tonnes/yr) (ECB 2002). The chemicals on this list are organic and inorganics but not polymers, alloys, mixtures of products or foodstuffs. The OECD maintains an HPVC list based on submission of the U.S., EU and other national inventories which consisted of 5,235 substances in 2000 produced at > 1000 tonnes globally.

There are six basic tests agreed to under the OECD's Screening Information Data Set (OECD/SIDS) program that are being used for screening HPVCs: acute toxicity, chronic toxicity, developmental/reproductive toxicity, mutagenicity, ecotoxicity and environmental fate. An EPA assessment of the HPVCs found that as of 1998 43% of these chemicals were missing all of these tests and 93% were missing one or more (U.S. EPA, 1998). The International Council of Chemical Associations (ICCA) has established a list of 1000 HPVCs for which SIDS are to be developed by 2004 (ICCA 2003).

To screen these large lists for PB&T substances requires information on chemical structure and properties. In the USA no single list for evaluation of chemicals in commerce exists. However, the EPAs EPIWIN software (U.S. EPA, 2000) has 103,000 organic chemicals with CAS numbers and Simplified Molecular Input Line Entry System (SMILES) notations. There are numerous US government agencies and contractors involved in evaluating chemicals. The oldest evaluation process is operated by the Toxic Substances Control Act (TSCA) Interagency Testing Committee (ITC) which has examined new chemicals and recommended potentially toxic and bioaccumulative chemicals for testing since 1976 (Walker et al. 2002).

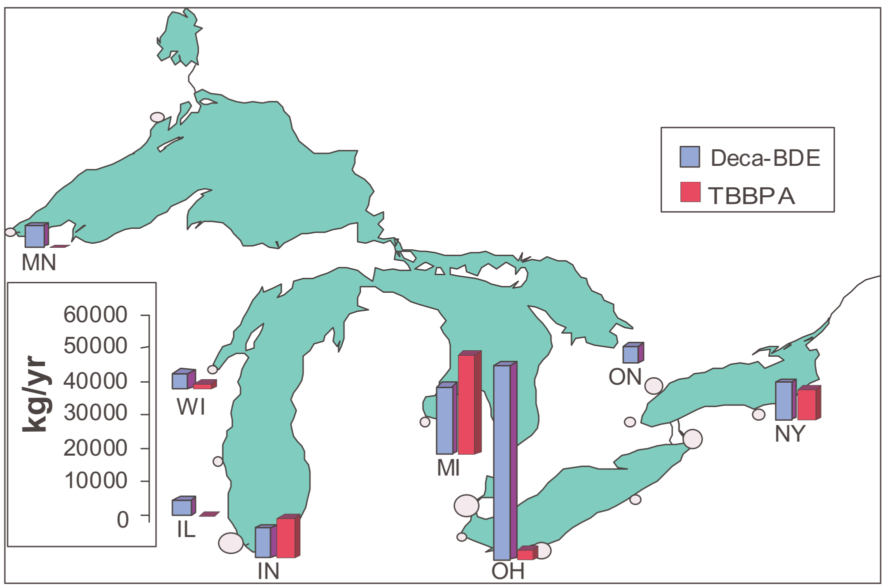
A very large list of chemicals in commerce consisting of about 58,000 discrete chemicals has been generated for the Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC) (Gray, 1998; Patlak, 1996; Hong et al., 2002). A QSAR model for estrogen receptor binding activity (RBA) has been applied to these 58,000 chemicals (Hong et al., 2002) and additional QSAR screening for androgenic and thyroid activity is underway. As part of this evaluation a database of 92,964 chemicals was developed; however, a final list of about 58,000 chemicals was used after eliminating 35,000 for which structures were not available (Walker et al. 2001). Application of four QSAR models for predicting RBA to the 58,000 chemicals found that only 104 chemicals were predicted to be active by more than three models, i.e., high probability of estrogen receptor binding. Some of these chemicals were well known such as o,p'-DDT and kepone.

In addition to the HPVC program the U.S. EPA's Toxics Release Inventory (TRI) tracks approximately 650 chemicals used in greater than 10000 lb/yr (~4.5 tonnes) or manufactured at >11 tonnes/yr as well as PBT substances such as PCDD/Fs and PCBs (http://www.epa.gov/tri/). In Canada, the National Pollutant Release Inventory includes about 230 HPVC compounds (10 tonnes/yr) as well as PCDD/Fs, mercury, hexachlorobenzene (HCB) and polyaromatic hydrocarbons (PAHs) (http://www.ec.gc.ca/ pdb/npri/npri_home_e.cfm).

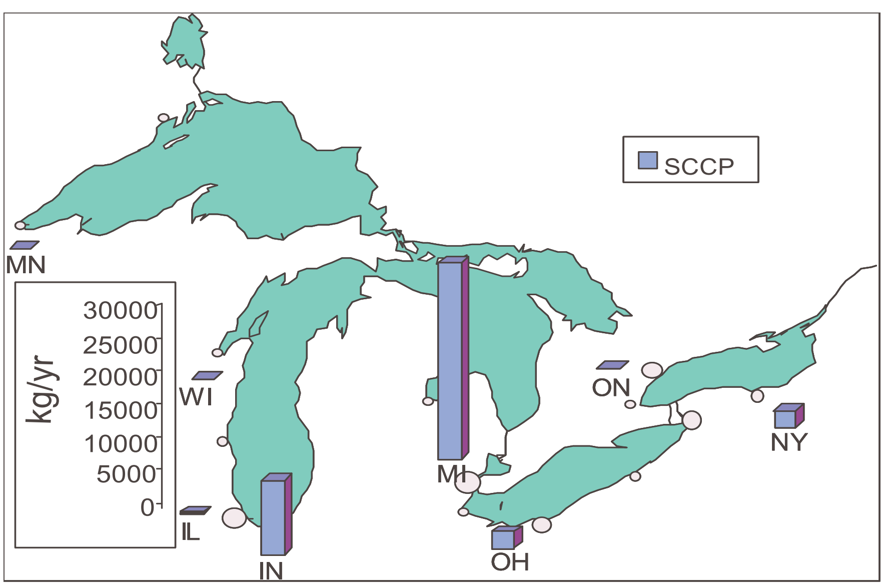
Because the TRI and NPRI can be assessed on a postal code basis it is possible to assemble maps of emissions for selected HPVCs and selected priority toxic chemicals for the Great Lakes basin. For example, brominated flame retardants decabromodiphenyl ether and tetrabromobisphenol A are used industrially in the Great Lakes region (Figure 1A). The emissions of these two substances by state based on PRI and NPRI data for 2000 are shown in Figure 1A. Short chain chlorinated

Figure 1. On site and off site releases of two major brominated flame retardants and short chain chlorinated paraffins (SCCPs, C10-C13 chlorinated alkanes) in 2000 from the US EPA TRI and the Environment Canada NPRI

1 A.



1 B.

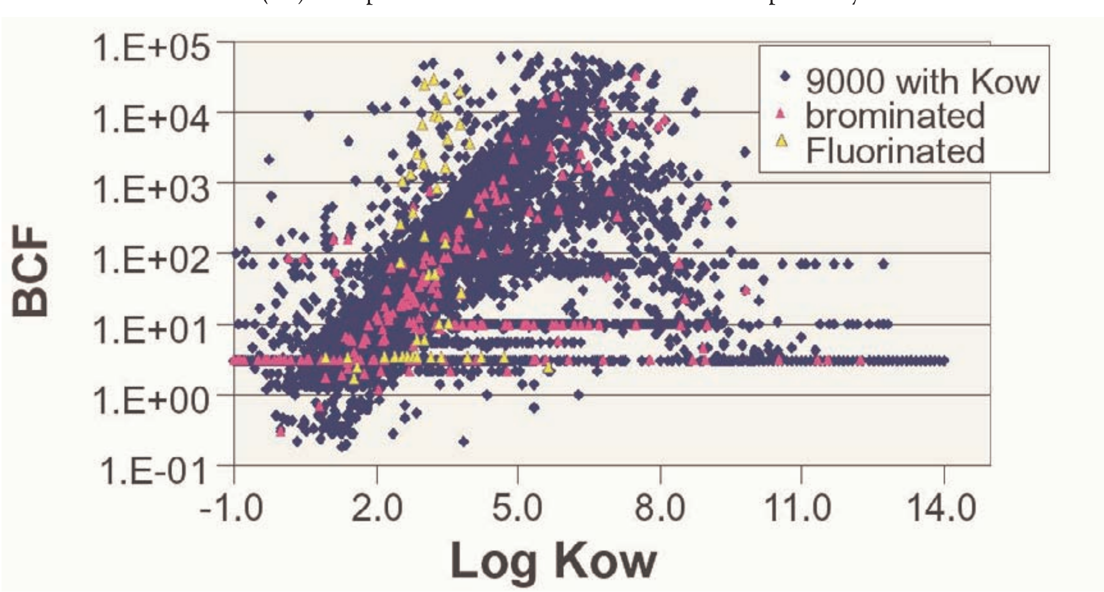


paraffins (SCCPs) are mainly used as flame-retardant high-temperature lubricant additives in metal working fluids (Muir et al., 2000). Their industrial use in the Great Lakes region is illustrated in Figure 1B. Unfortunately these inventories do not include emissions from consumer use, e.g., volatilization, washoff, disposal and recycling which could be very important for flame retardants.

In Canada, the Existing Substances Branch of Environment Canada (http://www.ec.gc.ca/substances/ese/eng/esehome.cfm) is in the process of categorizing the 23,000 chemicals on Canada's Domestic Substances List (DSL). These are chemicals which were imported or manufactured in Canada at greater than 100 kg in the period 1984-86 prior to enactment of the first Canadian Environmental Protection Act (CEPA) in 1988. In 1999, the new CEPA legislation required the categorization and screening of chemicals on the DSL. The categorization of the 23,000 chemicals involves use of QSAR modeling to predict physical chemical properties, persistence and toxicity (Macdonald et al. 2002). About 38% of the 23,000 are polymers (18%) or substances of unknown or variable composition (20%) that cannot be assessed by a conventional QSAR approach. Log Kow, BCF, atmospheric oxidation half-life and half-lives in soil and sediment have been predicted for 10,300 organic chemicals on the DSL using primarily EPIWIN suite of models (SRC 2002). Toxicity (LD50 to fish, Daphnia and green algae) also has been predicted for all 10,300 using several QSAR packages (Macdonald et al. 2002). Very little of this predicted data was available from EPA or ECB programs because the focus in other programs has been on HPVCs or EDCs.

Of the 10,300 individual chemicals currently being assessed, 9000 have been assigned log Kow values, corrected for disassociation, using KOWWIN. About 20% (1760) have predicted log Kow's ≥5, a criterion for bioaccumulation potential under the CEPA and also under the Stockhom POPs protocol (UNEP 2001). Predicted BCFs (using BCFWIN) for 355 of the 10,300 compounds were > 5,000 and 2763 had predicted sediment half-lives of ≥180 days. Two classes of chemicals, fluorinated and brominated compounds, represent about 3% of the chemicals with known log Kow's on the DSL. Predicted BCFs for these groups were generally under 5,000 (Figure 2); however, 36% of the brominated compounds and 93% of the fluorinated compounds were estimated to have soil half-lives of 180 days, a criterion for persistence under CEPA.

Figure 2. Predicted bioconcentration factors (BCF) versus predicted log Kow values for 9000 chemicals from the Canadian DSL categorization process. Brominated (232) and fluorinated (56) compounds on the list are identified separately.



Walker and Carlsen (2002) examined 8,511 chemicals, with 1998 production volumes reported to the US EPA, to screen for persistence and bioaccumulation potential. This screening used the EPA's "PBT Profiler" which uses a Level III fugacity mass balance model (Mackay, 2001) to predict persistence, and the Degradation Effects Bioconcentration Information Testing Strategies (DEBITS), a series of QSAR programs for predicting persistence and bioaccumulation potential. BCF and probability of biodegradation (BDPs) were predicted with EPIWIN programs yielding 56 chemicals with medium bioaccumulation (BCFs >1000) and persistence (BDPs < 2). The two programs yielded identical predictions for BCF but differed in predictions of persistence in environmental media. This screening identified 10 highly persistent (Sediment half-life = 1,620 days) and moderately bioaccumulative chemicals (BCF >1000 and <5000). Interestingly, three were perfluorinated while seven others were non-halogenated but with multiple aromatic and/or aliphatic rings.

The screening assessments of HPVCs and other less widely used chemicals in commerce using QSAR programs are providing a means to prioritize large numbers of chemicals in commerce for persistence, bioaccumulation and toxicity and could help direct future monitoring for new chemicals. However, there still are many problems inherent in the process such as lack of structural information on a significant fraction of chemicals which prevents determining the SMILES notation needed to estimate physical properties. "Training sets" i.e., of compounds with measured physical properties and toxicity for use in QSARs, are small (generally <1000 substances) and may not be representative of the majority of chemicals. For example, BCFWIN uses 694 chemicals of which 610 are non-ionic.

Log Kow prediction is more robust; KOWWIN has 12,000 experimental Kow values. For example, a significant fraction of DSL chemicals are acids (sulfonic acids, carboxylic acids) while most BCF and log Kow predictions are based on persistent neutrals. Metabolism by fish is also not well predicted by current models and thus BCF can be overestimated especially when based solely on Kow. The possibility of false negatives is a concern especially for toxicity predictions, e.g. EDCs, because these chemicals would receive low priority for testing. The possibility of false positives is a concern from an industry perspective because of the cost of having to conduct full environmental or toxicology studies.

Recent Measurements of "New" Chemicals in the Great Lakes

Advancements in Analytical Methodology

There are a growing number of environmental measurements of chemicals in commerce such as flame retardants, surfactants and PPCPs. Many of these recent studies have included samples from the Great Lakes region. Current-use pesticides, also have been the subject of detailed studies during the 1990s by the USGS under the NAWQA program (USGS, 2000; Frey, 2001) and by Environment Canada in open lake waters and tributaries (Struger et al., 2002; 2003). Much of this work is not driven by the categorization and screening activities discussed previously but represents the refinement and extension of existing analytical methodology to new groups of chemicals. This is particularly the case for brominated diphenyl ethers and chlorinated naphthalenes which can be determined with existing methodology for PCBs and dioxin/furans (Luross et al. 2002; Kannan et al., 2001a). However, new analytical methodology, especially the use of liquid chromatography (LC) with electrospray tandem mass spectrometry (ESI-MS/MS), has made possible the determination of perfluorosulfonates in surface waters and biota (Hansen et al., 2001;2002). LC-ESI-MS/MS is now also being applied to the determination of pharmaceuticals in surface waters and effluents (Ternes et al., 2001; Kolpin et al., 2002; Miao et al., 2002). The LC- ESI-MS/MS technology is particularly well suited to analysis of anionic compounds such as sulfonic acids and carboxylic acids, at detection limits that are similar to GC-MS. Thus a much wider range of substances can, in principle, be determined at low levels in environmental samples than was the case until the late 1990s. However, at the present time the number of pharmaceuticals, hormones and related phenolic compounds for which validated methods are available for surface waters and waste waters is relatively small. The largest study to date on PPCPs, hormones and other chemicals in U.S. surface waters (including six streams on Lake Michigan), by Kolpin et al. (2002) determined 95 compounds by a combination of technologies including GC-MS and HPLC- ESI-MS. Metcalfe et al. (2003) determined 18 acidic and neutral drugs in Great Lakes tributary and harbor surface waters using LC-ESI-MS/MS.

Future investigations of chemicals, predicted to be P, B & T using QSARs, will likely require method development or at least refinements of existing procedures. For example, of the 50 high- and medium-production volume chemicals identified by Walker and Carlsen (2002) as potentially bioaccumulative and persistent, only three (HCB, hexabromobenzene and hexabromo-cyclododecane) could be considered to be routinely determined in environmental samples while three others (tetradecafluorohexane, heptadecafluoro-1-decanol and heptadecafluoro-N-methyl-1-octanesulfonamide) might be readily analyzable by GC-MS or LC-MS. Similarly of the 355 compounds on the DSL list with BCF>5000 only a small fraction, approximately 3%, appear to be chemicals currently analyzed in environmental samples i.e. some PAHs, HCB and tetra- and pentabromodiphenyl ethers.

Polybrominated Diphenyl Ethers (PBDEs)

PBDEs were first reported in Lake Michigan salmon (*Oncorhynchus kisutch*) (Manchester-Neesvig et al., 2001) and subsequently in lake trout (*Salvelinus namaycush*) from Lakes Superior, Huron and Ontario (Luross et al., 2002;Dodder et al., 2002). An early study by Stafford (1983) was the first to report the presence of PBDEs in eggs and tissues of fish-eating birds in the Great Lakes region but it was not followed up. Recent studies on the temporal trends of PBDEs in herring gull eggs (Norstrom et al. 2002) and lake trout (Luross et al., 2003; Chernyak & Hickey, 2003) have shown that these compounds are increasing in Great Lakes biota with a doubling time of about three years. More specifically, it is the tetra- and penta-bromo congeners that are the major components of pentabromo diphenyl ether flame retardants that are increasing as illustrated in Figure 3 for lake trout in Lake Ontario (Luross et al., 2003). PentaDBE also has increased about four-fold during the period 1990-1996 in Lake Michigan (Saugatuck) lake trout and in Lake St. Clair walleye (Chernyak & Hickey, 2003). Analysis of a dated sediment core from the western basin of Lake Ontario showed that decabromodiphenyl ether (BDE 209) was the major PBDE present. Concentrations of BDE 209 were highest in the surface (0-1 cm; 112 ng/g) and declined rapidly with depth to non-detect levels in sediments dated to the early 1980s indicating a major increase during the 1990s (Muir et al., 2003a).

PentaDBE is used almost exclusively in polyurethane foam which is used primarily in upholstered furniture and automobile seating (Alcock et al. 2003). It is relatively non-volatile and would likely to be landfilled following consumer use. Thus the reasons for its exponential

Figure 3. Temporal trend of major PBDE congeners in 5 year old Lake trout (whole fish) from Lake Ontario. Adapted from Luross et al. (2003).

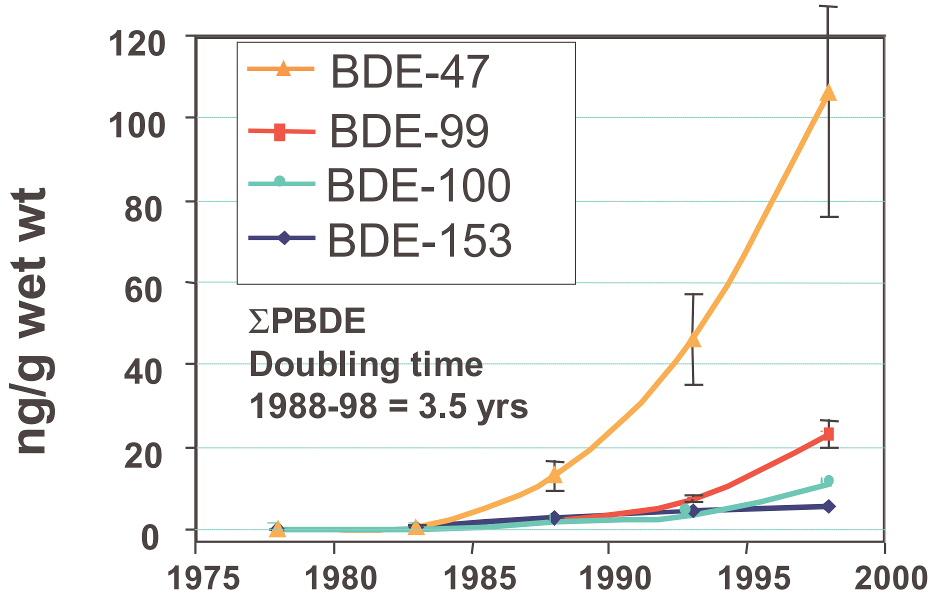
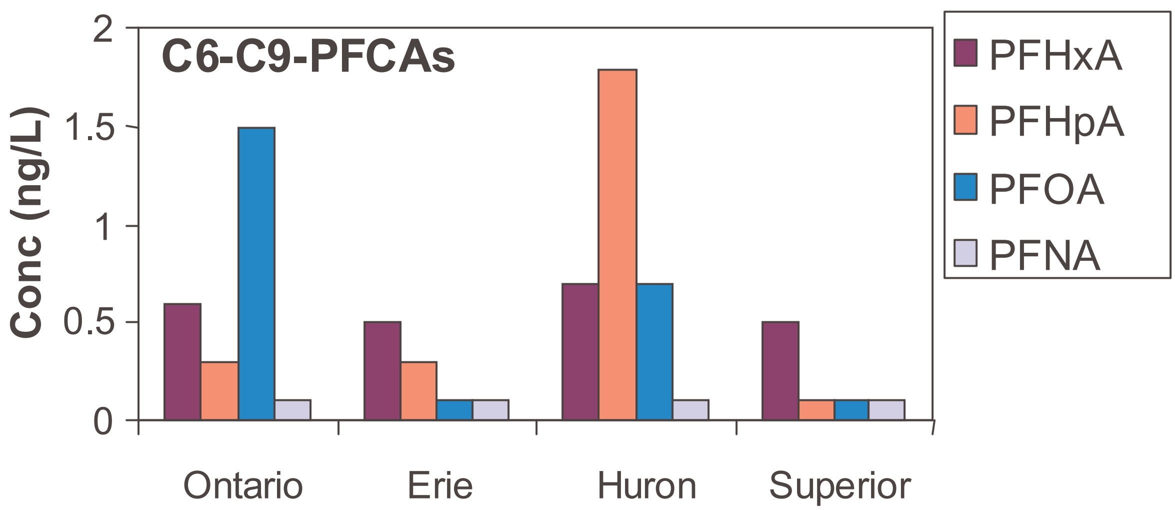


Figure 4. Concentrations of perfluorohexanoic (PFHxA), perfluoroheptanoic acid (PFHpA), perfluoroctanoic acid (PFOA) and perfluorononanoic acid (PFNA) in water samples from mid-depth at the deepest point in Lakes Ontario, Erie, Huron and Superior (Scott et al. 2003a). Detection limit is approximately 0.1 ng/L.



increase are not clear although use of PBDE flame retardants in general has increased exponentially in the past 20 years due to concerns about fire safety (Alaee et al., 2003). PBDEs also have been detected in Great Lakes air at sampling stations of the Integrated Atmospheric Deposition Network (IADN) (Strandberg et al., 2001) and may be entering the lakes via atmospheric deposition and gas exchange as well as via municipal waste effluents. Analysis of air sample extracts archived by the IADN may permit future assessment of the temporal trends of PBDEs in air.

Perfluorosulfonates and Carboxylates

The detection of perfluorooctanesulfonic acid (PFOS) and the corresponding carboxylate, perfluorooctanoic acid (PFOA) in Great Lakes biota was first reported by Geisy and Kannan (2001). These perfluorinated acids (PFAs) are members of the class of fluorinated surfactants, characterized by a perfluoroalkyl chain and a sulfonate or carboxylate solubilizing group. PFAs have been used increasingly over the past 20 years because of their temperature and chemical stability, lipophobicity and effectiveness as surfactants at low concentrations. Production volumes of PFOS and derivatives in North America were low (3,000 t in 2000) compared to pentaBDE (8,500 t in 1999). However, this compound is highly recalcitrant to biotic and abiotic degradation mechanisms and appears to be bioaccumulated by enterohepatic recirculation like a bile acid (Goecke-Flora & Reo, 1996). Kannan et al. (2002) reported average PFOS concentrations in mink livers from Illinois of 0.09-4.8 ug/g wet wt. Other perfluoro compounds including PFOSA, the amide derivative of PFOS and PFOA, also were detected. A recent temporal trend study using Lake Ontario lake trout has shown significantly increasing concentrations of PFOS during the 1980s and 1990s (J.Martin, Univ. of Toronto, unpublished data, 2003). Moody et al. (2002) detected perfluoroalkanesulfonate (6 and 8 carbons) and perfluorooctanoate in Etobicoke creek, a tributary to Lake Ontario, following a spill of aqueous fire-fighting foam at Pearson airport in Toronto. Perfluorosulfonate concentrations ranged from <0.017 μg/L to 2260 μg/L over a 153-day sampling period with concentrations.

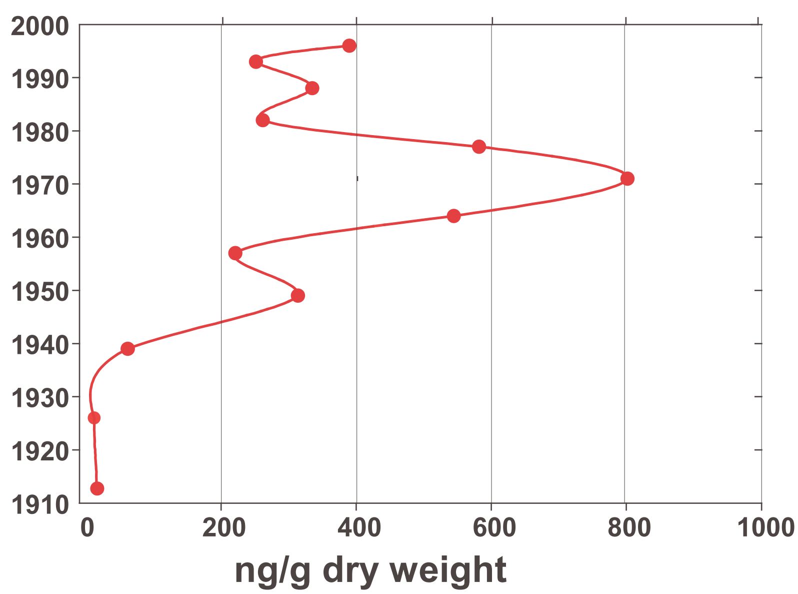
Martin et al. (2002) detected six polyfluorinated alcohols and amides – perfluorotelomer alcohols (FTOHs), N-ethyl perfluorooctane sulfonamide (NEtFOSA), N-methyl perfluorooctane sulfonamidoethanol (NMeFOSE) and N-ethyl perfluorooctane sulfonamidoethanol (NEtFOSE) in air near Lake Erie and in Toronto. These compounds are possible precursors of PFOS and PFOA (J. Martin & S. Mabury, Univ. of Toronto, personal communication). FTOHs and polyfluorinated sulfonamides in the troposphere were observed at concentrations ranging from 7 to 196 pg/m^3 and 14 to 393 pg/m^3 respectively, which were higher than PCBs or PBDEs in Great Lakes air. Perfluorinated carboxylic acids are detectable at low or sub-ng/L concentrations in Great Lakes waters as shown in Figure 4 for the perfluorohexanoic, heptanoic, octanoic and nonanoic acids (Scott et al., 2003a). Lake Ontario is distinguished by higher concentrations of PFOA compared to the other lakes. These PFAs also were found in Lake Ontario surface waters at low ng/L concentrations at all depths. Scott et al. (2003b) detected these PFAs in discharges of four Toronto STPs (Scott et al., 2003b) and in the STP discharges of three communities on Lake Superior (Scott et al., 2002). Because of their hydrophilic characteristics and low or negligible biodegradability the PFAs are likely to remain in the water column for a long time. Their temporal trends in lake water remain to be investigated.

PFOA also has been detected at the ng/L level in precipitation samples collected at the Canadian atmospheric precipitation monitoring sites, including the one situated at the Turkey Lakes near Sault Ste Marie (Scott et al., 2002), which indicates that atmospheric inputs pathways are probably important for PFA entry into the Great Lakes.

Chlorinated Paraffins (C10-C17 chlorinated n-alkanes)

Chlorinated paraffins (CPs) are HPVCs, by comparison with PBDEs and PFAs, with North American production of about 26 kt/yr (CPIA 2000). TRI and NPRI surveys suggest that much of the use of CPs in the USA and Canada occurs within the Great Lakes basin. CPs resemble many POPs in terms of molecular weight and physical-chemical properties but are generally less bioaccumulative and toxic (Tomy et al., 1998). Short-chain (SCCP; C10-C13) CPs are used mainly in metal working fluids. Medium-chain (MCCP;C14-C17) CPs are used as flame retardant plasticizers in plastics and rubber, although a significant portion also are used as lubricant additives (CPIA 2000). Analysis is very difficult because of the complexity of the commercial mixture and the need for high-resolution negative ion mass spectrometry to avoid interferences from other persistent organochlorines (Tomy et al., 1997). Short chain CP (SCCP) concentrations in the low ng/L range were found in Lake Ontario water (Muir et al., 2000). The profile of SCCPs in a sediment core from western Lake Ontario suggests that maximum inputs occurred in the 1970s and 1980s (Marvin et al., 2003a) (Figure 5). Concentrations of SCCPs in the surface 0-1 cm of this core (410 ng/g dw) were about 4.5x higher than total PCBs (88 ng/g dw) in the same samples. The Lake Ontario average SCCP sediment concentration was 49 ng/g, which was somewhat higher than the lake-wide average for ΣDDT (32 ng/g) but lower than the average for PCBs (100 ng/g dw) (Marvin et al., 2003b). Temporal trends of the medium-chain CP group (C14-C17), which are more widely used than SCCPs, are not known at present. Canada has proposed a CEPA Track 1 (virtual elimination) designation for SCCPs while in the U.S. they are on the TRI but not proposed for removal from use.

Figure 5. Total C10-C13 SCCPs in a dated sediment core from a profundal zone in the West Basin of Lake Ontario, 43°26'N; 79°,24'W. Adapted from Marvin et al 2003a.



Chlorinated naphthalenes

This group of chemicals may have been important historically in the Great Lakes region because they were originally manufactured for use as electrical insulators and capacitor fluids, prior to use of PCBs. They also are formed in combustion and, indeed, combustion sources of PCNs predominate in Great Lakes urban air (Harner & Bidleman, 1997; Helm & Bidleman, 2003). Some PCNs have Dioxin Toxic Equivalent Factors (TEFs) assigned due to them and thus their measurement in the Great Lakes adds to Toxics Equivalents (TEQ) information available for various species. Kannan et al. (2000; 2001a) have reported PCNs in fish from the Detroit River and in eggs of cormorants and herring gulls from Lake Michigan. PCNs made up a high proportion of TEQs (57%) in the Detroit River fish but were a small portion of TEQs in herring gull eggs (2-3%). The authors concluded PCN contamination was relatively localized within the Great Lakes region. However, PCNs were detectable at pg/g concentrations in lake trout from Isle Royale in Lake Superior and at similar (lipid weight) concentrations in Lake Superior lake trout indicating an atmospheric pathway of contamination in non-urbanized areas of the Great Lakes.

Kannan et al. (2001b) found PCN concentrations in the low ng/g range in sediments from the Rouge River and at sites in the nearby lower Detroit River. Total PCN concentrations were much lower (<0.1 ng/g) at upstream sites on the Detroit river. A study of water and suspended solids from the Detroit River showed that PCNs were present at concentrations of about 14000 pg/L in the Trenton Channel and near method detection limits (about 20 pg/L) in the inlet Lake St Clair (McCrea et al., 2003). Marvin et al. (2002) found that the spatial distribution of PCN contamination in the Detroit River suspended sediments was similar to that of PCDDs/PCDFs and dioxin-like PCBs, with the highest level of total PCNs (8200 ng/g) detected in the Trenton Channel. Marvin et al (2002) concluded that PCNs represent a significant contribution to dioxin-like biological activity in Detroit River suspended sediments.

Helm and Bidleman (2003) compared PCN concentrations and congener patterns in air from downtown Toronto and an industrialized area of north Toronto. Concentrations at the two sites were similar, however, the downtown location showed a congener pattern similar to technical PCNs implying emissions from past use while at the more industrial site the PCNs were influenced by combustion sources. Harner and Bidleman (1997) also noted higher PCNs in Chicago as a result of local burning. These results suggest that PCNs will continue to be a contaminant issue in the Great Lakes region due to their formation during low temperature combustion similar to dioxin/furans.

Pharmaceuticals and Personal Care Products (PPCPs)

Kolpin et al. (2002) determined 95 PPCPs in US surface waters (including six streams on Lake Michigan). Samples generally were collected in the vicinity of municipal waste treatment plants and thus represent dilution of MWTP effluents. Steroids, nonprescription drugs, detergent metabolites and plasticizers were the predominant types of products. Acidic and neutral drugs (e.g. ibuprofen, dicofenac, clofibic acid and others) are routinely found in municipal waste effluents and adjacent waters in the Great Lakes region depending on dilution of waste waters (Metcalfe et al., 2003).

In their survey of Hamilton Harbour and the Detroit River near Windsor by Metcalfe et al. (2003), acidic drugs and the antiepileptic drug carbamazepine were detected at ng/L concentrations at sites that were up to 500 m away from the STP, but the hydrological conditions of the receiving waters strongly influenced the spatial distribution of these compounds. Clofibric acid, ketoprofen, fenoprofen and carbamazepine were detected in samples collected in the summer of 2000 at sites in Lake Ontario and at a site near Fort Erie on the Niagara River that were relatively remote from STP discharges. The anti-depressant fluoxetine and the antibiotic trimethoprom also were detected in most STP effluents and some surface water samples in the same region. For the first time, the lipid regulating drug atorvastatin was detected in samples of STP effluent and surface water (Metcalfe et al., 2003).

Gatermann et al. (1999) identified the synthetic musks HHCB (1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[g]-2-benzopyrane, e.g., galaxolide®), AHTN (1-(5,6,7,8-

tetrahydro-3,5,5,6,8,8-hexamethyl-2-naphthalenyl)-ethanone; e.g., tonalide®), as well as nitro musks, musk xylene (MX) and musk ketone (MK), in lake trout samples from Lake Ontario. Concentrations were in the low ng/g range with AHTN predominating. These compounds and many other fragrance materials (FMs) have been detected in municipal waste waters in the USA (Simonich et al., 2002) but there are as yet no published results for effluents entering Great Lakes waters. The bioaccumulation potential of some FMs, combined with continuous emissions from STPs, suggests that these chemicals deserve further study in the Great Lakes context.

Phenolics

Many phenolics are of interest for their degree of estrogenic and androgenic activity (Walker et al., 2002). Alkyl phenol ethoxylate surfactants have received the greatest attention because they are microbially degraded to alkyl phenols (e.g. 4-nonyl phenol (NP) and 4-octyl phenol (OP)) which have weak estrogenic activity (White et al., 1994; Servos, 1999). Bennie et al. (1997) surveyed 24 Great Lakes locations (Lake Superior, Georgian Bay in Lake Huron, St Clair, Detroit and Niagara Rivers, Lake Ontario) including nearshore waters, tributary waters, and municipal and industrial effluents and nearby bottom sediments. NP, OP and NP-mono and diethoxylate were present in surface waters near industrialized areas, e.g. downstream of Detroit, Hamilton harbour, Toronto harbour and were non-detectable (< 10 ng/L) in water sampling locations distant from sources. All sediments, which were collected at the mouths of rivers draining urban areas or near STPs contained detectable levels of NP, OP and NP-mono and diethoxylate. Bennett and Metcalfe (2000) also found NP, and NP-mono and diethoxylate at ug/g concentrations in sediments and in caged mussels, at ng/g levels, from the Detroit River and Hamilton Harbour. Concentrations generally declined with distance from STP sources. NP predominated in the mussels reflecting its higher bioaccumulation potential than the ethoxylates. Kannan et al. (2001b) also surveyed alkylphenols (butyl phenol, OP and NP) in sediments from the Detroit River as well as the Rouge River and off shore of Muskegon in Lake Michigan. NP was present at highest concentrations of the three alkyl phenols. NP concentrations ranged from < 1 ug/g (dw) in the upper Rouge River to 60 ug/g in sediments near industrial sites. NP was non-detectable (<10 ng/g dw) in nearshore Lake Michigan sediments. NP was detectable (10 ng/g wet wt) in fish from Lake Michigan near the mouth of the Kalamazoo River and at higher concentrations in fish immediately downstream of the cites of Kalamazoo and Battle Creek, Michigan. NP mono-ethoxylate was present in the same fish at concentrations near detection limits which the di- and tri-ethoyxlates were undetectable (Keith et al., 2001).

The phenolic group can be considered to include products such as triclosan (5-chloro-2-(2,4-dichlorophenoxy)-phenol), as well as tetrabromobisphenol A, a major BFR, and bisphenol A. The latter two substances are both listed on the TRI. There are only a few measurements so far of TBBA. Quade et al. (2003) reported low ng/g concentrations of TBBPA in Detroit River sediments. Levels were lowest in southern Lake St. Clair (0.60 ng/g) and highest downstream from the mouth of the Rouge River (1.82 ng/g). Triclosan, a widely used anti-microbial chemical used in a variety of PPCPs, was detected in blood plasma of fish from the Detroit River as part of a survey of phenolic compounds (including pentachlorophenol, hydroxy-PCBs and 4-OH-heptachlorosytrene) (Li et al., 2003; Letcher et al., 2003).

Organophosphate Flame Retardants

Halogenated and non-halogenated phosphate esters account for a significant portion of the flame retardant market in North America. They are widely used in rigid polyurethane foam. These compounds, such as tributylphosphate (TBP), tris(2-chloroethyl)phosphate (TCEP), tris(1-chloro-2-propyl)-phosphate (TCPP) and bis(1-chloro-2-propyl)(3-chloro-1-propyl)phosphate, are semi-volatile (vapor pressures 1-10 Pa at 25^{o}C and have come into increasing use during the 1990s for use as flame retardants in plastics (IPCS, 1998). Scott et al. (1996) detected TBP, TCEP and two TCPP isomers in Lake Huron, Lake Erie (near Ft. Erie), the mouth of the Niagara River and in eastern Lake Ontario (Wolfe Island). Total trialkyl phosphate concentrations were in the range of 1.5-23 ng/L indicating significant inputs into open waters of the Great Lakes. These compounds were also detected in precipitation samples in the western Lake Ontario area at ng/L concentrations suggesting that precipitation could be a significant pathway of input for these semi-volatile compounds.

Current-use Pesticides

The entry of current-use pesticides into Great Lake waters has been documented since the early 1970s (Miles & Harris, 1971). Early work focused on organochlorine insecticides, while measurements of herbicides and less persistent insecticides began in the late 1970s (Frank et al., 1979; Richards & Baker, 1993). Surveys of major tributaries of Lakes Erie and Huron showed that atrazine and metolachlor were the major herbicides entering these lakes (Frank & Logan, 1988; Bodo, 1991; Richards & Baker, 1993; Richards et al., 1996). Measurements of tributary loadings of atrazine, other herbicides and insecticides are very limited for the other Great Lakes. Current-use pesticides have also been the subject of detailed studies during the 1990s by the USGS under the NAWQA program including on the Fox River watershed in Wisconsin (USGS 2000) and in the western Lake Erie/Lake St. Clair area (Frey 2001). USGS has identified about 20 pesticides in current use which have the potential to accumulate in sediments and biota, ranging from the organochlorines endosulfan and lindane (which are widely measured in the Great Lakes e.g. IADN) to dinitroaniline herbicides like pendamethalin and trifluralin. There are few measurements of current-use pesticides in biota. Most current-use pesticides are generally not expected to bioaccumulate because of relatively low lipophilicity and degradation by vertebrates. All current use pesticides have measured or estimated BCFs of <5,000, the quideline limit used in the assessment of persistent/bioaccumulative substances. Nevertheless, some accumulation would be expected given annual inputs from pesticide use in agricultural and urban watersheds within the Great Lakes basin. Roberts et al. (1979) did not detect atrazine in fish (detection limit ~0.1 ug/g) in Hillman Creek, a tributary of Lake Erie, which had concentrations of atrazine of 0.3 ug/L at time of sampling.

There have been far fewer measurements of current-use pesticides in the open waters of the Great Lakes. Schlotter and Eisenreich (1994; 1997) determined atrazine, alachlor and metolachlor in all five Great Lakes over the period 1991 to 1994. Of the three herbicides, atrazine and its degradation product des-ethyl atrazine were found at highest concentrations in all lakes. Highest average annual concentrations of atrazine were present in Lake Erie (0.077 ug/L) and Ontario (0.084 ug/L). Atrazine concentrations in Lakes Ontario and Michigan were remarkably constant with depth indicating it was well mixed and had a long water residence time. Modeling of atrazine concentrations suggested that atmospheric inputs represented the major pathway for Lake Superior while agricultural stream inputs predominated in the lower Great Lakes (Schlotter & Eisenreich 1997). Schlotter and Eisenreich (1997) estimated degradation half-lives of atrazine in Great Lakes waters of two to fourteen years using a dynamic mass balance model. Tierney et al. (1999) predicted half-lives of atrazine of two to five years using a dynamic time step model calibrated with the data from Schlotter and Eisenreich. Rygwelski et al. (1999) concluded that atrazine concentrations in

Lake Michigan could be modeled by assuming no degradation of atrazine in the open lake waters along with a smaller watershed export estimate than used by Schlotter and Eisenreich (1997). Thus there is some disagreement on the extent of degradation of atrazine. There is little doubt that atrazine is much more persistent in the cold oligotrophic waters of the Great Lakes than in agricultural soils and stream waters and this finding has implications for other pesticides and compounds shown to degrade in standard laboratory tests.

Struger et al. (2003) determined a suite of about 30 herbicides and organophosphorus (OP) insecticides in surface waters at offshore locations in Lakes Superior, Erie, Huron and Ontario over the period 1994 to 2000. Thirty-three pesticides were detected with atrazine, simazine and metolachlor present in almost all samples (91-93%). Atrazine and metolachlor concentrations observed in open water sites in Lake Erie in July 1998 by Struger et al. (2003) averaged 62 ng/L and 32 ng/L, respectively, excluding two sites heavily influenced by the Maumee River. These concentrations were very similar to the lake-wide averages observed in the early 1990s by Schottler and Eisenreich (1994;1997). OP insecticides (dibrom, dimethoate, terbufos, fonofos, diazinon, malathion, chlopyrifos, parathion, ethion and azinphos methyl) were detected only in Lake Erie, at low ng/L concentrations. The highest concentration of diazinon was measured near the zone of influence of the Maumee River in the western basin of Lake Erie. Monitoring of tributaries of Lakes Erie and Ontario has shown the presence of OP insecticides during the growing season (Richards & Baker, 1993; Struger et al., 2002; Muir et al., 2003b). The lower frequency of detection of the OP insecticides is probably due to their lower quantities of use compared to herbicides used in corn combined with more rapid degradation in surface waters than compounds such as atrazine (Struger et al., 2003). While OPs concentrations were at or below detection limits in the open lake waters of Lake Erie, concentrations of several compounds, e.g. azinphos-methyl and diazinon, approached or exceeded water quality criteria (WQC) for protection of aquatic life at a site in western Lake Erie offshore of the Maumee River (Struger et al., 2003). Exceedences of WQCs for OP insecticides also have been observed in tributaries of Lake Ontario in the Niagara peninsula and of Lake Erie (Struger et al., 2002).

Conclusions

The past five years has seen a major increase in measurements of chemicals in the Great Lakes environment that are not on the GLQA/GLBNS priority lists. However, the list of chemicals measured represents only a tiny fraction of the chemicals in commerce or of even high production volume chemicals used within the basin. QSARs are being extensively applied to screen chemicals for PB&T characteristics in the US and Canada and one outcome will be priority lists of additional chemicals that will be candidates for measurement. Given the large numbers of chemicals, QSAR represents the only approach for screening the large numbers of possible chemicals. The TRI and NPRI may be useful for identifying emission regions for selected chemicals that EPA and Environment Canada have targeted. Modeling of inputs using regional scale models such as BETR (MacLeod et al. 2002), which have been used for POPs inputs, might be helpful in ranking and priorizing “new” chemical inputs to the basin if source regions and emissions were known. This has been done for toxaphene (MacLeod et al. 2002) and also for dioxins (Cohen et al. 2002). This would be especially useful for semi-volatile organics with relatively long atmospheric half-lives which, like the legacy POPs, could be atmospherically transported to Great Lakes basin.

Many of the recent measurements of new chemicals have been driven by advances in analytical methodology especially in the case of PFAs and PPCPs. However, there are no analytical methods for determining the vast majority of organic chemicals identified as potentially bioaccumulative and persistent on HPVC, DSL or other lists at environmentally relevant concentrations. Developing appropriate multi-residue methodology is feasible given that persistent and bioaccumulative organic compounds have some similarities in terms of their behavior in extraction, isolation and separation systems currently used in environmental analytical chemistry. However, this will take time and significant resources.

For bioaccumulative compounds such as PBDEs, PFOS and PCNs, temporal trend studies using archived samples provide a good perspective on the status of the chemicals. For other recalcitrant but non-accumulated compounds such as decabromodiphenyl ether, analysis of dated sediment cores may provide insights into current emissions to the lakes. For many less bioaccumulative polar compounds other archives need to be investigated such as long-term maintenance of sample extracts that can be reanalyzed.

While a list of "new" chemicals that are persistent and bioaccumulative is easily assembled from the temporal and spatial trend studies, and from QSAR screening using existing PB&T guidelines, many PPCPs, phenolics and current-use pesticides are not identified by such screening because of low Kow values and structural characteristics indicating biodegradability. Nevertheless, these compounds may be important from the point of view of effects on aquatic biota in waters adjacent to STP outfalls as well as in agricultural and urban tributaries, and are not so easily characterized or priorized using PB&T guidelines. There is a need for water quality criteria for a much wider range of substances than are available at present. Current WQCs heavily emphasize pesticides and some POPs. This in turn requires good aquatic toxicity data which is available for currently registered pesticides but typically is lacking or very limited for most industrial chemicals.

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Can QSARS Identify Emerging Pollutants That Will Threaten the Great Lakes Ecosystem?

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Abstract

Quantitative Structure Activity Relationships (QSARs) were used to screen 2697 industrial chemicals and pesticides for biodegradation, bioconcentration and aquatic toxicity potential and to characterize the environments in which these chemicals and pesticides are likely to be found. In addition, QSARs were used to predict hydrolysis half-lives, Henry's Law Constants and ultimate biodegradation probabilities in water as well as bioavailability and modes of toxic action. As a result of using these QSARs, 43 industrial chemicals and pesticides were predicted to partition to and persist in sediments. QSARs predicted that all 43 of these industrial chemicals and pesticides should have acute aquatic toxicities < 1mg/L and bioconcentration factors > 5000. In addition, QSARs predicted that only one of the chemicals and pesticides was likely to hydrolyze and only two were likely to evaporate from water. However, QSARs predicted that as many as 31 of the chemicals and pesticides could have non-narcotic, irreversible modes of toxic action and 40 were likely to have at least one conformer that was bioavailable. The implications of these predictions are discussed with two caveats. First, while this paper focuses on chemicals and pesticides that could threaten the aquatic life of the Great Lakes Ecosystem, it is equally important to provide resources for using QSARs and other computational chemistry tools to identify those chemicals that are likely to enter other environmental compartments, e.g., through evaporation, and cause adverse impacts to human, terrestrial wildlife and avian populations in the Great Lakes Ecosystem. Second, while this paper focuses on persistent parent industrial chemicals and pesticides, it is imperative that resources be dedicated to developing QSARs to identify the persistent biodegradation products and stable reactive mammalian metabolites that are likely to be produced from the parent compounds, so that monitoring resources can be more effectively used to quantify these products and metabolites, and remediation measures can be implemented to remove the parent compounds before they enter the Great Lakes Ecosystem.

Introduction

The Great Lakes Water Quality Agreement commits the United States and Canada to restore and protect the chemical integrity of the Great Lakes Ecosystem. In particular, the Agreement commits to "virtually eliminate" selected persistent toxic substances. While progress has been made reducing these substances in the Great Lakes Ecosystem, other chemicals are emerging as potential pollutants. With the numerous industrial chemicals, pesticides, pharmaceuticals, food additives and other substances that could be contaminating the Great Lakes Ecosystem, Quantitative Structure Activity Relationships (QSARs) are proposed as tools that could be used to identify these emerging pollutants and characterize the environments where they are likely to persist so that monitoring studies can confirm their presence in these environments and remediation measures can be implemented. The purpose of this paper is to demonstrate how QSARs were used to screen 2,697 industrial chemicals and pesticides to identify 43 of these industrial chemicals and pesticides with persistent (P), bioconcentration (B) and toxic (T) properties and to characterize the environments where these PBTs are likely to be found so that monitoring studies could confirm their presence in these environments and remediation measures could be implemented.

Methods

Previously described QSAR methods were used to screen 2,697 industrial chemicals and pesticides for biodegradation, bioconcentration and aquatic toxicity potential (Walker & Carlsen, 2002; Carlsen & Walker, 2003). Hydrolysis half-lives, Henry's Law Constants and ultimate biodegradation probabilities in water for the industrial chemicals and pesticides were predicted using the BIOWIN program from the Syracuse Research Corporation (SRC) EPI Suite of estimation programs-(http://www.epa.gov/opptintr/exposure/docs/episuite.htm). Chemicals and pesticides were classified by mode of toxic action based on the techniques described by Bradbury et al. (1989, 1990, 1991), McKim et al. (1987a,b,c) and Russom et al. (1997) for predicting acute toxicity to fish. Previously described methods were used to identify bioavailable industrial chemicals and pesticides (Dimitrov et al., 2002a,b; 2003).

Results

QSARs used to screen 2,697 industrial chemicals and pesticides identified 43 industrial chemicals and pesticides with acute aquatic toxicities < 1mg/L, bioconcentration factors > 5000, and potential to partition to and persist in sediment for greater than 340 days (Table 1). Of the 13 industrial chemicals and pesticides for which hydrolysis half-lives could be predicted, only one had a hydrolysis half-life < 30 days. Of the 39 industrial chemicals and pesticides for which Henry's Law Constants could be predicted, two had Henry's Law Constants > 10^{-2} atm m^3/mole (Table 1). Thirty-five of the industrial chemicals and pesticides had biodegradation probabilities > 1.75. Only 11 of the 43 industrial chemicals and pesticides had a narcotic mode of toxic action; most had an unexplained mode of toxic action (Table 1). Forty (40) of the 43 industrial chemicals and pesticides were likely to have at least one conformer that was bioavailable (Table 1).

Table 1. QSAR predictions for 43 industrial chemicals and pesticides

QSAR predictions	Number of industrial chemicals and pesticides
Partition to sediment	43
Persist in sediment	43
Bioconcentration factors > 5000	43
Aquatic organism LC50 < 1/mg/L	43
Hydrolysis half-life < 30 days	1
Henry's Law Constant > 10^{-2} atm m^3/mole	2
Biodegradation probabilities > 1.75	35
Narcosis mode of toxic action	11
Esters (narcosis or reactive electrophile)	9
Phenols/Anilines (polar narcosis)	4
Unexplained mode of toxic action	19
Bioavailable conformers $\geq$ 1	40

Discussion

Industrial chemicals and pesticides with half-lives in sediment of greater than 180-360 days, bioconcentration factors > 5000 and acute aquatic toxicities < 1mg/L have been internationally recognized as substances that could persist (P) in sediment, have potential to bioconcentrate (B) and be acutely toxic (T) to aquatic organisms (ACC, 1996; Environment Canada, 1995; IJC, 1993; NAFTA-CEC, 1997; UNECE-LRTAP, 1997).

Based on these internationally recognized criteria, the QSARs used to screen the 2,697 industrial chemicals and pesticides identified 43 industrial chemicals and pesticides that could be characterized as PBTs. However, these criteria do not take into consideration the potential for chemicals to hydrolyze or evaporate. Nor do they consider modes of toxic action and bioavailability. When QSARs were used to predict hydrolysis half-lives for the 43 industrial chemicals and pesticides, one was predicted to have a hydrolysis half-life < 30 days, suggesting that it would not persist in water unless it rapidly absorbed to and persisted on sediment particles. When QSARs were used to predict Henry's Law Constants for the 43 industrial chemicals and pesticides, two industrial chemicals and pesticides were predicted to have Henry's Law Constants > 10^{-2} atm m^3/mole, suggesting that these chemicals would evaporate from water, assuming that they did not rapidly absorb to and persist on sediment particles. Since QSARs predicted that all 43 industrial chemicals and pesticides partition to and persist in sediment, it is reasonable to suggest that these three chemicals and pesticides could rapidly absorb to and persist on sediment particles and be PBTs. This suggestion could be confirmed by predicting sediment organic carbon partition coefficients for these three chemicals and pesticides comparing the strength of the sediment organic carbon partition coefficient with the hydrolysis half life or Henry's Law Constant.

QSARs predicted that 35 industrial chemicals and pesticides had biodegradation probabilities > 1.75 (Table 1). These predictions were based on expert opinions that different structural groups could be used to estimate a chemical's biodegradation potential (Boethling et al., 1994). A biodegradation probability of 1.75 corresponds to a half-life of six months, which meets the international persistence criteria substances in water (ACC, 1996; Environment Canada, 1995; IJC, 1993; NAFTA-CEC, 1997; UNECE-LRTAP, 1997). Based on these criteria, the 35 industrial chemicals and pesticides with predicted biodegradation probabilities > 1.75 could be PBTs.

Modes of toxic action have only been adventitiously associated with PBTs, i.e., modes of toxic action may have been used to characterize certain chemicals without recognizing or acknowledging that the chemicals were PBTs. The terms mode of toxic action and mechanism of toxic action are often used interchangeably, but they mean something quite different. The mode of toxic action is a behavioral property associated with a type of biological effect, e.g., narcosis. In contrast, the mechanism of toxic action is related to the biochemical interaction, predominately covalent that underlies the biological effect. QSARs predicted that 11 of the 43 industrial chemicals and pesticides had a narcotic mode of toxic action, i.e., these chemicals caused toxic effects that could be reversed by removing the causative substance (Table 1). Similarly, four of the 43 industrial chemicals and pesticides were anilines or phenols and were polar narcotics. The predicted mode of toxic action for nine of the industrial chemicals and pesticides was for esters. Esters can have a narcosis or reactive electrophile mode of toxic action (Russom et al., 1997). Most of the chemicals had an unexplained mode of toxic action, emphasizing that assigning a toxic mode or mechanism of action to a specific chemical is often not straightforward and in some cases multiple and competing mechanisms may exist (Walker et al., 2003).

Bioavailability has only been recently used to differentiate PBTs because new molecular cross-sectional area and maximum molecular diameter criteria for defining bioavailability have only been available since 2002 (Dimitrov et al., 2002a,b; 2003). By applying these criteria to the confirmers of the 43 industrial chemicals and pesticides, it was determined that 40 of the 43 industrial chemicals and pesticides were likely to have at least one conformer that was bioavailable (Table 1).

Conclusions

The uses and limitations of QSARs to categorize substances as PBTs have been discussed (MacDonald et al., 2002). However, this is believed to be the first publication to describe the use of QSARs for identification of PBTs and characterization of the environments where PBTs are likely to be found.

QSARs used to screen 2697 industrial chemicals and pesticides identified 43 that satisfied international criteria for persistence (P) in sediment, bioconcentration (B) and acute aquatic toxicity (T). Assuming that the hydrolysis half-life of < 30 days for 1 chemical and Henry's Law Constant of > 10^{-2} atm m^3/mole for two chemicals are negligible compared to their sediment organic carbon partition coefficients, then the 43 industrial chemicals and pesticides could be PBTs. In water based on biodegradation probabilities, 35 of these industrial chemicals and pesticides were predicted to persist for six months, satisfying the international criteria for persistence (P) in water. Between 15 and 24 of the industrial chemicals and pesticides had a narcosis mode of toxic action, the effects of which could be reversed, assuming the exposed organisms were not exposed to a lethal concentration. Between 22 and 31 of the industrial chemicals and pesticides had a reactive electrophile or unexplained mode of toxic action that could be irreversible. Based on new criteria, at least one conformer of 40 of the industrial chemicals and pesticides should be bioavailable. In conclusion, QSARs that were used to screen 2697 industrial chemicals and pesticides identified 40 that could be PBTs and threaten aquatic organisms if released into the Great Lakes Ecosystem.

Recommendations

Short-term business plans should be developed for making resources available to use QSARs and other computational chemistry tools to predict the persistent (P), bioconcentration (B) and toxic (T) properties of emerging pollutants likely to be released into the Great Lakes Ecosystem. In addition, resources should be made available to conduct monitoring studies in the environmental compartments (water, sediment, soil, air, biota) where the emerging pollutants are likely to persist to quantify their concentrations and assess their threat to aquatic, benthic, terrestrial, avian and human populations in the Great Lakes Ecosystem because the return on investment is great and the risk-reward ratio is small.

Long-term business plans should be developed for making resources available to develop and validate QSARs to identify the persistent biodegradation products and stable reactive mammalian metabolites that are likely to be produced from the parent compounds released to the Great Lakes Ecosystem, so that monitoring resources can be more effectively used to quantify these products, and metabolites and remediation measures can be implemented to remove the parent compounds before they enter the Great Lakes Ecosystem.

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Back to the Future: Rediscovering the Requirement for Monitoring in the Great Lakes Water Quality Agreement

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New Effects as an Emerging Issue in the Great Lakes

From the 1950s through the 1970s unprecedented reproductive failures and population declines were observed in several species of fish-eating birds in the Great Lakes. Reproductive effects also were seen in salmonid fish and in ranch mink fed Great Lakes fish. The devastating effects in birds and mink were associated with persistent bioaccumulative contaminants. Concern over widespread toxic contamination in Great Lakes food chains contributed to the content and signing of the Great Lakes Water Quality Agreement (GLWQA) in 1972 and particularly the revisions in 1978. The identification and quantification of chemicals in environmental media and the development of new methods to subsequently document additional, more subtle effects, became an important activity for the Parties and the research community. Improved industrial practices and the introduction of regulations resulted in decreased releases and associated effects. Although concern generated by the endocrine disruption hypothesis (Colborn and Clement 1992) brought a burst of research and policy-related activity in the 1990s, less and less attention and resources have been directed by the Parties on toxic chemical issues in the Great Lakes. In a workshop held at Wingspread in 2003, discussions of "emerging issues" suggested that many current and emerging problems stem from lack of information. The needed information was formerly provided by research, early-warning, monitoring, and surveillance systems mandated in the GLWQA.

Is the term "new effect" an oxymoron? Both Webster's and Oxford Dictionaries suggest that an effect is a consequence of an antecedent (cause). Therefore for an effect to be new, it would have to be new in relation to that particular cause. In reality, as environmental scientists we come at the process in reverse. We find a 'new' (previously unknown, unidentified or undetected) abnormality and then try to associate it with a cause. Only then does it truly become an effect. This may lead to hypothesis generation, and with time we may prove in a controlled experiment that the 'effect' is indeed a result of that particular cause. At this point we move from association to causation. Some effects may be emergent properties of cumulative stress and therefore may not have a single or identifiable cause. Finding a new effect implies we have an 'early warning' system or monitoring program in place.

'Adverse' Effects and Responses of Concern

The presence of an effect suggests the exposure was biologically significant and that there is potential for further harm. In ecological risk assessment, an effect is defined as a "change in the state or dynamics of an organism or other ecological system resulting from exposure to a chemical or other stressor" (Suter, 1993). The GLWQA defines a 'toxic substance' as one that "can cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions or physical deformities in any organism or its offspring," thereby drawing attention to broad categories of effects of concern. The Agreement lists tumors, deformities, reproductive problems, degradation of populations and habitat, or restrictions on consumption as 'impaired beneficial uses' of fish and wildlife among those used to identify Areas of Concern. The International Joint Commission's Virtual Elimination Task Force concluded that virtual elimination of persistent toxic substances would be characterized by an absence of injury to living organisms and society. These 'injuries' (listed in Foran, 1993) span the whole spectrum of biochemical to demographic changes, from tumors to population declines. "Of particular concern are subtle, chronic effects of chemical exposures expressed at the level of the hormonal homeostatic systems." Such evidence of serious problems provided the catalyst for the development of, and the commitment to implement, a strategy of virtual elimination. For the wildlife or fisheries biologist, a response of concern is generally a functional impact that leads to a negative effect on one or more of reproduction, development, growth, survival, behavior or immune competence. In fact, adverse ecological effects from environmental pollutants occur at all levels of biological organization. They may be acute or chronic, temporary or permanent, local or global. The most serious of these effects influence the ability of species to adapt and respond to other stressors and community interactions, alter dynamics of communities, change ecosystem processes (energy flow, nutrient cycling) and components, or eliminate valuable species. These ecological losses in turn may be economically, aesthetically or socially important.

In the case of human health, the World Health Organization (1948) has defined health holistically as "a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity." In discussing reports of neuro-developmental, reproductive and possible immunological deficits in contaminant-exposed human populations in the Great Lakes, Johnson et al. (1998) noted that these deficits have been described as subtle, but could have profound implications for the population as a whole. "These are deficits that once incurred, unlike budget deficits, cannot be repaid." In keeping with the WHO's holistic definition, an 'adverse effect' could reduce an individual's quality of life. We know that such effects in humans have serious implications for the individual, family, the community and the health care system. Tremblay and Gilman (1995) observed that, "People's perceptions of their health and the effects on social structures and functions are as significant as clinically demonstrated disease conditions." No 'social safety net' exists in nature and similar effects in wildlife may adversely affect individuals without affecting their growth, survival or reproduction.

Although the term 'effect' is by definition neutral, the modifier 'adverse' is not; policy and regulation focus on 'adverse effects'. However, 'adverse' is rarely well-defined. There is no agreement on what constitutes an adverse ecological effect in general and decisions are made program by program and risk assessment by risk assessment (G. Sutter, pers com). They become contextualized without formalized criteria. In addition to scientific considerations, the definitions of 'adverse', 'injury', and 'significant' must incorporate societal and ethical considerations and therefore have political implications! Society must establish definitions or, at the very least, a framework within which to assess the significance of effects, to classify and quantify 'injury' and risk ('adverse' and 'acceptable risk'), and to determine whether biological recovery and virtual elimination have occurred. A forum is required for such discussions.

Successful environmental policies are dependent upon the recognition and integration of societal values. The public health approach to environmental solutions offers a valuable model for the integration of values, perceptions and ethics into environmental decision making. Ethical criteria provide a common vocabulary and framework of reasons for policymaking, cooperative action and conflict resolution from the perspective of what is right. Historically, health and environment were protected through public health strategies (generally proactive or precautionary) which were shaped by the level of scientific knowledge, technical feasibility, public support and acceptance of the interventions (see Burke 1996).

Monitoring

The Significance of Individual Health

We can search for new effects at any of the following levels of biological organization: macromolecules, organelles, cells, tissues, organs, organisms, populations and critical subpopulations, ecosystems and communities. In this biological continuum, processes at one level have their mechanistic origins in the preceding level and express their consequences in the next level. Therefore the health of the individual organism is central to the survival of the population and the detection of effects.

Many effects are detected in humans because the individual feels ill and seeks medical attention. The appropriate diagnostic tools (including biomarkers) are then applied at the organ, tissue and cellular or lower level. A diagnosis is made and the appropriate medical and social interventions are taken. In contrast, there is no self-reporting in the case of wildlife, and most grossly affected individuals (clinically diseased) are quickly eliminated from the population and the occurrence of disease less frequently detected. The less-affected individuals may survive but may be less successful in foraging, obtaining a mate or reproducing. Therefore, to detect sub-lethal effects in wildlife our focus must be on altered structure and function. Wildlife scientists employ (i) suites of biomarkers or biochemical markers that measure changes in cellular or subcellular processes within an individual's organs/tissues and (ii) biological endpoints which are measurable changes in the development, behavior, reproductive success or survival of the individual. Biomarkers respond quickly to contaminant exposure and thus constitute excellent early warning systems. They also aid in the demonstration of linkages between exposures and injuries. Optimally, these biomarkers would provide a direct linkage to, or be predictive of, a whole animal effect. The composition of the suite of biomarkers used is critical since it limits our 'field of vision' and determines the 'lens' through which we see, while their sensitivity and specificity provide 'resolving power.' Biological endpoints at the individual level that focus on measures that are crucial to the continuity of the population, such as growth, survival, reproduction and genetic diversity provide measures that can be incorporated into demographic models which can be used to predict population effects.

Today, it is possible to look at the macromolecular (gene) level, to determine how contaminants alter gene expression. Again the suite of genes examined determines the 'lens' through which we see. Genomics is in its infancy and we are just beginning to learn what up- or down-regulation of specific genes might mean in terms of an individual's function and health (Jelaso et al., 2002). However, genomics has revealed a remarkable similarity in the size of the core proteome in a wide variety of species and remarkable genomic homology. Advances in genomics and proteomics will greatly enhance our understanding of shared mechanisms of stressor-related adaptations and deleterious effects in humans and wildlife (Di Giulio and Benson, 2002).

Wildlife as Sentinels for Human Health Effects

Wildlife can serve as sentinels of human health effects (National Research Council 1991; Johnson et al., 1998, Fox, 2001; Winston et al., 2002). According to the Virtual Elimination Task Force (1993), "The adverse reproductive and developmental effects observed in wildlife may foreshadow human population effects." Are programs that look for effects in fish and wildlife adequate to protect human health from exposures to pollutants? Currently, the more subtle effects of concern such as neurotoxicological phenomena cannot be detected in wildlife, and new diagnostic tools are needed. To develop suitable diagnostic tools requires knowledge of the cellular mechanism of action and of the metabolism of the chemical, and the basic biology of the species, preferably at various life stages. Since investigators cannot communicate with their fish and wildlife subjects, most neurobehavioral, sensory and 'quality of life' effects go undetected. However, human experience has taught us that such effects are highly significant to individuals and may be disruptive to society.

On the other hand, medical practitioners have all the diagnostic tools they need to detect environmental health effects, but rarely think to consider environmental causes. In an effort to overcome this, the Faculty of Medicine and Dentistry of the University of Western Ontario has developed an Ecosystem Health Program to encourage students and faculty to "look outside the box" of traditional medical training and consider the bi-directional interactions between human actions and the environment. Students are taught to consider not just the health of the patient, but also the health of the community, the population and the biosphere by considering the medical, environmental, economic and socio-political factors that affect health. It is to be hoped that such programs become part of the curriculum of all medical schools, and that the parties will use this resource.

Regular monitoring for a wide array of chemicals in environmental media and tissues of biota using mass spectroscopy has frequently revealed the presence of new chemicals in the environment. Although this work is difficult and expensive, it provides the primary early warnings. Knowledge of the structure and identity of a new chemical in the environment can be a more informative signal than the detection of a new effect. The chemical's identity potentially provides the means to determine or predict properties, sources and environmental behavior, but less often its toxicity and mechanisms of action, which could provide guidance for selecting appropriate biomarkers of effect. These biomarkers then could be applied to fish and wildlife to determine whether there are detectable effects of these chemicals at environmental concentrations. In contrast, detection of a specific effect, such as estrogenicity, identifies a suite of potential causative chemicals, but we continue to find chemicals that have such action we would not have predicted or detected in routine toxicity screens. Recently concerns have been raised about the impact of pharmaceuticals and personal care products detected in the aquatic environment. What effects might result from exposure to fragrances, preservatives and disinfectants or their metabolites? On the other hand, pharmaceuticals have specific biological activities, but methods for detection of the effects of beta-blockers, antidepressants, antiepileptics and antineoplastics in free-living fish and wildlife are not obvious. Considerable laboratory experimentation will be required to identify biomarkers that respond to these classes of compounds at environmentally relevant concentrations that are practical for field assessments.

Effects Monitoring Programs: the Emperor's Missing Clothes

In 1972, the governments of the United States and Canada negotiated the GLWQA with provisions for the International Joint Commission (IJC) to assist in its implementation. In 1978, the Agreement was renegotiated and the Parties included a new policy that "the discharge of any and all persistent toxic substances be virtually eliminated." Therefore, appropriate indicators and monitoring efforts are necessary to track progress toward the virtual elimination goal of absence of injury to biota and to demonstrate ecosystem restoration and long-term protection and integrity. In the 1987 Protocol amending the 1978 GLWQA, the Parties are responsible for restoring and maintaining the chemical, physical, and biological integrity of the waters of the Great Lakes Basin ecosystem. In order to achieve this purpose, the Parties agreed to make a maximum effort to develop programs, practices and technology necessary for a better understanding of the Great Lakes Basin ecosystem. Included were recommendations and requirements for monitoring, research, surveillance and early warning systems (Tables 1a &b). Article VI states that, "The Parties, in cooperation with state and provincial governments, shall continue to develop and implement programs and other measures to fulfill the purpose of this Agreement…including implementation of a coordinated surveillance and monitoring program in the Great Lakes System."

Table 1a. Definitions and Requirements for Early-warning Systems and Monitoring Mandated in the GLWQA

Early-Warning Systems: "A procedure to anticipate future environmental contaminants (i.e., substances having an adverse effect on human health or the environment) and to set priorities for environmental research, monitoring and regulatory action."

An early warning system consisting of, but not restricted to, the following elements should be established to anticipate future toxic substance problems:

- toxicological research on chemicals and review of research conducted in other countries
- maintenance of a biological tissue and sediment bank to permit retroactive analysis to establish trends over time
- monitoring to characterize the presence and significance of chemical residues in the environment
- development and use of reproduction, physiological, and biochemical measures in wildlife, fish and humans as health effects indicators and establishment of a database for storage, retrieval and interpretation of the data

Monitoring: "A scientifically designed system of continuing standardized measurements and observations and the evaluation thereof."

Monitoring and research programs should be established at a level sufficient to identify:

- temporal and spatial trends in concentration of persistent toxic substances and other substances known to be present in biota and sediments
- the impact of persistent toxic substances on the health of humans and the quality and health of living aquatic systems
- the sources of input of persistent toxic substances
- the presence of previously unidentified persistent toxic substances
- the presence of previously unidentified persistent toxic substances
- ecosystem health indicators to assist in evaluating the achievement of specific objectives for the ecosystem pursuant to Annex 1

Table 1b. Definitions and Requirements for Research and Surveillance Mandated in the GLWQA

Research: "Development, interpretation and demonstration of advanced scientific knowledge for the resolution of issues."

Research should be intensified to determine the pathways, fate and effects of toxic substances with the aim of protection of human health, wildlife and fishery resources. In particular, research should be conducted to determine:

- the significance of effects of persistent toxic substances on human health and aquatic life
- interactive effects of residues of toxic substances on aquatic life, wildlife and human health
- cause-effect interrelations of productivity and ecotoxicity
- the relationship of contaminated sediments on ecosystem health
- pollution exchanges between AOCs and open lakes including cause-effect interrelationships among nutrients, productivity, sediments, pollutants, biota, and ecosystem health, and to develop in-situ chemical, physical and biological remedial options
- the aquatic effects of varying lake levels in relation to pollution sources, particularly respecting the conservation of wetlands and the fate and effects of pollutants
- the ecotoxicity and toxicity effects of pollutants in the development of water quality objectives
- the impact of water quality and the introduction on non-native species on fish and wildlife populations and habitats in order to develop feasible options for their recovery, restoration or enhancement
- action levels for contamination that incorporate multimedia exposures and interactive effects of chemicals as well as approaches to population based studies to determine the long-term, low-level effects of toxic substances on human health.

Surveillance: "Specific observations and measurements relative to controls and management."

Implementation of a coordinated surveillance and monitoring program to evaluate trends and assess compliance with pollution control requirements and achievement of objectives, to provide information for measuring local and whole lake responses to control measures, and to identify emerging problems. It will assess both nearshore areas and open waters, and concentrations in fish and wildlife.

Since the 1960s there has been a very large amount of research on effects in several species conducted by a relatively small cadre of government and academic scientists. In 1996, the IJC's Great Lakes Science Advisory Board hosted a Workshop on Environmental Results to evaluate progress made in reducing or eliminating the effects of persistent toxic effects in wildlife and humans. Based on the 19 papers presented, the organizers concluded, "While there are adequate long-term monitoring projects to document gross trends in the concentrations of organochlorine pollutants in the Great Lakes environment, there is no formal existing program in either country for gathering long-term evidence for determining trends in the incidence of the effects of persistent toxic substances on organisms." Past research and research-based monitoring provides ample justification for, and tools with which to build, such programs. However, in 2003 there is currently no ongoing, long-term effects monitoring program for wildlife in the Great Lakes Basin.

The bald eagle (Haliaeetus leucocephalus) was the first avian species to show the effects of persistent bioaccumulative chemicals in the Great Lakes Basin (Grasman et al., 1998). Eagle populations have been determined using aerial surveys throughout the Great Lakes basin since the early 1960s (Bowerman et al., 2002). Based on its basin-wide distribution, year-round residency in the basin, terminal trophic position and obvious sensitivity to contaminants, the bald eagle has been proposed by the IJC as the primary avian species to serve as a biosentinel of Great Lakes water quality (IJC, 1991). In 1999, the Surface Water Quality Division of the Michigan Department of Environmental Quality (DEQ) initiated a long-term wildlife monitoring program to monitor the spatial and temporal trends in environmentally persistent and toxic contaminants using the bald eagle. Productivity is monitored and blood and feathers are collected from nestlings (Bowerman et al. 2002). Similar monitoring also is being done in Wisconsin, New York, Minnesota, and Ontario.

In Canada, a long-term contaminant trends program has been built around Great Lakes herring gulls (Larus argentatus) (Mineau et al., 1984). Eggs have been collected each year since 1974 from 13 colonies representing all five Great Lakes and two connecting channels, including three colonies in U.S. waters. In 2002, Michigan DEQ joined the program by adding 10 additional collection sites in Michigan waters and funding the analysis of the eggs, to make this a truly basin-wide program. The herring gull program has been very successful for monitoring temporal trends and identifying new contaminants in the food chain (Pekarik & Weseloh, 1998; Hebert et al., 1999). Egg homogenates are archived in the tissue bank at the National Wildlife Research Centre in Ottawa for use in retrospective studies. In parallel, since the 1970s, there has been a variety of research and research-based monitoring for effects in this species (Fox et al., 1998; Hebert et al., 1999). More recently, contaminant trends in eggs and effects in hatchlings have been measured in common snapping turtles (Chelydra serpentina) from Ontario (Bishop & Gendron, 1998) as a reflection of more localized levels of contamination.

In 2001, the Fish and Wildlife Health Effects and Exposure Study was initiated by Environment Canada in Canadian Areas of Concern to determine if there are health effects in fish and wildlife that are associated with contaminants in the aquatic environment. The current focus is on the AOCs in Lakes Erie and Ontario and connecting channels (i.e., St. Clair River to Cornwall). In this study, both the herring gull and snapping turtle are being used, and the focus is measures of reproductive health, endocrine and immune function, and a suite of biochemical assays to detect abnormalities in organ function. Results to date clearly show the value of, and need for, ongoing health effects monitoring in the AOCs and other contaminated areas of the Great Lakes basin and are helping to build a workable model.

There are three obvious possibilities to overcome the current lack of a wildlife effects monitoring program in the U.S. waters; (i) U.S. funding of parallel sampling to that being conducted in Canadian AOCs, particularly for those herring gull colonies where there is historical data (lower Green Bay, northern Lake Michigan and Saginaw Bay), (ii) development of a protocol incorporating a suite of sensitive effects biomarkers which could be applied basin-wide to monitor effects in nestling bald eagles and (iii) introducing the Biomonitoring of Environmental Status and Trends (BEST) Program into the Great Lakes basin.

The Michigan DEQ's initiation of a long-term program to monitor the spatial and temporal trends in environmentally persistent and toxic contaminants in bald eagles institutionalizes what has been to this point a research-based monitoring program. Although the majority of Great Lakes bald eagles nest on Michigan's shorelines, similar monitoring also is being done in Wisconsin, New York, Minnesota and Ontario, providing the basis for a basin-wide program. According to the Michigan DEQ's proposal, plasma and breast feathers will be collected from nestling bald eagles and will be analyzed for organochlorine compounds, metals and associated biomarkers to assess spatial and temporal trends in the levels of these contaminants and to evaluate potential adverse effects. There is, therefore, potential to develop a protocol incorporating a suite of sensitive effects biomarkers validated in nestling bald eagles which could be applied basin-wide.

The BEST program is a monitoring and assessment program of the Biological Resource Division of the U.S. Geological Survey. Its goals are to measure and assess the effects of contaminants on selected species and habitats throughout the United States and to conduct research and synthesis activities directed at providing innovative biomonitoring methods and tools for operational applications. Contaminant effects are measured by evaluating biochemical, physiological, morphological and histopathological responses in monitoring species. During its conception in the late 1980s and early 1990s, considerable thought was given to selecting monitoring species and effects measures that would be applicable in the Great Lakes setting. The Black-Crowned Night Heron (Nycticorax nycticorax) was chosen as an estuarine and freshwater sentinel species. To date, the focus has been on assessments of fish health in large river basins and coastal environments.

There are a number of ongoing programs which identify and quantify contaminants in fish tissues. The Great Lakes Fish Contaminants Surveillance Program was initiated by Fisheries and Oceans Canada (DFO) in 1977 as an annual, basin-wide long-term monitoring program in response to the requirements of the GLWQA. It provides data on burdens of a suite of toxic chemicals in top predators (lake trout and walleye where appropriate), prey fish (smelt, sculpin and alewife) and invertebrates (Mysis and Diporeia) to detect spatial and temporal trends and shifts in contaminant dynamics and pathways for various Great Lakes food webs. A similar program was initiated by the U.S. EPA Great Lakes National Program Office (GLNPO) for U.S. waters. However, they no longer monitor residues in the forage base.

DFO, GLNPO, the nine Great Lakes states, Ontario and tribal governments all monitor contaminant concentrations in edible portions of sportfish to set local fish consumption advisories. The Ontario Ministry of Environment has monitored contaminant levels in young-of-the-year spottail shiners (Notropis hudsonius) from 30-40 locations in the basin for over 25 years. In contrast to the widespread and extensive monitoring of contaminants in fish tissues, this author is not aware of any formal, long-term ongoing effects-monitoring program for fish in the basin. There have been recent assessments in the tributaries to Lake Erie, some of which applied the BEST effects procedures. There is an intention to move the BEST program into the Great Lakes where they would conduct assessments on fish in the major tributaries.

In 1990, Congress amended the Great Lakes Critical Programs Act, mandating the EPA, in consultation with the Agency for Toxic Substances and Disease Registry (ATSDR), to assess the harmful human health effects of water pollutants in the Great Lakes basin. ATSDR developed the Great Lakes Health Research Strategy to investigate and characterize the association between consumption of contaminated Great Lakes fish and short- and long-term harmful health effects. This program was funded for five years. Similarly, Health Canada established the Great Lakes Health Effects program in 1989 in response to health issues addressed in the 1987 protocol of the GLWQA. The program's objective was "to protect human health in the Great Lakes basin from the effects of exposure to environmental contaminants" (Tremblay and Gilman, 1995). This program ran from 1989 to 1997. Common activities of these programs were: (i) epidemiological research that identified high-risk populations and investigated the impact of the Great Lakes environment on their health, (ii) improvement of analytical methodology, development of sampling strategies and analysis of contaminant levels in human tissues and fluids, food and environmental media, (iii) characterization of human exposure to environmental contaminants and (iv) toxicological research that focused on the effects of persistent chemicals and identified sensitive human health endpoints.

The final act of Health Canada's Great Lakes Health Effects Program was the release in November 1998, of a series of 17 reports tabulating health data and statistics on morbidity and mortality for each of the Canadian AOCs for the period 1986-1992, relative to the province of Ontario as a whole. ATSDR is currently conducting public health assessments on hazardous waste sites within the 26 AOCs in U.S. waters. Other than these studies, the Parties are not currently monitoring health effects in the human residents of the Great Lakes basin or analyzing routine health statistics (where they are available) for potential environmental associations.

The research and research-based effects monitoring of fish and wildlife that were common in the 1970s to early 1990s lasted as long as the investigators were funded and their research positions survived. These were, at best, assessments only some of which were repeated. Similarly, the U.S. and Canadian Health Effects Programs produced assessments that may or may not be repeated. Environment Canada's current Fish and Wildlife Health Effects and Exposure Study consists of health assessments in the various AOCs. The USGS BEST Program also conducts assessments. In today's fiscal and political reality, such assessments may be the best we can do. If the same protocols are followed and the assessments are repeated periodically, they become monitoring.

What Could the Parties Do with Knowledge of Effects, Especially New Effects?

The Krever Commission (1997) recommended that action to reduce risk not await scientific certainty. According to Justice Krever, the Parties, as regulators: (i) must not accept the lack of resources as a reason not to perform their functions adequately, (ii) must not delegate essential functions to others nor rely on consensus decision making as a substitute for independent judgment, (iii) should not rely solely on or defer to manufacturer's information, expertise and judgment but seek their own confirmation and (iv) must not assume a passive or responsive role or rely on voluntary compliance. Harremoes et al. (2001) list similar precautions among the lessons learned from a recent analysis of 14 case studies of well-known hazards to workers, the public and environment where sufficient knowledge is now known about their impacts to enable conclusions to be drawn about how they were dealt with by governments and civil society. According to Harremoes et al. (2001), "General research and long-term monitoring can be dismissed as being too expensive and unfocussed. Yet well-planned research and monitoring are essential to the systematic identification of areas of uncertainty. It is, however, necessary to consider how to conduct general monitoring to increase the prospect of timely alerts to problems arising out of ignorance. Awareness of uncertainty and ignorance helps the posing of appropriate research questions for scientific evaluation. It follows that the adequate funding of research and monitoring intended to pick up early warnings is central to a robust approach to regulatory appraisal of potential hazards."

Currently, society is confronted with potential public health issues that must be addressed despite uncertainty. By using the weight-of-evidence approach we could overcome this challenge and move the science to public health practice. Early-warning systems, monitoring, surveillance and research are required to provide that evidence. The Parties must show leadership, vision and, above all, make long-term commitments of resources if we are going to adequately detect new effects and act to protect the health of people, wildlife and fish in the Great Lakes basin.

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Changing Ecology of the Great Lakes

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Introduction

The primary purpose of this paper is to review the changes in the ecology of the Great Lakes and to make some educated guesses about future changes. A secondary purpose is to explore possible management actions that will help avoid the most undesirable changes or to improve planning for the unavoidable. In undertaking this task, certain biases are acknowledged. First, predictions about future changes in Great Lakes ecosystems is difficult, if not impossible. The Great Lakes are complex systems, and our perceptions about stress and response characteristics of the ecosystems are fragmentary and heavily weighted to periods of degradation. Because the management framework for dealing with this degradation is also fragmented among various jurisdictions, it is not surprising that the lack of coordinated management has resulted in highly unstable and unpredictable systems, especially in the lower Great Lakes. Attempting to make predictions about future changes is further hampered by the fact that we are making these predictions as the Great Lakes recover from the impairments of physical, chemical and biological integrity.

Second, is a point of view that the central problems for future management are meeting the challenge of managing recovery transients and excessive reliance on simple cause-effect reasoning to understand change. Like any complex system, we should expect the Great Lakes to show hysteresis, but much of the understanding and data we need for prediction comes from periods of degradation and not recovery. Since the 1980s, we have been battling a loss of control of Great Lakes ecosystems and, especially since the 1990s, dealing with one major surprise development after another. A main feature of these surprises has been the spectacular population expansions of non-indigenous species. Zebra mussels, for example, entered Lake Erie at the time of an amazing resurgence of a walleye fishery. The subsequent decline of walleye and other Lake Erie fish species was quickly associated with the zebra mussel expansion, and zebra mussels have been a speculative cause of the decline of *Diporeia* throughout the Great Lakes despite repeated failures to find expected experimental consequences. This list goes on and on. Whole research programs are launched to track phantom *Microsystis* blooms in Lake Erie, unexplained fish kills cry out for simple explanations and, more recently, we are seeing an epidemic of botulism in fish and wildlife.

The approach to address these and other changes draws on four basic ideas:

1. The Great Lakes are large, adaptive, complex systems. Causal networks and scaling hierarchies thus limit identification of simple cause-effect linkages needed for prediction.
2. Spatial and temporal patterns of disturbances interact with self-regulation in complex ways. Prediction thus meets the problem of stochasticity.
3. Patterns of human use of the Great Lakes and their watersheds have disrupted historical regulatory hierarchies replacing them with a less-structured regulatory framework, which although adaptive is less robust. Thus lessons of the past may have less explanatory value.
4. The consequence of human use of the Great Lakes is unstable biotic communities with a steady stream of unexpected occurrences. We should thus "expect the unexpected."

The following review comprises some of the major changes in the ecology of the Great Lakes, presents a framework for understanding these changes that emerges from complexity theory, and concludes with some practical suggestions about the use of this framework to avoid the worst of possible future scenarios.

Review Changes and Stressors

The literature on changes in Great Lakes ecosystems is exhaustive. The biennial State of the Lakes Ecosystem Conferences (SOLEC) conducted by Environment Canada and the U.S. Environmental Protection Agency provide readily accessible summaries. In a keynote presentation at SOLEC 2002, Ciborowski (2002) presented an overview of the state of the Great Lakes ecosystem. In it, he noted improvements and new or continuing problems. Five of the continuing problems concerned the health of the food web in the Great Lakes: 1) the *Diporeia* decline in Lakes Michigan and Ontario 2) the Zebra mussel invasion 3) outbreaks of botulism in fish and wildlife 4) declining prey fish biomass and 5) the spread of exotic fish species (Ruffe, gobies). These recent changes are part of a longer-term record of changes that include invasion of sea lamprey, establishment of more than 140 other non-indigenous species, loss of native species, contraction of age and size structure of the fish community with particular reference to the loss of large mobile organisms, and fragmentation and loss of habitat in Great Lakes watersheds.

Meyers (2002), in reviewing the major stressors associated with the changes for SOLEC 2002, raised concern with four categories of stressors:

- Non-Native Species Native Species
- Toxic Contaminants
- Excessive Nutrients
- Physical Processes
    - Shoreline hardening
    - Water level fluctuations
    - Climate Change

The stressors related to physical processes were a major concern in SOLEC 2002 presentations with fragmentation of habitat, urban sprawl, wetland losses and the overwhelming loss of lake accessible reaches of Great Lakes tributaries all receiving emphasis. This list is similar in scope to that developed in the first SOLEC paper in 1994 dealing with aquatic community health (Koonce 1995):

- large-scale degradation of tributary and nearshore habitat for fish and wildlife
- imbalances in aquatic communities due to population explosions of invading species such as sea lamprey, alewife, white perch, and zebra and quagga mussels
- reproductive failure of lake trout
- alterations of fish communities and loss of biodiversity associated with over-fishing and fish stocking practices
- impacts of persistent toxic chemicals on fish and wildlife

Context for Understanding Changes

Understanding changes in the ecology of the Great Lakes is necessary to derive expectations about future changes and to devise management actions to minimize ecological risks. Linking stressors to ecosystem response, however, is not easy. Unlike the period of earlier degradation of Great Lakes ecosystems, simple cause-effect relationships have given way to more complex causal networks with disturbances and community structures changing over many domains of scale. Since the negotiation of the Great Lakes Water Quality Agreement, systems modeling has been an important tool in bridging the gap between understanding change and its management. These tools continue to provide insight, but not the sorts of predictions required for many management activities. Recent developments in complexity theory offer an emerging framework for better integration of understanding Great Lakes ecosystems and the management of their natural resources.

Large ecosystems, such as the Great Lakes, develop regulatory hierarchies that span many domains of scale. Holling (1995) called attention to an important feature of space-time scaling in ecosystems in a comparison of the scaling of ecosystem components with various disturbance events. His analysis showed that the spatial and temporal extent of biological elements increase with its size following a diagonal path in a space-time continuum. He also argued that disturbance regimes also will organize along a diagonal path. This scheme draws on the reality of space-time scaling in ecosystems. Body size of an organism is a strong predictor of both the extent and grain of its interactions in an ecosystem. Large, mobile organisms with long life spans (such as lake sturgeon) do not respond directly to population fluctuations of phytoplankton species. Their intrinsic rates of increase are different by orders of magnitude, and the response of large organisms to high-frequency variation is limited both functionally and numerically (Holling 1959).

Many other ecologists have noted the importance of hierarchical organization of ecosystems (Allen and Starr, 1982) and the role scaling plays in ecological complexity (Levin, 1992). One of the appeals of this approach for systems modeling is that it potentially provides a basis for aggregating state variables and processes in a computationally efficient manner to explain pattern. Explicit modeling of spatial pattern and dynamics of ecological systems has proven difficult for both conceptual and computational reasons (Hartway et al., 1998). Because ecological systems are nested hierarchical systems, however, implied system modularity provides a way of simplifying the complexity of an ecosystem sufficiently to understand it. Using a spatially explicit, hierarchical approach, Wu and David (2002) proposed a modeling framework for understanding pattern and process in heterogeneous landscapes. Their methodology is instructive and involves a three-step process: 1) identification of appropriate patch structure of a landscape, 2) making observations and developing models at focal levels and 3) extrapolating information across domains of scale hierarchically. The tricky part of this methodology is identifying the domains of scale. Theoretically, a scale domain is a set of patterns and processes that operate in the same domain of scale in space and time. The idea that these domains are arranged in a nested hierarchy results in the filtering of high-frequency influences from domains at finer scales with constraints imposed by higher levels in the hierarchy.

In Great Lakes research, biomass spectrum analysis has emerged as an approach to identifying nested hierarchies in aquatic food chains. Biomass spectrum analysis relies on trophic cascades to explore effects of scale on the structure and function of pelagic ecosystems (Kerr and Dickie, 2001). In their analysis of the biomass spectra of Lake Michigan and Lake Ontario, Sprules and Goyke (1994) found evidence for existence of nested hierarchies of body size of pelagic organisms. Combining theory and observations, Kerr and Dickie (2001) contend that the biomass body-size spectrum provides a way of exploring effects of various perturbations on the characteristic shape and structure of these spectra. Natural breaks in the biomass spectra, therefore, provide a glimpse of the scaling domains that derive from trophic interactions among species and suggest that phytoplankton, zooplankton and fish are members of a functional hierarchy in aquatic ecosystems. From a modeling perspective, the pattern and processes at the phytoplankton level are naturally filtered when the hierarchy is functioning normally, and it may not be necessary to include detailed spatial and temporal dynamics of phytoplankton in models focused fish populations.

Over the past 30 years, various modeling approaches have been applied to Great Lakes ecosystems. These include the early water quality models (Ditoro & Connolly, 1980) as well as more recent attempts to develop whole lake models for Lake Erie (Koonce et al., 1999; Locci & Koonce, 1999). Issues of adequacy of model scope and resolution were of concern for these modeling initiatives and have been addressed in various modeling workshops (Tulen & Depinto, 2000). Viewing these kinds of models in the context of space-time hierarchies is instructive (Figure 1). Early water quality modeling efforts focused more on dynamics with fine grained representation of time, but coarse grained representation of space. The Lake Erie Ecological Model (Koonce et al., 1999), in contrast, is coarser grained in both time and space. LEEM is a focal level model in the sense of Wu and David (2002). It relies on hierarchical filtering of lower trophic level processes and pattern to omit detail of lower trophic level dynamics in the model and depends upon higher-level landscape influences (nutrient loading, coastal and tributary habitat limitations, and contaminant loading) to set constraints on lake-wide dynamics of fish populations. LEEM proved to be an especially useful tool with which to evaluate various hypotheses for the changes in the Lake Erie fish community.

Figure 2 summarizes trends of yellow perch and walleye over the period 1960 to 2000. The trends are virtual population reconstructions from harvest data collected by Lake Erie fishery management agencies. An important feature of this trend was the decline of both yellow perch and walleye after 1990. This decline also occurred in other species and led to the hypothesis that these systematic declines in fish abundance were associated with the declining loads of phosphorus and the invasion of zebra mussels. Analysis of these various hypotheses with LEEM (Koonce & Locci, 2000; Koonce et al., 1999; Locci & Koonce, 1999) revealed

Figure 1. Characteristic domains of various models in a space-time continuum. Models contrasted include the Lake Erie water quality model of DiToro and Connolly, Lake Erie Ecological Model (LEEM), and individual based models (IBM). Dotted lines represent scale domains of models and the black bar represents the scale of the Lake Erie fish community.

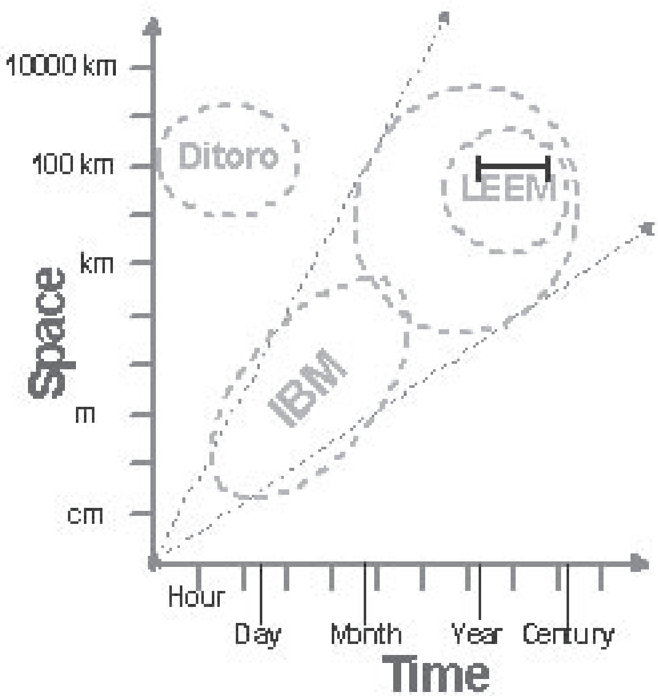
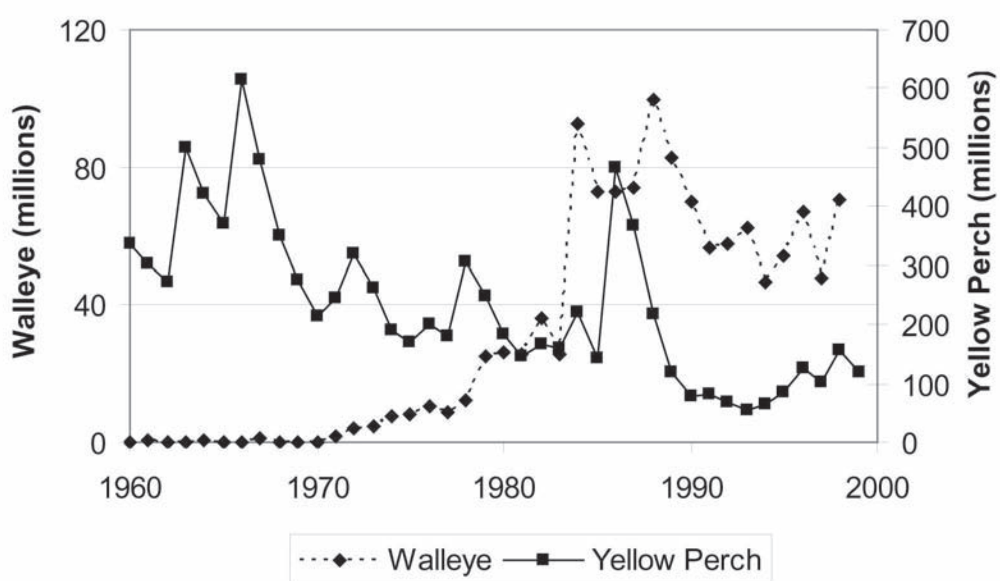


Figure 2. Changes in abundance of walleye and yellow perch over the period 1960 to 2000. Data provided by Lake Erie Committee.

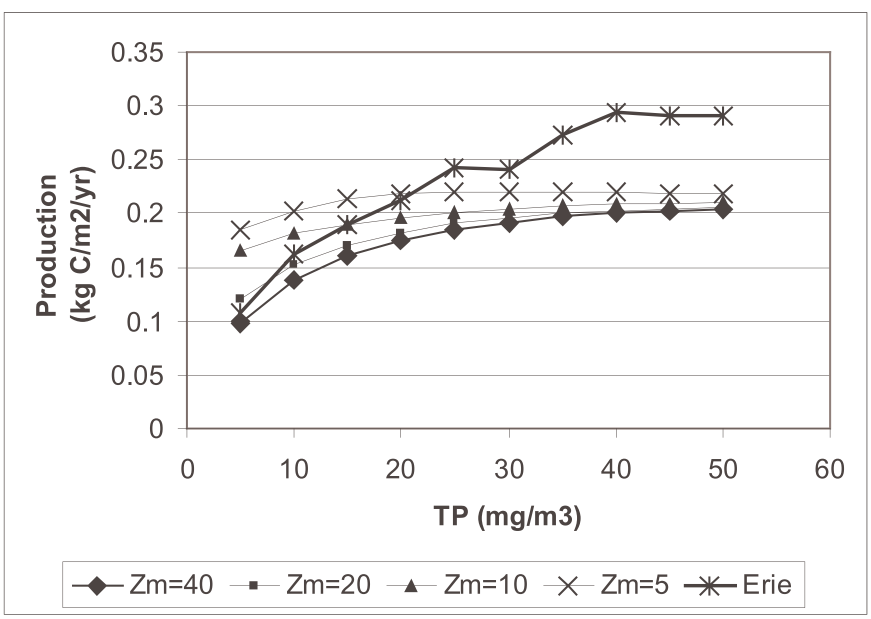


that the more likely mechanism was a predator-prey oscillation that was induced by the increases in walleye abundance over the period of 1970 to 1988. A clear implication of this result is that changes in fishery management practices can persist for long periods of time, and that these time courses interact with other patterns of variation in complex ways not all of which are simple cause effect linkages.

Does this apparent utility of a focal model like LEEM imply that Lake Erie's fish community is a scale domain? If the answer is yes, pattern and process in the fish community could be a useful indicator of the overall state of the ecosystem and could be the crystal ball in which we gaze to determine future changes in the Lake Erie ecosystem. The answer would be no if we could show that lower trophic level influences are not merely filtered but are involved in complex feedback relationships. Alternatively, failure to respond to constraints imposed at higher levels of scale also would imply that the fish community is not a scale domain. Full evaluation of these possibilities is beyond the scope of this paper, but there is evidence to suggest that lower trophic level influences are filtered and that the fish community is responsive to constraints at a landscape level of scale.

Recent analysis of system primary production in aquatic ecosystems indicates that trophic level feedbacks on primary production may affect allocation of production into pelagic and benthic components more than on overall levels of productivity. An unexpected insensitivity of system level primary production of a lake to variation of nutrient loading (Figure 3) has been reported by the author (Koonce, MS in review). This result was derived from a simple model that allocated primary production between benthic and pelagic components as a function of competition for light. The result was consistent with experimental results from systems of different trophic status (Vadeboncoeur et al., 2001; Vadeboncoeur et al., 2002). Figure 3 shows the effects of the shape and size of the lake basin on the response of a lake to a

Figure 3. Variation of system primary productivity with nutrient loading and lake morphology. The first four are for lakes with the same area but different depth, and the Lake Erie data represent the effects of Lake Erie bathymetry. System primary productivity is the sum of pelagic and benthic primary production.



range of nutrient loading levels. For comparison, Lake Erie's morphology is also included. In all cases, pelagic primary production increased as a function of nutrient loading as expected (Dillon & Rigler, 1974; Smith, 1979). Total system production, however, reflected the allocation of primary production into pelagic and benthic locations. Variation in nutrient loading, therefore, may shift overall primary production less than it shifts spatial allocation of production. Given the well-documented importance of centers of production in aquatic ecosystems (Junk et al., 1989), it thus seems clear that landscape features help shape centers of production and that fish communities adapt to the spatial patchiness of these centers throughout their life cycles.

What do changes in the fish communities of the Great Lakes tell us about stressors and future trajectories? The main characteristic of change in Great Lakes fish communities over the past 200 years has been the loss of native species and their replacement by non-indigenous species. Exploitation and habitat alterations have been the two most important stressors causing these changes (Koonce et al., 1996). Regier and Hartman (Regier and Hartman, 1973) referred to this phenomenon as 150 years of cultural stress. The result of this fishing-up process has been the elimination of large, long-lived species and the systematic decrease in the average body size of species. As Sprules and Goyke (1994) observed, the biomass spectrum of Lakes Michigan and Ontario shows a deficit of biomass in the upper end of the size spectrum implying an impairment of ecosystem function. Accompanying changes in fishing methods and intensity, the Great Lakes also experienced substantial decline in the quality and quantity of fish habitat (Dodge & Kavestsky, 1994). Although not traditionally thought of as habitat *per se*, eutrophication also represents habitat change through the changes in land use and land cover of the drainage basin. The cumulative effect of these habitat changes has been the systematic isolation of the lakes from their drainage basin and a shift in the relative importance of pelagic production sources over benthic and coastal wetlands. The consequence of these changes for the fish community has been catastrophic. Fisheries exploitation has led to the elimination of large fish species, which tended to integrate production sources and stabilize fish community structure, diminished critical nearshore habitat for native species and provided opportunity for the expansion of non-native, opportunistic fish species. The result is the reduction in the regulatory constraint of an important scale domain. Similarly, fragmentation of the landscape has altered the slow dynamics of terrestrial systems leading to increasing dominance of high-frequency variability. The result is potentially chaotic and most certainly less predictable fish community with a subsequent breakdown in the regulatory hierarchy of Great Lakes ecosystems.

Practical Implications

If changes in the patterns and processes of scale in the fish communities of the Great Lakes are informative, the next 10 to 20 years of changes in Great Lakes ecosystems should continue to be unpredictable with a seemingly endless series of new problems appearing every few years. One reason for this behavior is a fundamental breakdown in the hierarchical scaling of these large ecosystems. The overall effect of decreasing the body-size and age structure of fish species coupled with the fragmentation of the drainage basin landscape is the erosion of the boundaries of high-level scale domains and loss of their regulatory constraints to the entire ecosystem. Even if recovery of this regulatory structure were possible, it will require a very long time to accomplish. After over 30 years of lake trout rehabilitation, for example, there is only minimal natural reproduction of reestablished populations in Lakes Huron, Michigan, and Ontario. To be sure, there are many other examples of successes in restoration. Lake Sturgeon populations now seem to be increasing, excess nutrient loadings are declining and contaminant burdens seem to be declining. Although the behavior of biological systems to these recovery transients may be unpredictable given the diminished regulatory hierarchy, there do appear to be some management strategies that may reduce the instabilities. Two examples worth considering are ecosystem-based fishery management and emphasis on protection and restoration of centers of biological organization in the ecosystems.

Ecosystem-based fishery management is not a new concept, but it derives new impetus from both the Canadian Fisheries Act and the U.S. Magnuson-Stevens Sustainable Fisheries Act. In Canada, the Federal Fisheries Act has resulted in the implementation of a policy for the management of fish habitat in the Great Lakes. Although no comparable direct policy exists in the U.S., the Magnuson-Stevens Sustainable Fisheries Act has required the National Oceanographic and Atmospheric Administration to develop plans for preservation of essential fish habitat as part of the effort to develop fish management plans. Within the Great Lakes region, the U.S. federal government, the Great Lakes states, The federal government of Canada, and the province of Ontario have entered into a Joint Strategic Management Plan for Great Lakes Fisheries (Dochoda & Koonce, 1994). This planning process requires the formulation of fish community objectives for each of the Great Lakes and the identification of ecosystem and environmental objectives necessary to achieve them. Recognizing that fishing is an inherently valued use of natural resources, the challenge of ecosystem based fishery management is to minimize the unintended damage that fisheries may cause in ecosystems. The four following ideas will need to guide the transition to ecosystem-based fishery management in the Great Lakes:

- Fish community structure is a dominant influence on unexpected changes in the Lake Erie ecosystem
- Single species management has not worked in the Great Lakes
- Heuristic rules focusing on stabilization of fish community offer promise that predictive modeling of fishery performance lacks
- Heuristic approaches fit well with more general tools for risk assessment under uncertainty.

To implement heuristic approaches to ecosystem-based fishery management will require moving away from the optimization framework of traditional fishery management. Certainly quantitative analysis will continue to play an important role in fishery management, but heuristic rules will be needed to guide management policy. For example, a clear heuristic implication of LEEM analyses of Lake Erie fish management is that prey and predator species cannot be managed independently and that some combinations of single-species policies are not sustainable. Policies that seek to maintain high predator biomass to provide high-valued recreational fishing opportunities are not compatible with high levels of prey exploitation. Yet this may be the characteristic of the fisheries that leads to the observations of declining prey populations in all the Great Lakes (Ciborowski, 2002). More important, heuristic rules will turn the focus of fisheries management from harvest levels to effects of harvest on fish community structure. Increasing prey to predator biomass ratios, for example, lead to increasing probability of long-term predator-prey instability (Locci & Koonce, 1999).

The other management strategy to consider for restoring the regulatory hierarchy of Great Lakes ecosystems is to think about human impacts on the Great Lakes ecosystems in a landscape context. Since SOLEC 96, there has been increasing emphasis on the need to identify, protect and restore Biodiversity Investment Areas (Morrisson et al., 2001). This emphasis stems from a growing awareness that watersheds are fundamental landscape units that require integrated management for restoration and protection of the physical, chemical and biological integrity of Great Lakes ecosystems. Watersheds function as centers of biological organization on a regional scale, and landscape features of watersheds directly affect the regional and whole-lake productivity. From a systems perspective, tributaries, flood plain, wetlands and estuaries of watersheds are interrelated with nutrient flux and animal migration serving as important linking processes and with the physical environment providing important constraints on biodiversity. In any one of the Great Lakes, these areas exist as a network of habitat types that potentially restrict biological diversity and productivity of the entire ecosystem. The extent to which these spatially distributed areas entrain the biodiversity and productivity of a whole lake is the fundamental question that links watershed and coastal zone planning with management concerns for Great Lakes fish populations.

To promote strategic planning in the Biodiversity Investment Area (BIA) context requires the development of criteria to identify and demarcate areas in a way that will lead to prioritization of habitat restoration initiatives and improve the efficiency of restoration of the chemical, physical and biological integrity of Great Lakes ecosystems. Recent work by Minns and his colleagues (Minns & Bakelaar, 1999; Morrisson et al., 2001) indicates that habitat supply inventory and habitat supply analysis are practical ways for regionalizing BIAs. Using the concept of watersheds as centers of organization provides a way to identify specific areas that are productive and support high biodiversity. The areas identified then could be ranked according to their contribution to the integrity of Great Lakes ecosystems either by virtue of relative scarcity on a regional basis or by their quantitative impact on fish and wildlife populations.

From a landscape perspective, however, the Great Lakes ecosystems, particularly the lower Great Lakes, are highly disturbed. The list of problems on the landscape is impressive. Most of the coastal wetlands have been destroyed, farms have replaced forests and cities grow into former farm land. The natural flow regime of watersheds is thus greatly altered, and urban sprawl and its associated land use and land cover changes produce a landscape with less and less natural soil and vegetation coverage. The result is the conversion of the flow regimes of the major tributaries in the lower Great Lakes to storm water runoff conduits. So recognizing and protecting watersheds is not necessarily going to restore the functional integrity of this watershed without restoring their natural flow regimes.

In conclusion, the Great Lakes system is unstable, particularly in the lower lakes; and because it is unstable, we have little predictive capability. The changes that we are seeing largely come from disruption of regulatory mechanisms at the upper-scale domains of the ecosystem: the fisheries and the landscape. To deal with these stressors, we will need new management strategies. Certainly, ecosystem-based fisheries management will be a vital part of emerging strategies, but we also must understand the landscape constraints to protect and restore critical areas. Ken Greenberg (reference to these proceedings) has argued that images will be important to convince the public of the need and effectiveness of future strategies. In a similar vein, the SOLEC process has attempted to define a set of indicators to map progress toward the restoration of the physical, chemical and biological integrity of the Great Lakes ecosystems (Bertram & Stadler-Salt, 1999). But indicators are not images. A candidate for an image is the lake sturgeon. In part, the regulatory hierarchy of the Great Lakes is disrupted by the lack of large, long-lived fish species like the lake sturgeon. It is a large animal, and large animals are missing from the Great Lakes. It is interesting that the Great Lakes Fishery Trust selected this animal as its symbol. Restoration of lake sturgeon populations requires integration of both landscape and fishery management, and the restoration goal provides the public with a glimpse of the spatial and temporal scales of restoration required. Lake sturgeon are intrinsically interesting animals, and the public would have a tangible indicator of improvements in the ecosystem. The Great Lakes may remain unpredictable for the foreseeable future, but the extent to which sturgeon recovers is going to tell us a lot about the extent to which we've gotten ahead of the curve.

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Response to Koonce: Managing Great Lakes under Environmental Uncertainty

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Joseph Koonce (this volume) has provided an overview of the difficulties of managing large ecosystems that are in a state of transition following severe disruption. A caution to management based on this overview could be summarized as follows: 1) returning the systems to their original state is not possible, and even establishing cause and effect of the changes will be difficult (although modeling can help); 2) these ecosystems will continue to exhibit large amplitude changes that surprise us. While the Great Lakes ecosystems may exhibit dynamics that are not fully predictable (or largely chaotic, for pessimists), ecosystem objectives can still be pursued with a view to the big, ecosystem-level picture and long-term goals. Although new challenges may arise, the cornerstones of environmental policy need not, and should not, be sacrificed. To elaborate on this theme, major threats to Great Lakes ecosystems are reviewed, focusing on whether they present management dilemmas, and how they should be managed from a long-term and holistic perspective.

Excess nutrients. Most of the water quality problems in the Great Lakes are caused, or at least exacerbated, by high nutrient loading. However, there could be a trade-off between nutrient reduction and fisheries (Rand and Stewart 1998; Ryan et al. 1999; Ludsin et al. 2001). These suggestions have been made concerning the richest parts of the lakes, including Lake Erie where the plankton is weakly, if at all, limited by nutrients (Guildford et al. 2003) and not more limited than it was before phosphorus reduction (Lean et al. 1983). There was a short-term reprieve from eutrophication-related problems in Lake Erie, apparently caused by reductions in nutrient loading and invasion of *Dreissena*. However, that reprieve is very likely to be temporary, and currently there is a resurgence of nutrient-related problems in the lower lakes: tastes and odor problems (Ridal et al. 2000); *Cladophora* (Howell 1998, Hiriart-Baer et al. 2003); *Microcystis* (Murphy et al. 2003), and botulism (Timmermans et al. 2003), possibly related to the end of the *Dreissena* colonization phase (Hecky et al. in press) and recent high nutrient loads (Dolan and Richards 2003). Furthermore, the human population is growing and agricultural areas in North America are so saturated in phosphorus (Bennet et al. 2001) that eutrophication problems are like an oil tanker heading for a reef; there is very limited ability to stop or steer. The oligotrophication of Lake Erie during the 1970s and 1980s did result in rehabilitation of fish communities from an ecological point of view, even if some species did decline (Ludsin et al. 2001). Nutrient management must be kept at the top of our agenda, and not let minor and likely misplaced concerns over the decline in yield of some fisheries compromise the much larger economic, ecological, health and social benefits of clean water.

Invasions of unwanted species are an ongoing, perhaps even accelerating, problem in the Great Lakes. Susceptibility to invasion is likely a characteristic of disturbed and enriched systems (Levine 2000, Ricciardi 2001). However, efforts to prevent invasion of undesirable species, as eradication of invading species is possibly futile and, if feasible, likely to be very expensive and have negative effects on desirable species. Efforts towards eradication will inevitably focus on the most economically important and tractable problems, like the sea lamprey. With the possible exception of the sea lamprey, the resources invested in suppressing aquatic invaders are considerably less than those invested in suppressing forest and agricultural pests. It is apparent that society is prepared to accept, albeit with reluctance, those invaders with less costly impacts. Some invading species are relatively benign, some not. Some species like the steelhead and the brown trout, are foreigners that have been here for over a century and are highly valued and that play important ecological and economic roles. While some invaders may cause little disruption to ecosystem function and aesthetics, native biodiversity should be preserved because native species and especially strains adapted to our Great Lakes represent a natural capital that, once lost, cannot be recovered. But given the number of species and subspecies that have been lost already, and the extent to which the systems have changed, the reality is that foreign species will and must always be an important part of these systems. The unpredictability of ecosystem behavior does not make management of exotics problematical.

Over-fishing, contaminants and the invasion of the sea lamprey resulted in the loss of many fish species and the ongoing depression of others. The Great Lakes became under-populated with large, and especially long-lived, predatory fish and overpopulated with opportunistic marine planktivores subject to strong population oscillations, particularly alewife (Eshenroder and Burnham-Curtis 1999) and, as a result, the zooplankton community was dominated by small species, not large enough to be good fish food and contributing to long and inefficient food chains (Sprules and Goyke 1994). Signs of recovery (reproduction or population increases of native species, occurrence of large zooplankton, and clear water episodes) have occurred as exotic marine planktivores have declined with increases in piscivores. In Lake Ontario, concern about overstocking and declining condition of chinook salmon in the mid 1990's coincided with evidence for limited natural reproduction of lake trout, and increases in 3-spine stickleback, burbot and whitefish (Ontario Ministry of Natural Resources 2002). In the upper lakes, high piscivory has permitted a partial recovery of coregonids and burbot (reviewed in Eshenroder and Burnham-Curtis 1999). Although cause and effect is more controversial, planktivore suppression and large zooplankton has been coincident with clear water conditions (Scavia et al. 1986; Wu and Culver 1991). While the temptation must be resisted to manage the Great Lakes as a put and take sport fishery for chinook salmon, there is no conflict between the stocking of Pacific salmon and the recovery of native piscivores. The negative effect of alewife, smelt and gizzard shad on the reproduction of top predators through thiamin deficiency is a fascinating story (Fitzsimons et al. 1999), illustrating that the effect of exotic piscivores on natural piscivores is positive rather than negative, and so the stocking of piscivores actually promotes natural reproduction. Stocking of piscivores should be sustained and as the environmental conditions for natural reproduction improve, accept declines in the condition of the Pacific salmon as piscivore populations increase. This would bring the hope of diversifying the forage base and improving the performance of long-lived and iteroparous predators, including native ones. Salmon stocking began in the 1960s for alewife control. It should continue, along with any other action that might assist native and iteroparous species. Allowable harvests must be set with broader ecosystem objectives in mind, particularly a high standing stock of diverse piscivores, rather than high yield and condition of a few exotic species.

The drainage basins of the Great Lakes have a major impact on the loading of sediments, nutrients and contaminants to the lakes, and on the reproduction of top predators, many of which enter rivers, littoral areas and wetlands to spawn. There are still too many impassable dams on Great Lakes tributaries, too many warm and silty streams in agricultural and urban areas, and too many lost or degraded wetlands and littoral zones that used to be important fish habitat. Remediation of the Great Lakes ecosystems is an activity that must occur mainly outside of the lakes themselves, and along their margins, where the impacts are and where important gains are to be made. Efforts to improve aquatic and wetland habitat in the basin and at the margins of the lakes will pay dividends in water quality and fisheries, and have no downside.

Toxic contaminants have been a dominant issue in the Great Lakes for decades. There are issues concerning priorities and standards, but little controversy about the need to reduce their loading and, ultimately, their concentration in biota. An exception may be the environmental costs and benefits of reducing the populations of lamprey control by treating tributary streams and connecting channels with pesticides to control an economically and ecologically important invader. Other issues of this type have arisen and will arise again in the context of controlling unwanted invasive species, whether the control is a pesticide, a bio-control agent, or a modification of the habitat. This exception aside, the goal must be to reduce contaminant loading.

One particular issue that is both ecologically interesting and distressing is that management for long-lived species and lower nutrient levels in the Great Lakes might be, at the same time, management for high contaminant levels in top predators. The native lake trout relative to pacific salmon and trout tends to have higher contaminant levels, likely because of their lipid content, place in the food web, and metabolism. However, the differences are not large (eg, Rowan and Rasmussen 1992). Also, nutrient poor systems are likely to have more contaminated biota than nutrient rich systems (Larsson et al. 1992) although more recent comparative work finds that the situation defies simple generalities (Skei et al.2000; Berglund et al. 2001). Nonetheless, here are two possible ways in which ecosystem management for native species and clean water might conflict with management goals for less contaminated fish and fish-eating wildlife. On the other hand, very high lipid levels and resulting high contaminant burdens in piscivores are an indication of their under-population relative to nutrients and forage. Their high trophic level is related to the inefficiency of Great Lakes food chains, and again can be ultimately traced to under-population of top predators and overpopulation of exotic planktivores. While this is not the forum for a detailed discussion on bioaccumulation, the case can be made that ecosystem restoration in the Great Lakes is compatible with managing for low contaminants.

One important paradigm shift that has occurred is that while persistent, bioaccumulative and toxic organic pollutants (PBTs) first came to our attention in the Great Lakes, and Great Lakes scientists led the way in their study, PBTs are clearly global problems. Many are distributed throughout the biosphere, and their concentration in biota may have more to do with ecological factors and physical chemistry than proximity to sources (Rowan and Rasmussen 1992; Wania and Mackay 1993). The focus has shifted from the Great Lakes to aquatic systems everywhere and to the atmosphere as the link. A second major shift in thinking is at an early stage, but it seems that chemicals that are less hydrophobic and persistent, but very biologically active are also important. Recent evidence of strong effects on endocrine and immune systems by compounds in current use like malathion (Gilbertson et al. 2003) and atrazine (Hayes et al. 2002) is alarming, and the risk posed by many compounds must be reexamined, even ones that are not as persistent, toxic and prone to bioaccumulation. Muir (this volume) discusses the challenge of re-evaluating potential endocrine-disruptors.

Great Lakes ecosystems will likely continue to challenge us with surprises, exhibiting behaviour that is difficult to predict in specific terms. However, as Dr. Koonce has argued, this behaviour will exhibit pattern and trend on long time scales, and it is at these time scales that our management strategy must be directed, even though our tactics may need to change with new challenges. The task is simplified by the fact that the major elements of that strategy: nutrient control, re-population of the lakes with a large and diverse standing stock of fishes; conservation of tributary, wetland and nearshore habitats in the drainage basin, and reduction of contaminant loading, are all complimentary long-term goals that can be unconditionally embraced. Instances of conflicts and trade-offs in these goals are few and minor. Therefore, agreement on long-term, ecosystem-level goals should be possible, and management decisions can be made accordingly.

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The Evolution Towards New Policies

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Several major events have largely influenced the management and protection of the Great Lakes, and progress under the Great Lakes Water Quality Agreement since its inception in 1972. This account comprises a historic, personal perspective in order to contribute to the discussion on new policies. In order to validate or test the rigour of the ideas, it is acknowledged that it would be necessary to employ scientific methodology, such as use of opinion research or social survey to elicit stakeholder perceptions and identify consensus. Such an activity could form the basis for a future research project to understand and confirm how the evolution of policy in both countries has affected progress under the agreement.

Conservation groups have been around a long time; however, large environmental groups dedicated to purely environmental or pollution control and related resource management issues rose to prominence relatively recently, in the late 1960s. The decade-by-decade emergence of many groups at the local, national and international levels became the genesis of the modern environmental movement. Based on shared values, they gave impetus to the evolution and implementation of a variety of new policy approaches and ideas for addressing the challenge and crisis of environmental management.

One example of the role of non-governmental organizations in policy development in Canada is Pollution Probe, which was initially formed from a student movement at the University of Toronto in 1969. Early approaches might be characterized as advocacy and raising awareness of specific issues through the media. Since that time, Pollution Probe has evolved to the point where its effectiveness is now based largely on partnerships "within the system" as opposed to outside the system. By focusing on how to get solutions in place, the current role of Pollution Probe is to act as a policy catalyst to assist industry, government and the public to answer their own questions, and to develop policies that implement the solutions that have been identified.

From the beginning, scientists were important to the environmental movement, especially including those who popularized environmental science. Books like Rachel Carson's *Silent Spring* were prescient to the thinking that has occurred during the past four decades.

Government ministries of environment did not exist in the late 1960s, and industries did not have the capacity to deal with the environment as an issue. For example, industries did not have vice presidents of the environment, and research capabilities to understand the impact of pollution based on scientific knowledge generally did not exist. The media, recognizing that environment and pollution were new and exciting issues, alerted the public. As the public became alarmed, government policy was driven by that alarm. By the 1970s, the call of "polluter pays" became the predominant environmental principle. Environment ministries were created in the early 1970s and environmental groups continued to proliferate. World leaders met in Stockholm in 1972, and they held the first discussion at a global level on environmental issues. Catastrophic events were a key driver of environmental policy, and they occurred quite frequently in the 1970s. The command and control regulatory framework was largely developed in the 1970s. And of course, the Great Lakes Water Quality Agreement came into existence in 1972.

As the predominant principle in the 1970s, the policy "polluter pays" resulted in industry installing end-of-pipe controls in response to the new regulatory framework to cut down gross levels of pollution. It was also during this time that government agencies were formed with specific environmental responsibilities arising from legislation, and industries adopted more sophisticated approaches and associations in response to laws and enforcement of environmental regulations.

The decade of the '80s marked the maturing of environmental policy. In Canada, by the late 1980s, the public had put the environment at the top of their priorities, along with the economy, reflecting a decade of ongoing concern. For example, Canada pioneered the concept of a multi-stakeholder process and applied it as a consultative mechanism to the management of toxic chemicals. The United States began adopting the use of market mechanisms, such as emissions trading, which were generally not favorably accepted in Canada. During this time, the second gathering of world leaders occurred in 1987 –- the World Commission on Environment and Development (WCED), which introduced sustainable development as a policy idea linking the environment, the economy and social goals. However, the dominant principle of the 1980s was pollution prevention. The idea of avoiding pollution entirely was heavily supported by industry, primarily as an alternative way of managing the high cost of regulatory compliance and liability.

During the 1990s the linkage of environment and economy as outlined in the 1987 report of the WCED was supposed to be developed and implemented as policy. Termed, "sustainable development", it became the dominant principle during that decade. Canada wrote its famous Green Plan. But the 1990s was a period of economic hardship, and even though the public had again put environment at the top of their list of priorities by 1989, the $6 billion promised from the government was eventually reduced to $3 billion or less.

During the early 1990s the performance of the North American economy was suffering, and public perception of the environment as a top priority issue began to wane. Political priorities changed and, as a result, the environment began to slip on the political agenda. Globalization of trade became the real driver, and occasionally global trade provisions to ensure fair trade were used to challenge national policies related to environmental protection. In terms of policy, the decision-making process often became an end in itself. There also emerged a widely held view that North America was not competitive or productive, at least partly because of environmental standards based on uncertain science. The further strengthening of multi-stakeholder processes to avoid controversial decision making became a norm that has carried through to the 21st century.

The Rio Summit, convened by world leaders, was held at the beginning of the decade in 1992, primarily to address the emerging issue of climate change. In terms of other events later in the decade, a promising management approach arose as industry began to adopt the science of total quality management and continuous product improvement to environmental management systems. The ISO 14000 series of environmental management standards was developed in 1997. "Sustainable development" became the dominant principle of the 1990s. Unfortunately the linkage of environment and the economy as the inherent characteristic of this principle was threatened in Canada. In an attempt to control government deficit spending, severe budgetary constraints were implemented to environment ministries, resulting in cuts to programs and services, and making it very difficult to enforce the environmental regulatory framework as a basic mechanism of policy.

In terms of the current decade, the challenge is to identify and develop new policy approaches. The public has re-engaged their concern for environmental protection, particularly with respect to human health issues. After reducing their environmental capacity, the governments not only have to manage this serious public concern, but also have to accommodate powerful new stakeholders with impressive scientific credibility, such as the Ontario Medical Association on air issues. The convergence of environmental and public health has created a new imperative for effective policies and action.

Industry credibility in convincing people that the work they are doing on a voluntary basis is sufficient to meet their responsibilities is no longer the general perception. The nature of multi-stakeholder processes to impart the illusion of consensus is no longer generally assumed to inevitably result in effective policy. The emergence of public crisis, such as occurred in Walkerton, Ontario, served to remind the public of the risks of complacency. It is apparent that even though governments may want to avoid the regulatory approach, a new receptivity to regulation is occurring from the public, especially in areas related to public health and safety.

Based on this and other considerations, the precautionary principle would appear to be the dominant environmental principle of the current decade.

In conclusion, have environmental policy actions over the past 30 to 40 years been sufficient to address the challenges? While there is one toolkit that is being pioneered largely by the corporate sector based on volunteerism, there is another beginning to emerge based on environmental sustainability and its linkage to economic performance. Managing the environment, as with managing the economy, has traditionally been viewed as a responsibility and public trust of government. While this view still prevails, there is growing recognition of environmental responsibility as a shared mission by industry and by the public.

Figure 1 illustrates a framework being developed by Pollution Probe to demonstrate how various policy tools can be applied in solving environmental challenges. Eventually, with such a framework and a toolkit, it is envisaged that it will be possible to disassemble a business operation, or even a government or other institutional operation, and apply these tools to find ways to drastically reduce the amount of toxic chemicals and the amount of energy used, as well as the amount of materials used, while maintaining economic efficiency. In the long run, the goal is to seek convergence among societal goals to obtain outcomes that are also favorable for the environment. The 1990s created new opportunities to consider the development of other approaches to address environmental challenges. Now the task is to assess and use the most appropriate and useful policy tools to drive improvement. In essence, the era of continuous environmental and economic improvement has begun.

The role of science, monitoring and measurement is fundamental to achieving progress. Science has to be understood by policymakers as the fuel upon which we understand whether or not the application of environmental sustainability tools is resulting in benefit to the environment. For the International Joint Commission and others in the scientific community, the policy framework provides an important context and relevance to science knowledge. Government funding of science is more likely to occur when it is seen to be linked to the application of tools that are in the public, as well as the corporate interest, and will result in a good business case that can benefit everyone.

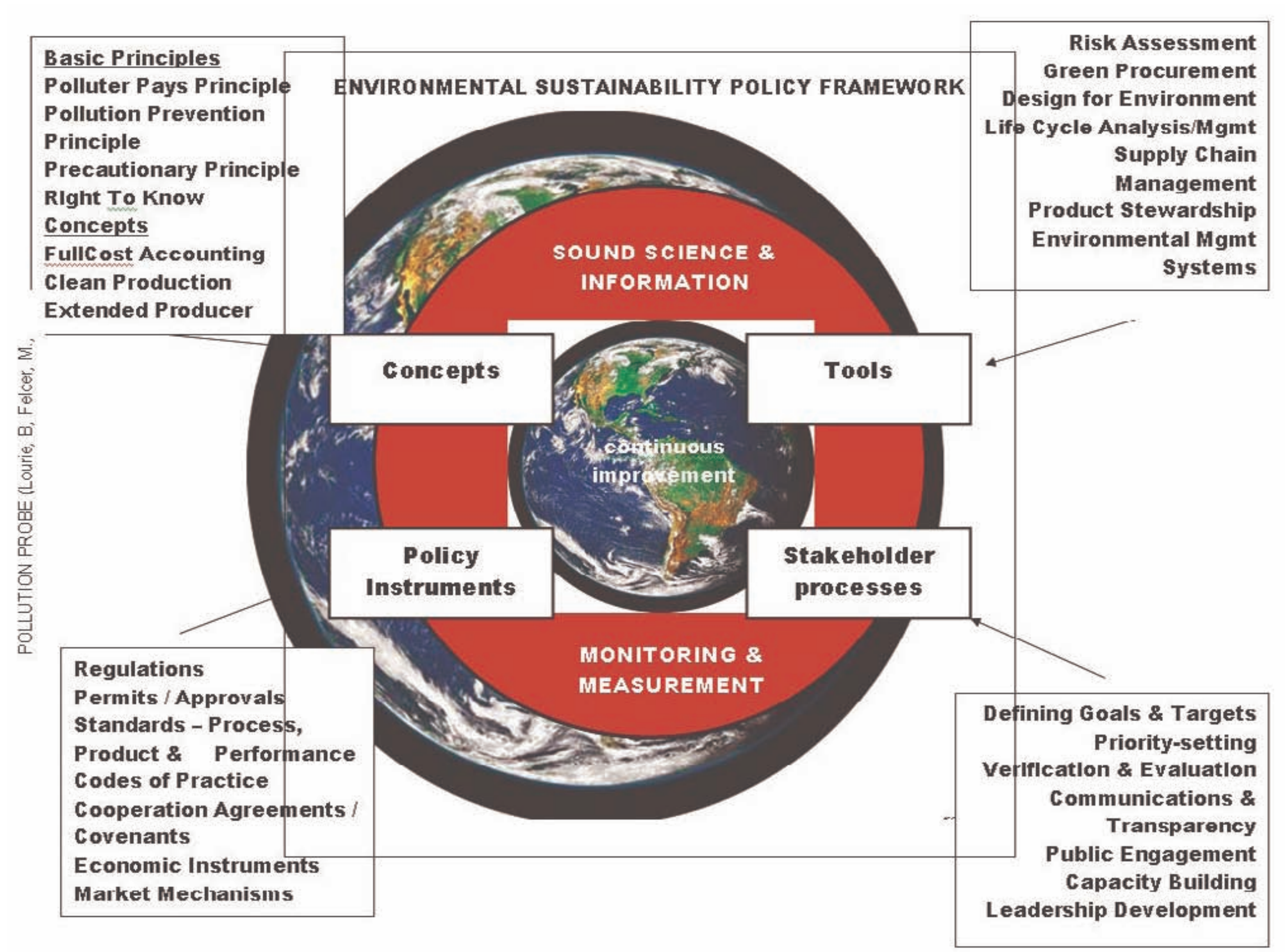

Figure 1. Environmental Sustainability Policy Framework

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Emerging Issues Wingspread Proceedings

A Regulatory Perspective to Great Lakes Water Quality Management: Past Present and Future

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The issues central to water quality management for the purposes of this paper are:

- Water Quality
- Ecology Management
- Water Resource Management
- Tools and Strategies

The historic perspective is based upon the personal experience of the author as Director of USEPA's Great Lakes National Program Office in the mid-1980s. The present situation currently is interpreted from the author's recent membership on the Great Lakes Water Quality Board (WQB), representing the State of Illinois, and a current assignment serving as a consultant to the Council of Great Lakes Governors on the Great Lakes Water Management Initiative under Annex 2001 of the Great Lakes Charter. The author's vision of the future is based upon the issues and challenges that are being addressed and will require a long-term approach for accomplishment.

To summarize:

- Great progress has been made in some areas, nutrient control being the best example
- By the mid-1980s the water quality focus started to shift to the control and remediation of toxic chemicals. The 1987 Protocol to the Great Lakes Water Quality Agreement (GLWQA) recognized contaminated sediments and diffuse sources of toxicants, including atmospheric deposition. Though awareness of these issues is now strong, the implementation of control and remediation programs will still be an important effort 20 years from now

- The focus of the GLWQA to date has been on water quality. Now and in the near future that focus needs to be broadened to an ecosystem approach and an understanding of the inter-relationships between water, habitat and biodiversity.

Water Quality

Through regulatory strategies, including the setting of standards, writing of permits and strong enforcement, and through massive public works projects, the once very serious nutrient problem in the Great Lakes has been largely solved, yet requires continued management. New scientific information involving nutrients lead some to believe this continues to be an issue. For example, local beach closings due to combined sewer overflow and wet weather by-pass situations remain a critical issue to some Great Lakes cities and will be for the next several years.

Toxic chemicals have been for the last 20 years and will be, into the future, the water quality concern of the most importance to the lakes. If one looks at the list of chemicals developed by the WQB in the 1980s it includes banned pesticides and other chemicals that are or have been phased out. Here are some observations about the status of toxic chemical efforts now and what will be needed going forward:

- The Parties have continued to develop and implement important initiatives; worth noting are the Bi-national Toxics Strategy, US Water Quality Guidance for the Great Lakes System and Canadian Environmental Quality Guidelines. These efforts are a roadmap for implementation and provide benchmarks for improvement
- Individual states and provinces continue to regulate toxic chemical releases of municipal and industrial discharges
- Contaminated sediments are and will remain a critical concern. On the positive side, the extent of the problem is understood and technology alternatives have been evaluated. In addition, there have been some localized successes in addressing sediment problems in the Areas of Concern. Remediating contaminated sediment is costly and will remain a priority for years. New efforts regarding Great Lakes priorities and the Improvement Standard of Annex 2001 can promote progress in this area
- The joint efforts of the WQB and the International Air Quality Board, have resulted in a continued focus on the extent and sources of atmosphere deposition of toxic chemicals into the Great Lakes. This is an example where new regulatory authority and approaches will be needed in the next several years if this problem is to be effectively addressed
- Controlling toxic chemical pollution from agriculture has been and will continue to be a priority. New herbicides and pesticides, some more persistent than thought when licensed, continue to reach the basin. Atrazine, for example, is still widely used in the basin. This chemical is a known endocrine disrupter, likely causing reproductive failures and birth defects. These non-point issues need to be addressed both through continued and stronger regulatory efforts and through innovations, such as trading programs and environmental management systems (EMS).

Ecology Management

In the 1980s Great Lakes managers were beginning to discuss the relationships between water quality and ecosystem health. In the GLWQA Protocol of 1987, for example, the Parties agreed to develop ecosystem health indicators for the Great Lakes. Goals for Lake Superior were specified. However, there existed no comprehensive plan for ecosystem management, including the lack of fishery management goals and objectives. There is a growing awareness that ecosystem objectives and management must be a key component of Great Lakes management efforts. Here are some thoughts for moving forward:

- The GLWQA should be amended to include ecosystem management concepts, including habitat restoration and protection, biodiversity objectives and programs and aquatic nuisance species control programs
- The Lakewide Management Plan program should require fisheries and biodiversity objectives for each lake and the parties must support these efforts
- Habitat protection and restoration programs should be a focus of the Great Lakes Priorities and Annex 2001 Improvement Standard
- Comprehensive aquatic nuisance species management programs must be put in place by both parties. These programs should be both management system-based and regulatory. This must be a priority now and for the next several years.

Water Resource Management

Lake levels and the potential of the massive diversions of Great Lakes water out of the basin has been a historic concern. This has been potential issue for many years, for example, based on personal experience since the mid-1970s. These concerns continue today and will extend into the future. The Great Lakes Governors and Premiers signed the Great Lakes Charter Annex on June 18, 2001. In the Annex, the Governors and Premiers outlined the framework for a set of binding agreements among the Great Lakes states and provinces and established a series of principles for a standard for reviewing proposed withdrawals of Great Lakes basin water.

The 10 Great Lakes states and provinces, working through the Council of Great Lakes Governors and with the guidance from a multi-stakeholder advisory committee, released a draft decision-making standard and proposed agreements for public review in early 2004. Key elements of the proposed standard included:

- Water conservation requirements
- Return flow guidelines
- A showing of no impacts
- Improvement projects.

This water management effort has a long way to go to become operational. Legislative approval will be required by all 10 jurisdictions, and federal support will be necessary. This could take years. However, the implementation of Annex 2001 has the potential to be a new and powerful tool for addressing Great Lakes ecosystem issues.

Tools and Strategies

Given the evolution of the problems, including the continued need to focus on water quality issues and the recognition to move beyond to ecosystem management, there is a need to rethink the use of regulatory and other problem-solving tools. This rethinking should include an examination of governance. Here are some thoughts on this subject:

- There is a need to recommit our support for the basic command and control regulatory system. Progress cannot be sustained without a strong enforcement effort
- Great Lakes authorities should actively seek to take advantage of the beyond compliance environmental innovations being used successfully around the world, including trading and environmental management systems
- There is a need to refocus and recommit to developing and implementing remedial action plans and lake-wide management plans; these concepts are sound
- The new efforts on Great Lake Priorities and Improvement should focus on solving ecosystem stresses
- There is a need to continue to support the State of the Lakes Ecosystem Conference efforts and expand research into the following areas:
    - watershed and airshed management, including land use
    - ecosystem approach
    - biodiversity
    - groundwater
    - habitat restoration, protection and improvement
    - sustainable use
    - endocrine disrupters and pharmaceuticals
    - climate change adaptation
    - modeling of long range transport of air pollution
    - aquatic invasive species.
- The GLWQA should be reviewed and revised to address the emerging issues
- The WQB should be expanded to include stakeholders from all Great Lakes interests
- There is a need for continued dialogue between all Great Lakes institutions to foster partnerships and teamwork. There is now a growing sense of urgency and priority for addressing Great Lakes problems, and everyone needs to work together.

This topic of emerging issues is timely. Some of the issues to be faced are old and some are relatively new. To summarize, there is a need to focus on the sustainability of the Great Lakes and the Great Lakes region. Progress and success is attainable if both countries recommit and work together.