1993-95 PRIORITIES AND PROGRESS UNDER THE GREAT LAKES WATER QUALITY AGREEMENT

Chapter Two: Great Lakes Science Advisory Board

2.0 SCIENCE ADVISORY BOARD ACTIVITIES

FIGURES

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2.0 Great Lakes Science Advisory Board Activities

Introduction

The Great Lakes Water Quality Agreement provides the Terms of Reference for the **Science Advisory Board** (SAB) as a joint institution to be "... the scientific advisor to the Commission and the Water Quality Board." Through an integrative approach, including the natural, physical and social sciences, the principle role of the Board relates to three areas:

- assessment and advice on Great Lakes Basin Ecosystem health, including the scientific underpinning of public policy
- review and evaluation of science policy and programs related to the Parties implementation of the Agreement
- identification and evaluation of emerging issues and future priorities.

To meet these responsibilities, the Board comprises 18 members appointed by the Commission on the basis of their experience and expertise, to provide independent scientific advice under the Agreement. Science Advisory Board members are recruited from industry, academia, government and nongovernment organizations, and the Board is multi-disciplinary in its expertise.

To substantively address matters referred to it by the Commission under the 1993-95 Priorities, the Board continued to employ three workgroups composed of SAB members and non-Board members with pertinent expertise. The Board workgroups focus on Ecosystem Health, Parties Implementation, and Emerging Issues. Generally, each workgroup met quarterly and reported to the Board at its regular meetings. During the 1993-95 Biennium, the IJC priorities assigned to the Board and Board initiatives regarding emerging issues and technology assessment were delegated to the workgroups as follows:

- Workgroup on Ecosystem Health: Toxicological Mechanisms; Weight of Evidence; and Measuring Ecosystem Health
- Workgroup on Parties Implementation: Parties Toxics Reduction Programs; and Followup on the Virtual Elimination Task Force
- Workgroup on Emerging Issues: Climate Change; Emerging Issues; and the technology component of the Water Quality Board's Workshop on Pollution Prevention

Workgroup reports, conclusions and recommendations are reviewed, compiled and approved by the Board for submission to the Commission in its Biennial Report.

In addition to non-Board members serving on the workgroups, the SAB also benefitted from the involvement of Water Quality Board and Council of Great Lakes Research Managers members serving on the workgroups in a support and/or liaison role. This involvement provided consultation and coordination on advisory activities under the priorities.

2.1 Summary of Science Advisory Board Recommendations

2.2 Human Health in Ecosystem Health: Issues of Meaning and Measurement

The Science Advisory Board recommends that:

- the Commission, in its priority activities and its advice to the Parties, support further research to determine ambient levels of exposure to toxic chemicals in the Great Lakes basin and incorporate the following general principles for further development of environmental burden of illness indicators:
- continued monitoring of toxins in media, including trihalomethanes, nitrates, microbial contaminants in drinking water, PM-10, ozone and sulphates in air, and toxic bioaccumulative chemicals in general
- systematic synthesis of water sampling results for microbial contaminants that result in beach closings. Consider complementing these with information on symptoms among beach users
- inclusion of relevant ambient exposure factors (e.g. time outdoors, based on activity record) and consumption factors (e.g. freshwater fish and wildlife) in population-based health surveys. General population-based measures of body fluid levels of key contaminants (e.g. PCBs or DDE for the organochlorines in serum and breast milk, mercury and lead in whole blood for the metals) could be linked with these and other relevant social factors
- surveillance of established environmental health outcomes, such as asthma, such that these conditions may be considered as sentinels for pollution effects
- recognition that some human illness indicators are poorly suited to provide useful information on the impact of environmental matters on human health, e.g. most morbidity and mortality data that is routinely collected, including cancer rates
- development of longitudinal designs around exposures and conditions of interest to enable stronger inferences concerning relationship between exposure and health outcomes.
- the Commission support actions that would lower human exposure to persistent toxic substances such as PCBs and lower concentrations of these substances in human tissues.

- the Commission support the development of indicators and scales that measure the environmental component of illness and wellbeing and indices of environmental stress and environmental condition.
- the Commission continue to monitor state of the environment and sustainable development reporting in order to inform, in its recommendations to the Parties, regarding Great Lakes basin indicators. As these reports often take a broad-based approach to indicator selection, this monitoring is necessary to help ensure the integration of human exposure considerations into assessments of contamination in relevant fish and wildlife species.

2.3 Weight of Evidence Approaches to Decisionmaking in the Face of Uncertainty

The Science Advisory Board recommends that:

- scientific risk characterization formally include disclosure of: (1) choices embedded in the design of supporting research; (2) modifiers of risk factors used; and (3) all relevant uncertainties.
- risk characterizations prepared for environmental decisionmaking explicitly examine the potential indirect consequences resulting from the characteristics of the hazard, pathways and host response as outlined in Appendix I of this section.
- decisionmakers seek out or recommend relevant valuation assessments, legal and regulatory analysis, socio-economic assessments, equity analysis, ethical analysis and cumulative impact assessments as necessary inputs into risk management decisions.
- Commission weight-of-evidence decisions be clear as to evidence used, assumptions, values, uncertainties and consequences involved.
- the level of proof required (beyond a reasonable doubt, or more likely than not) be clearly stated.
- the risk of non-action be included in deliberations on risk management.
- Commission recommendations and decisions based on weight of evidence include parallel decisions on reasonable monitoring needed to serve as a measure of progress toward the desired goal, or conversely as an indicator of a wrong decision.
- Commission recommendations and decisions based on weight of evidence, because tentative, incorporate clear strategies for ongoing cooperation between scientists and managers.
- further development of an ethical basis for ordering and prioritizing goals of human health and/or environmental integrity, when there is a potential conflict between those goals, be undertaken.

2.4 Toxicological Mechanisms: Environmental Exposure to Chemicals Acting as Endocrine Modifiers

The Science Advisory Board recommends that:

- cooperative efforts occur between the governments, academia, the general public and industry to focus research:

    1. to identify which, if any, environmental exposures to chemicals are or have the potential to be endocrine modulators in humans. For those chemicals identified, what are the exposure and dose-response relationships that define the potential for adverse effects?
    2. to identify what effects and disease state in humans may be linked to endocrine modulation as a result of exposure to chemicals in the

environment, and at what stage of development is the human most susceptible to these effects
3. to identify the mechanisms of action of environmental exposures to chemicals relative to endocrine modulation, and how such knowledge can be factored into the risk assessment process
4. to determine if structure/activity relationships can be developed to accurately predict which environmental exposures to chemicals have the potential to modulate the endocrine system
5. to determine if sensitive biomarkers of endocrine modulation can be developed and validated for use in animals and humans exposed to chemicals in the environment
6. to determine in animals if environmental exposures to chemicals that are endocrine modulators can be differentiated from other environmental stressors, such as loss of habitat, malnutrition, or changes in ecosystem dynamics that can similarly exert effects on the endocrine system
7. to determine in humans if environmental exposures to chemicals that are endocrine modulators, can be differentiated from endocrine effects that are caused by endogenous, dietary or other lifestyle stressor factors (loss of jobs, etc.). How can their interactions be studied?
8. to identify chemically-exposed cohorts that can be used to study the potential for environmental exposure to chemicals to alter endocrine function or endocrine responsive organ function
9. to identify if technologies can be devised to control the release of endocrine modulators. Can more effective technologies be developed?

2.5 Federal and Provincial/State Toxic Reduction Programs and Related Activities in the Great Lakes Basin: A Preliminary Evaluation

The Science Advisory Board recommends that:

- the Commission consider toxics reduction programs as a priority for further action within the next biennial cycle. To further this priority item, the Commission should establish a special task force of the Science Advisory Board, in cooperation with the Water Quality Board and the Council of Great Lakes Research Managers, with a mandate to:

  (a) develop standardized binational mechanisms and criteria to assess toxic chemical management laws, programs and data collection activities
  (b) provide advice to the Commission on the design and implementation of such activities in order to assess toxics loadings to the Great Lakes basin.

- the Commission reiterate and re-emphasize to the Parties the recommendation from the Commission's *Seventh Biennial Report on Great Lakes Water Quality*, which stated:
  - Governments adopt a specific, coordinated binational strategy within two years with a common set of objectives and procedure for action to stop the input of persistent toxic substances into the Great Lakes environment, using the framework developed by the Virtual Elimination Task Force.

2.6 Progress Toward Virtual Elimination of Persistent Toxic Substances

The Science Advisory Board recommends that:

- the Commission consider transition planning as a priority for further study and research within the next biennial cycle. Components of this research should include:
  - a study researching a number of case histories of where there were specific efforts to facilitate the transition of an industrial sector owing to some change in circumstance (such as the downsizing of the military establishment or the phaseout of certain substances such as CFCs) to determine the lessons learned from those experiences
  - an investigation to identify the major contributors of dioxin to the Great Lakes
  - the development of a transition plan, with the participation of the important stakeholders, for the virtual elimination of dioxin inputs from one of the major contributors. The development of the plan design would serve as a forum for a discussion on both the general framework and the key components of a transition plan. The terms of reference of the study would include:
    1. the definition of transition planning
    2. important principles that would be included in plan design (such as who should participate in the fashioning of a plan, when it is necessary, among many others)
    3. identification and feasibility of transition mechanisms (such as a transition fund) and the potential and obstacles for them to work in practice
    4. the need to establish, if at all, an institutional framework for the development, implementation and monitoring of the transition process, whether at a local, regional, national or international level.
- the Commission sponsor one or more roundtables to engage the dialogue of stakeholders in the topic, and to further elaborate on how the term should be interpreted and applied.
- the Commission actively seek avenues to participate in international dialogue both within North America and beyond, on transition planning.
- the Commission reiterate recommendation 20 in its *Seventh Biennial Report* to the government in particular, which stated that governments, industry and labour begin devising plans to cope with economic and social dislocation that may occur as a result of initiatives designed to promote virtual elimination.

Further to this recommendation, that the Commission recommend to the governments within the Great Lakes basin that:

- transition planning components, when deemed necessary in the sense that there is a risk of significant worker or community dislocation, be included into the specific commitments to those substances that are already candidates for phaseout, such as those identified under the Canada-Ontario Agreement, and the Lake Superior Binational Program
- governments report back to the Commission biennially on progress made in furthering these transition mechanisms.

2.7 Impacts of Climate Change on the Great Lakes: Progress Towards a Binational Strategy

The Science Advisory Board recommends that:

- the Parties be encouraged to support the completion of the binational implementation plan through to 2001 according to the scheduled timeline as indicated in Table 6.
- a quinquennial symposium on climate change in the Great Lakes basin be sponsored by the Parties and be sustained following the event planned for 1996, as an important scientific forum for discussion and to measure progress towards climate change assessment and adaptation.

- the recommendation from the 1993 Science Advisory Board report, that the Parties make a long-term commitment to climate change research under Annex 17 of the Great Lakes Water Quality Agreement, and report progress in a holistic and systematic fashion within the context of a State of the Great Lakes Basin Ecosystem report, receive further consideration and emphasis in the Commission recommendations to the Parties.

2.8 Identification and Assessment of Emerging Issues

The Science Advisory Board recommends that:

- the issues identified as potentially important for the Commission be considered as priorities for serious deliberations during the next biennium. They are complex issues, especially the issue of sustainability that reappeared in each survey, that would require Commission resources to address in terms of implications for progress under the Great Lakes Water Quality Agreement. The issues assessed as most salient include:

    1. sustainable development
    2. stability of water levels
    3. uv-B effects on biota
    4. various implications of **North American Free Trade Agreement** (NAFTA)
    5. lifestyle choices as a factor in ecosystem integrity
    6. incidence of endometriosis in women who eat fish from the Great Lakes

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2.2 Human Health in Ecosystem Health: Issues of Meaning and Measurement

2.2.1 Introduction

The original task undertaken by the Subgroup on Measuring Ecosystem Health under the priorities for the 1993-1995 biennium was to prepare a discussion paper on methods for the diagnosis, prognosis, treatment and rehabilitation of ecosystems under stress. Most members attended the First International Symposium on Ecosystem Health and Medicine in Ottawa, on June 19-23, 1994. This symposium addressed the issues associated with this priority task in great detail. Based on the input from this symposium and discussion in the Subgroup, the scope of this task was focussed on clearly addressing the impact of ecosystems on human health and the role of human values in defining the "health" of an ecosystem. A contract was let with the Chair of Environmental Health, McMaster University to produce a monograph on this topic. This research chair within the Eco-Research Program under Environment Canada's Green Plan addresses environmental issues in an interdisciplinary way and includes exploration into the concept of ecosystem health among its research goals. The chairholder, John Eyles, a world renowned social geographer and his research associate, Donald Cole, an environmental epidemiologist, had the precise balance of skills to address the task. Their monograph, *Human Health in Ecosystem Health: Issues of Meaning and Measurement* has now been produced.

This section of the **Science Advisory Board** (SAB) Report draws heavily on the material contained in the monograph with the permission of the authors, as it was produced in parallel to the writing of the monograph. It is, however, not simply a condensation of the monograph. It represents the opinions of the Workgroup on Ecosystem Health of the SAB as accepted by the Board, and not necessarily in all aspects the opinions of Drs. Eyles and Cole.

The monograph discusses ecosystem health in relation to human environmental wellbeing in its broadest sense as an essential context for human health. It argues that a systematic review of quality of life indicators from a range of literature should be undertaken to develop appropriate health and wellbeing measures for Great Lakes basin populations that go beyond simple measures of environmental burden of illness. This section, because of its more limited scope, addresses human health primarily as defined as an absence of disease, i.e. to highlight for the SAB what is known about human disease that flows from exposure to agents within ecosystems, rather than being determined by human genetics, lifestyle behaviours, nutrition or social determinants such as class, poverty, education and self-esteem. The discussion of this environmental burden of illness and appropriate indicators for its measurement in the Great Lakes basin first requires a discussion of the concepts of ecosystem health and human health.

Ecosystem

The concept of ecosystem is rooted in the broader concept of ecology. Ecology refers to the branch of biology that deals with the interrelationships between organisms and their environment. Our experience of the natural world is highly conditioned by our experience of ourselves as body and other creatures as detected by our sense of vision as discreet organisms. Ecology attempts to see the whole and to understand the interconnections of things. The term ecosystem has been used in the science of ecology with many definitions but in three general senses.

Ecosystem can refer to an identifiable natural region; in this sense it is something real, an entity in itself rather than a human mental construct by which reality is understood. It is the geographical landscape and everything in it. As such it is something that we as humans can value and relate to, but it is not a model or analytical framework for scientific inquiry. The Great Lakes Basin Ecosystem, for example, has a geographic dimension that humans can understand and perceive. Ecosystem as a scientific model within which measurements can be made has been approached from two perspectives. One approach is the population-community approach, which focuses on the growth of populations, the structure and composition of communities of organisms and the interactions among individual organisms (O'Neill et al. 1986). This approach views ecosystems as networks of interacting living populations, so in effect the biota are the ecosystem while the non-living components are understood to be external influences or the backdrop in which biotic interactions occur. The other approach is the process-functional approach that emphasizes biophysical models of energy flows and nutrient cycling (e.g. Kay 1991).

Ecosystem can also be viewed as a completely abstracted management tool. Allen and Hoekstra (1992) argue that the observer uses a filter to engage the world. It involves not only definitions and identifying critical changes, but also the nature of measurement and the data collection process. The ecosystem is the system our measuring tools and information gathering techniques allow us to see. Put slightly differently, the human impact on ecosystems is dependent in part on *how* as well as *what* we observe (Bandurski 1994).

Human Health

What is human health? This term has been used in positive and negative senses. The biomedical approach to health has been the absence of disease, in which disease is an abnormality in a part of the body (or by extension of the mind). This biomedical approach is the basis for most toxicological and epidemiological research on human health consequences, on exposure and outcomes. This concept of absence of disease can be used analogously with ecosystems as an absence of distress.

A second "negative" definition of health is the absence of illness. Illness may or may not be associated with disease. The distinction often used is that disease is diagnosed by a physician or other health care professional, while illness is experienced. If an individual does not experience anxiety, pain or distress even if they are diseased, s/he is healthy. Conversely, even in the absence of disease, if an individual does experience anxiety, pain or distress, that individual is unhealthy. In the environmental arena the perception of risk related to exposure to chemicals or other agents in the environment is often a cause of anxiety and distress and thus a source of ill health. It is important to note, however, that the risk that is feared is that a toxic agent has already or will cause a disease. Our concept of what is good and bad in our modern science-oriented society is highly conditioned by the biomedical model. This definition of health does not easily translate to ecosystems. Our common anthropocentric belief is that humans are the most conscious organisms in the ecosystem and therefore we are more subject to pain and anxiety than other organisms.

There are four positive definitions of human health. First, health may be seen as that which enables people to achieve their maximum personal potential (Seedhouse 1986). Health requires basic necessities to be achieved but also provides the basis for higher human needs, such as caring and self-actualization. Dubos (1959) views health as the ability to adapt to new or changing circumstances. This capacity is seen as a fundamental human trait, part of which is humankind's ability and willingness to alter the environment or ecosystem for human purposes. The third positive definition is that of the **World Health Organization** (WHO; 1948) in which health is a "state of complete physical and social wellbeing and not merely the absence of disease or infirmity." Finally, Parsons' (1972) definition also emphasizes the ideal, seeing health as "the state of optimum capacity of an individual for the effective performance of the tasks and duties for which he/she has been socialized." All the positive definitions of health emphasize human capacity to function.

Ecosystem Health

Callicott (1992) creates a definition of ecosystem health based on Leopold's concept of land health. For Leopold (a conservationist scientist in the late 1930s and 40s) the concept of land health is associated with structural integrity and the continuity or stability of biotic communities over long periods of time. Callicott suggests that ecosystems displaying order, stability and continuity are healthy, and maintaining land health is as possible and fundamental as the maintenance of human health or the health of a nation's economy. Similarly the definition of Haskell et al. (1992) incorporates Leopold's concepts of stability, sustainability and self-renewal:

> "An ecological system is healthy and free from "distress syndrome" (the irreversible process of system breakdown leading to collapse) if it is stable and sustainable - that is, if it is active and maintains its organization and autonomy over time and is resilient to stress. Ecosystem health is thus closely linked to the idea of sustainability, which is seen to be a comprehensive, multiscale, dynamic measure of system resilience, organization and vigour. Accordingly, a diseased system is one that is not sustainable and will eventually cease to exist (p. 248)."

Parallel to the concept of ecosystem health is the concept of ecosystem (or ecological) integrity. The goal of the Great Lakes Water Quality Agreement (1978) is to "restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." Ecosystem integrity refers to the ability of a natural system to function optimally. It is analogous to the positive definitions of human health. While ecosystem health implies the ability of a natural system to operate under normal environmental conditions, ecosystem integrity implies that the system can maintain an optimal operation point while stressed and can continue evolving and developing through a process of self-organization (Kay 1993).

Scientific Models and Root Metaphors

Scientific inquiry requires structuring observations into a model that allows measurement. The model enhances our understanding of the phenomena of interest, but its validity depends on its ability to predict the behaviour of the system's components as a whole, even if the purpose for constructing the model was not utilitarian. Specific measurements are designated indicators because they reflect the significance of a particular characteristic within the model or encapsulate the predictive power of the model. Hunsaker and Carpenter (1990) define an environmental indicator as "a characteristic of the environment that, when measured, quantifies the magnitude of *stress*, habitat characteristics, degree of *exposure* to a *stressor*, or degree of ecological *response* to the exposure" (emphases added). Underpinning this approach to indicators are conceptualizations identified by the IJC (1991), namely self-maintenance or self-sustainability of ecological systems, sustained use of the ecosystem for economic or other social purposes and sustained development to enure human welfare. But goal or use -- the purpose of the indicator, what it is meant to measure -- is determined by the a priori model of how the world (society, environment or whatever) works. We must constantly be aware that indicators derive from models and depend on the nature of the models themselves.

In the case of ecosystem health, "health" is a word normally applied to human *individuals* that is applied to ecosystems as entities encompassing interconnected populations of many species. In its broadest sense, such a metaphor is seeing something from the viewpoint of something else (Brown 1977), involving transferring one term from one system or level of meaning to another. It works when that term is consciously used in a different context. Thus metaphors must not only be significant but must also pretend not to be literally absurd. This is especially the case with root metaphors which put forward fundamental images and values about the world. Ecosystem health is such a metaphor, with fundamental, psychological importance linked to self (through health) and holism (through ecosystem).

Both models and metaphors describe human experience and encapsulate human observations, but they do so differently. Models capture those elements that can be measured, that are quantifiable. Metaphors capture those elements that enrich our understanding in one area by analogy with another area, but cannot be measured. Scientific models ultimately are mathematical relationships and give us the power of prediction of how the system will behave. Metaphors capture the similarities between things but they are not inherent properties of the systems being described. Models and metaphors are both derived a priori from our understanding of the world. Both represent strongly held beliefs about how the world operates.

Their difference lies in their testability: a scientific model is meant to be testable and falsifiable whereas a metaphor is part of a world view, challengeable only by revolutions in thought. Yet if we accept Allen and Hoekstra's (1992) view that observational techniques are filters, then it is important to understand the "humanness" of models. Models have meaning only in the context of the "boundaries of science" and their meaning is dependent not just on their findings but on the form of the model itself: its scientific code. Thus as Bateson (1972) argued, the structure of meaning is dependent on the code and how that is transformed into a message (scientific findings). If we share a code (a scientific model), we can understand missing parts - they are intelligible because we use the code to make sure all parts of the message fit.

"Measuring" Ecosystem Health

The issue therefore is whether health can be more than just a metaphor, but also a measurable property of ecosystems. Much of the literature employing the concept of ecosystem health (e.g. Rapport 1989; 1992; CPHA 1992; Allen et al. 1993) relies on ecological principles of: 1) organismic theory (of Clements 1905), which has been abandoned by most ecologists (Ehrenfeld 1992); and 2) stability, succession, diversity which have been further challenged by the "new" ecology (Schrader-Frechette and McCoy, 1993; Zimmerman 1994). An ecosystem health model, rather than metaphor, would require that ecologists can distinguish between a healthy and a diseased ecosystem just as a physician can distinguish between a patient who is healthy or ill. But, as Ehrenfeld (1992, 137) explains:

> "[if] communities have fixed identities, [if] they are normative like organisms, we can easily apply the normative idea of health to them: if they are functionally and structurally similar to their abstract ideal, they are healthy; if they deviate significantly they are sick. If the idea that communities have a normative, equilibrium position, a balance point, were still widely accepted, then the idea of ecological health would pose few problems . . . but ecological concepts change . . . no longer are communities considered normative."

Kelly and Harwell (1990) lament that the analogy of ecological health to human health is strained, given that ecosystems are far more complex than human metabolism; exposure of an ecosystem to external disturbance of ten means differential exposure to only loosely connected parts of the system. Human tissues and organs, on the other hand, are strongly internally coordinated and highly interdependent.

Even with a characteristic set of normative ecosystem ideals, the health concept would still prove problematic. Just as the definitions of human health can vary between individuals, across cultures and over time, so can they vary for ecosystem health. The uncritical application of the concepts of ecosystem health and/or integrity can lead to the application of "medical diagnoses" to achieve an agreed upon state of "health." The "new ecology" (a term applied to describe a major theoretical shift in the field of biological ecology) which calls attention to the instability, disequilibria and chaotic fluctuations of environmental systems (Zimmerman 1994) may in fact make the ecosystem health concept problematic in scientific application. Although it may resonate with environmental action and policy debate and formulation, both Sagoff (1985) and Schrader-Frechette and McCoy (1993) have drawn attention to uncertainty in ecological science.

However, Fine and Sandstrom (1993) contend that people actually see and understand their world through simple slogans and metaphors like "ecosystem health," not through any complicated theories. Ecosystem health as a metaphor provides a commanding image of environmental concern in our ecological times (Worthington 1983) and the *normative* and personal nature of the health concept. Scientists respond to metaphor in much the same way as the general public (Gieryn 1983). They are guided by dominant cultural images in deciding suitable topics for research and in constructing limits around the "boundaries of science," which are of course also shaped by how observations can occur. The ecosystem health metaphor has indeed served as a point of departure, and as an important heuristic tool for scientific investigation into environmental *diagnoses* and *prescriptions* in general, and in the case of the North American Great Lakes in particular. For scientists and the lay public alike, the ecosystem health metaphor provides a method of common engagement, a "metaphorical resource" (Fine and Sandstrom, 1993, 26), packed with shared meaning and normative direction, that can be called upon to legitimate a cause or ignite an emotional response. Thus the ecosystem health metaphor encapsulates both the ecosystem approach to human health and as well, some notion that an ecosystem, like an organism, can react negatively to some external stressor and become diseased or "unhealthy."

Conclusions

- All indicators are goal-directed; they essentially monitor "system" change given desired outcomes. All indicators (as they are selected from an unknowable universe of all possible indicators) are normative.
- "Ecosystem" and/or "environment" is a core value of interest in the identity formation and concerns of populations in the Great Lake basin.
- The value sets that determine indicator selection for ecosystem health and human health should be clearly defined for any developed set of indicators.

2.2.2 Human Impacts on the Ecosystem

The 20th Century has brought an increasing role for the physical and chemical sciences. Elucidation of temperature gradients and basic chemical parameters in water bodies was among the first descriptive work. For toxic substances in environmental media, methods have developed to quantify levels of gases, particulates and organic compounds in air (e.g. Ministry of Environment and Energy 1994) and a wide range of traditional inorganic (e.g. mercury) and organic compounds (e.g. combustion products) in soil and sediment. In water, sampling methods permit collection at distinct points within water columns of dissolved substances (e.g. phosphates), chemicals adsorbed to suspended particles (e.g. PAHs) and functional properties (e.g. biochemical oxygen demand).

Chemical analyses with increasing sensitivity have also enabled measurement of contaminants in many biological tissues of species that make up the food web (Environment Canada, Fisheries and Oceans, and Health Canada, 1991). Monitoring organochlorine pesticides and their metabolites in the fat of fish and bird species along with human foods, fat samples and breastmilk was initiated during the 1960s in response to local use and aerial transport of DDT. Neurotoxic metals also became important: mercury, because of the discovery of the role free-living bacteria play in transforming it to methyl mercury, increasing its bioavailability and subsequent concentration up the food chain; and lead because of its widespread dissemination as a gasoline additive.

Together these data on media and species have permitted sophisticated modelling of contaminant sources and movements within the ecosystem (e.g. review by McKay and Patterson, 1992). For biological species within a toxicological framework they provide the raw material to determine exposure to toxic substances, including calculations of dose based on the various routes of entry. Yet, after some of the more dramatic cases of contamination were mitigated (e.g. phosphate loading), the task of ascription of causal relationships between ecosystem observations and past or present human activities has become increasingly challenging, because of the complexity of ecosystem relationships and the political and economic implications involved.

While the increasing impact of humankind cannot be doubted (see Goudie 1994), nor should the power of human invention and innovation. In studying the effect of human activity on ecosystems, we must, therefore, not only examine the ecosystem but human adaptability as well. A focus of ecological anthropology (e.g. Geertz 1963; Vayda and Rappaport, 1976) is based on Steward's (1955, 1978) ideas on the causal connections between social structure and way of life. The nature and rate of environmental change (often degradation) cannot be divorced from this way of life, including needs, wants, technology and values.

Why does human activity in an environment take the form it does? This is a vital question for advocating particular changes in activity for ecosystem protection. Further, the form of activity is predicated on how a people perceive resources and their relationship to the environment. There are several ways to perceive that relationship; Kluckhohn (1953) suggests three:

- people as subjugated to nature, living at the mercy of a powerful and dominant environment
- people as over nature, dominating, exploiting and controlling the environment
- people as an inherent part of nature, trying to live in harmony with nature.

In the Great Lakes area, tension exists between the second and third, although it may be easier to understand the present status of the debate over ecosystem by asserting that the tension is exacerbated by the fear of the first, especially with respect to human health and wellbeing if control over our affairs is apparently reduced to the demands of ecosystem health.

These concerns are often considered when credible scenarios of potential outcomes are expressed using a range of tools. Ecological risk assessment and the more legally bound, environmental impact assessment, are increasingly being carried out on a wide range of human development projects and interventions. These tools permit explicit examination of trade-offs between human-oriented outcomes and environmental impacts. Although often cast in traditional cost-benefit terms with the cost of mitigation procedures weighed against the benefits of the particular development, other approaches to incorporating human interests and values in ecosystems are increasingly advocated (Public Health Coalition 1992). Ecological economics is one emerging field that questions the usual micro-economics approaches to valuations in development (Costanza et al. 1991). Among its practitioners, Daly (1991) has argued for the need to estimate and set limits on the maximum scale of human development activities possible within particular ecosystems up to the global scale.

If values are important in understanding how human activity affects the environment, it is perhaps also necessary to examine environment as a value in relation to other values and life-domains. Environment tends not to be valued highly in relation to other domains, such as family income and standard of living that are most highly valued (Eyles 1985; 1990). In one investigation in which people were asked the defining characteristics of where they lived, environment trailed such dimensions as social relationships, economic wellbeing, memories, roots, and even no opinion and nothing (Eyles 1985). This ranking reflects a lack of understanding that all of the valued dimensions depend ultimately on the environment.

Environment or ecosystem does not then necessarily engage significant life-domains or core values. The issue can, however, be considered differently. When does environment engage us? And what values are expressed? Our answers can only be suggestive. First, we are engaged when we are threatened. Edelstein (1988) in his work on contaminated communities makes the useful distinction between lifestyle and lifescape, the former referring to people s way of living, the latter to our fundamental understandings about what to expect from the world around us our social paradigm. When lifescape is threatened, core values are threatened. These ideas have not been fully developed, although some research suggests they include those things that indicate threats to our children's health, property values, fear of unknown, latent health effects (Eyles et al. 1993).

Second, the values expressed in environmental concern are again not well-articulated in empirical research. There has been some use of altruism to explain intentions to ameliorate environmental problems (Black et al. 1985). As Stern et al. (1993) explain, Altruism suggests that pro-environmental behaviour becomes more probable when an individual is aware of harmful consequences to others from a state of the environment and when that person ascribes responsibility to her/himself for changing the offending environmental condition. This is but one value orientation. Others include the land ethic, which emphasizes the welfare of non-human species (Heberlein 1972) or of the biosphere itself, as in deep ecology (Devall and Sessions, 1985). Still others implicate economic and socio-biological orientations (Hardin 1968; Olson 1965). Altruism seems the most likely value basis for environmental concern. Through it, concerns for the ecosystem are linked to concerns for other humans. Implicated in it are other fundamental human values such as community, equity and justice. Thus ecosystem health is indirectly pursued through human actions directed at humankind. But, this emphasis on ecosystem health through altruism is but one value orientation, and it is a fragile commitment. Human activity is geared toward human betterment, health and wellbeing. However, those who perceive the dependence of these on the environment tend to have strong environmental concerns and values.

Human choices are not free of the limits imposed by being part of the ecosystem. We cannot choose whatever kind of world we want. We can and do have models of the impact of human activities on ecosystems and the predictable consequences for humans if the ecosystem shifts from one state to another, e.g. arable land to desert or forest to eroded hillside. It is a human value choice whether we attempt to extend the lifespan of the human species, as much as possible, or view the human good as the maximum potentiation of the present -- getting the most out of our environment as it is now. The moral issue is not the extinction of the human species; the species will become extinct sooner or later. Rather, it is whether the extinction is at human hands or by natural forces, not the number of premature human deaths involved in the extinction process. The ethical issue is the lifespan of the species, the number of generations that enjoy this planet earth before the extinction occurs.

Human health, especially the positive definitions of human health, focus on the individual. The maximum potentiation of humans alive today may result in the rapid extinction of the species. A fundamental flaw with the concept of ecosystem health as the value for environmentalists to champion lies in the concept of human health itself. And yet human beings have devised social systems which incorporate societal as well as individual values. Environmentalists tend to extend these societal concerns to include concerns for other species. In the long run, human welfare depends on these species.

Conclusions

- Separate indicators of ecosystem health and human health are required since their goals and targets are different, in the former case ecosystem stability, persistence or resilience, in the latter the disease or illness state of individuals.
- There is a link, however, between indicators of the health of human populations (public health) and indicators of ecosystem health.

2.2.3 Environmental Burden of Illness

As stated earlier, human health can be defined positively and negatively. In a negative sense it can be considered an absence of disease (defined against objective/medical criteria of pathological processes), or an absence of illness (defined by the experience of the individual). In this section we will address the evidence for effects on health as an absence of disease related to exposure to environmental agents.

The evidence for an effect on health comes from environmental epidemiological studies when available. Such studies are limited by the difficulties in assessing the exposures to toxic agents at environmental exposure levels (i.e. accurately classifying who is relatively highly exposed and who is not). All epidemiological studies examine the difference in health outcomes between those who are highly exposed and those who have low exposure to the agent of concern. If a gradient of exposure cannot be found, epidemiological methods are useless, even though the consequences of the exposure may be very real and very severe. Consider the difficulty in knowing whether smoking was related to lung cancer if everyone smoked 20 cigarettes a day. Even if there is a gradient of exposure, we have to be able to correctly classify those who are highly exposed and those with low exposure to get some reasonable measure of the exposures. Otherwise the misclassification of exposure will lead to false negative results in studies. It is quite possible that some widely dispersed pollutants in the environment are having effects we cannot detect epidemiologically for precisely these reasons.

Epidemiological studies also require that the outcome - the health effect - be measured accurately. Much of the concern regarding environmental exposures relates to subtle effects - influences on neurobehavioural development, IQ, psychosexual development and fertility - that may be significant if they occur broadly throughout the whole population, although the impact or deficit for an individual is of little consequence. Other outcomes are of high significance for the individual - cancers, birth defects - but are at low risk at environmental levels of exposure. Because these outcomes can be caused by many factors, it is often difficult to determine if an environmental factor is adding to the burden of illness. Overlapping exposures, all of which in themselves seem to increase the risk of a particular symptom, would seem together to account for more than 100 percent of increases in symptoms. Appropriate statistical techniques must be used to adjust for the lack of independence between exposures, and interactions between exposures and personal characteristics (see Walters 1983). The criteria to assess environmental epidemiological studies are found in Table 1 (Frank et al. 1988).

Environmental health risks can also be estimated by risk assessment protocols using animal data on cancer and birth defect risks. In some situations health effects that have manifested themselves in occupational settings can reasonably be extrapolated back to environmental exposures. More importantly occupational epidemiology often confirms that health outcomes seen in animals will occur in humans if exposure is high enough. For example, Friberg (1984) discusses the evidence for the effect of cadmium on the kidney-linking animal and occupational health data.

The environmental burden of illness refers to the proportion of illnesses, of particular health outcomes that can be attributed to particular environmental exposures. If the relative risk of an outcome occurring in exposed individuals is known and the prevalence of exposure is known, the risk attribution to the exposure in the population, the population attributable risk, can be calculated. We will limit this discussion to the impacts that are or may be occurring in human populations living in the Great Lakes basin as a result of exposures in the ambient environment (exposure to outdoor air, drinking water, recreational water use, exposures to soil) or mediated by the ambient environment (exposure through food). We have included those toxic substances in this section for which there is good evidence for the health effects outlined and for which significant exposure and/or community concern exists in the Great Lakes basin. This section is not an exhaustive review of the evidence on any of the health effects listed. It is meant to cover those areas for which further research and prudent action is recommended. Health effects related to occupational exposures, indoor air quality (except radon), or major environmental disasters are not considered. These exposures can, however, be instructive with respect to risks that may be present from lower-level exposures in the ambient environment. Unfortunately, little precise information exists on exposures to toxic chemicals through the ambient environment in the Great Lakes basin.

Exposure to ozone and particulate (PM-10, i.e. particulate matter of 10 micrometers or less), especially sulphate particulate is widespread in the Great Lakes basin. Attributable risk estimates for the role of air pollution in hospital admissions and deaths for cardio-respiratory illnesses have advanced considerably over the past decade. A series of studies, including one in Detroit, have failed to detect a threshold for increases in deaths associated with small increases in particulates that can be inhaled fully into the lungs (particulate matter of 10 micrometers or less, PM-10) (Schwartz 1991). Similarly, subjecting environmental data on air pollution and hospital admission data to advance-time series analyses, Burnett et al. (1994) showed the increases above baseline admission rates attributable to ambient air pollution, ozone and sulphates in particular. Sulphates in air are widely monitored in Ontario, but sulphate may be an indicator of acid aerosol or PM-10 exposure, rather than sulphate itself causing the effect. This effect was present only for the warm months of May through August. Infants up to one year of age were the most affected, with 14.8% of all admissions for respiratory illnesses to hospitals in Ontario attributable to ozone or sulphate exposure. This study has generated the best attributable risk estimates for an ambient environmental exposure of any study in the Great Lakes basin. Given its major role in environmental burden of illness, extrapolation of these figures to particular Areas of Concern should be possible based on local air pollution data collected by provincial or state authorities.

The second most general ambient exposure of concern is exposure to certain organic compounds and metals in the air of the major industrial cities of the basin. In this case, risk assessment methodology generates estimates of cancer risks related to lifetime exposure. Comparison to total population risks for particular cancers (up to 10 percent for some cancers) reveals that the proportion attributable to individual air toxics is very small, not exceeding 1/10 of one percent. Given the large population exposed to the risks associated with a number of these compounds, their presence in our air is a public health concern. Cancer risks related to these air pollutants are well covered in the Windsor Air Quality Study (MOEE 1994) and the review of the outdoor air quality in the City of Toronto (Campbell 1993). The agents in the Windsor study with the major portion of the cancer risk range greater than one in 100,000 for lifetime exposure as an outdoor air pollutant are benzene, 1,3-butadiene (from car exhaust) and chromium VI. Cancer risks for diesel fumes are well established (Carey 1987) but the risk at ambient levels of exposure is unknown. Radon gas comes from the natural environment into homes and buildings and concentrates in indoor air. There is a very low risk of lung cancer from this indoor exposure, which has been difficult to demonstrate in epidemiological studies (Lubin 1994). Radon could be a problem in the portion of the Great Lakes basin that is on the Canadian shield, but it is also a community concern in the Port Hope area.

A considerable body of toxicological and epidemiological data has developed because of the stakes involved for the producers of chemicals and those exposed to chemicals, particularly in occupational settings. Higginson (1992) reviewed studies attributing portions of the cancer burden to different factors, but pointed out gaps on exposure information that required considerable assumptions to produce estimates, particularly with respect to physical environment and non-occupational exposures.

Expert groups, such as that brought together by the International Agency on Research in Cancer, have estimated the theoretical preventability of cancers (Tomatis 1990). Miller (1992) carried out a similar process for Canada, examining a series of actions that might reduce cancer incidence and comparing the reductions to those that are potentially preventable, based on intercountry comparisons of incidence. Melanoma from ultra-violet radiation stands out (40% reduction), although uv-B exposure is only one factor related to melanoma risk. The thinning of the ozone layer over the Great Lakes basin may be associated with increases in skin cancer and cataracts over time, but these effects have not yet been documented. We do not know the trend in personal exposure to sunlight in the Great Lakes basin, but the role of ultraviolet exposure from sunlight in skin cancer is well established (Ontario Task Force on the Primary Prevention of Cancer 1995).

Trihalomethanes are known to be carcinogenic in animals and are generated in the chlorination process for drinking water. The strongest evidence with respect to drinking water is increased risk of bladder and rectal cancer (Morris et al. 1992), but the carcinogenicity of chlorinated drinking water for humans cannot be considered proven. The major public health benefits of treating water with chlorination are well recognized (see Bellar et al. 1974; Morris et al. 1992); the same authors establish the carcinogenicity of trihalomethanes, using a meta-analytic approach based on case-control studies. The proportion attributable to drinking water would be very low, but most of the Great Lakes basin population drinks chlorinated water. An association between cancer incidence and water supply trihalomethane concentrations has yet to be demonstrated in a Great Lake state or Ontario (Gilman et al. 1992), partly due to the variable sources of drinking water among Great Lakes populations. Nevertheless, further exploration of the risks and benefits to human health of chlorination and its alternatives is clearly warranted.

Tritium is a hazardous substance in areas adjacent to nuclear power plants in Canada because of the use of heavy water in CANDU reactors (ACES 1994). The **Advisory Committee on Environmental Standards** (ACES) in Ontario recommended that the objective for tritium in water be immediately reduced to 100 becquerels/litre (in response to the recommendation by the Ontario Ministry of Environment and Energy to reduce the current objective of 40,000 Bq/L to 7,000 Bq/L) and be further reduced to 20 Bq/L within five years. Tritium concentrations in some Ontario drinking water supplies currently exceed the 20 Bq/L standard from time to time. This recommendation was made on the basis that tritium is a human carcinogen and that the same level of acceptable risk should be applied to it as to other chemicals that are human carcinogens. Exposure occurs through drinking water but also occurs through air and the food chain.

Diseases involving stomach and intestinal infection due to foods and water contaminated by micro-organisms are another major category for which attribution to environmental exposures is routinely made by public health authorities (Todd 1991). Outbreaks from contamination of municipal water supply systems by recently recognized protozoa (e.g. Moorehead et al. 1990) have constituted the largest clearly identifiable human burden of acute illness based on use of water from the Great Lakes or waters flowing into them. Both Milwaukee (MacKenzie et al. 1994), drawing from Lake Michigan, and Waterloo, drawing from the Grand River which flows into Lake Erie, have experienced difficult-to-control outbreaks of contamination by cryptosporidium species. These outbreaks are linked to contamination sources within watersheds that cannot be managed efficiently and effectively at the point of water treatment plants, but are better dealt with by watershed management schemes. Small outbreaks of giardia (another protozoan) and viral diseases such as hepatitis-A do occur, usually transmitted through food (Todd 1991). Giardia is consistently present in some wellwater supplies. Viral diseases transmitted through food in the Great Lakes basin are almost always imported, i.e. acquired by the initial case outside the basin. Exposures to sewage-contaminated waters during bathing (Fleisher et al. 1993) also result in illness, although Great Lakes basin cases are poorly documented.

Emerging literature such as that linking persistent organochlorine pesticide exposure and breast cancer (Wolff et al. 1993) have not been fully incorporated into standard cancer risk estimates, partly due to the ongoing controversy as to the significance of these findings (Ritter 1994; Kreiger et al. 1994). Risk assessment techniques have been used to estimate the cancer impact of eating Great Lakes fish contaminated with persistent organochlorines (Foran et al. 1989). Based on DDT and dieldrin levels in the fish and consumption rates, increases in cancer numbers for various concentrations are calculated. Yet these are difficult to relate to particular areas unless distributions of fish consumption are known; such data are often of variable quality and representativeness (Ebert et al. 1994).

The established effect of dioxins in animal models and the probable effect of DDT, PCBs and other persistent organochlorines on the immune system are likely to be an endocrine modulation effect (see Chapter 2.4). Exposure to dioxin is primarily through the food pathway because of distribution through the atmosphere (Davies 1988). Reliable risk estimates associated with this exposure are not available.

There is significant public concern regarding exposure to currently used pesticides. Organophosphate pesticides are used in institutions such as to control pests like cockroaches. Although case reports for health effects related to exposure do exist, these effects in the majority of the concerned population likely fall in the category of environmental hypersensitivity (see below). There is evidence that aldicarb, a carbamate pesticide, may impair immune function (Fiore et al. 1986). This exposure has occurred through well-water in Wisconsin. The **International Agency for Research on Cancer** (IARC) has classified several herbicides as possible human carcinogens and the recent report of the Ontario Task Force on the Primary Prevention of Cancer (1995) has recommended reasonable and measurable timetables to sunset these herbicides. Some fungicides have been shown to be carcinogenic in animals and significant exposure can occur through food, such as the consumption of pick-your-own strawberries (Mitchell et al. 1987). Use of these fungicides is now restricted in Canada and the United States.

Recent concern has focussed on neurobehavioural deficits resulting from in-utero exposure to persistent toxic substances. The effect of low levels of lead exposure are now well established (Needleman and Bellinger, 1991). Mercury is known from environmental disasters to produce neurobehavioural deficits in children, and modelling of fish consumption and methylmercury intake is feasible (Richardson and Currie, 1993). Epidemiological methods have not established effects in the Great Lakes basin. The role that aluminum exposure, primarily through drinking water, may have in the development of Alzheimer s Disease has been extensively reviewed (Nieboer et al. 1993), and although there are major weaknesses in the epidemiological evidence, a possible role cannot be ruled out by other scientific evidence. Infants of PCB-contaminated, fish-consuming mothers were smaller than controls and had behavioural deficits and impaired visual recognition (Fein et al. 1984; Jacobson et al. 1984; Jacobson and Jacobson, 1988), but the significance of these findings is still debated. Several research projects in progress in the basin are attempting to resolve this issue (ATSDR 1994). Limited evidence exists for direct neurotoxic effects related to exposure to organic solvents from waste dumps (e.g. Hertzman et al. 1987).

Determining the burden of reproductive problems expected at the levels of exposure thought to exist among human populations in the Great Lakes basin is fraught with uncertainties that have been highlighted in the Commission' s *Seventh Biennial Report* (IJC 1994). Reproductive outcomes refer to birth defects and to the impact on fertility. Cadmium, lead, mercury and chlorinated solvents are toxic to human reproduction, but at levels considerably above those found through environmental exposure in the basin. Controversy has surrounded the attribution of reported reductions of sperm counts in industrialized countries to increasing exposure to exogenous (from outside the human body) estrogens such as nonophenols, phthalates and persistent organochlorines (Carlsen et al. 1992; Bromwich et al. 1994). Studies are underway to examine contaminant levels in a range of angler, minority and other populations in the basin (ATSDR 1994) and new sensitive outcomes are being examined in relation to these levels (e.g. time to pregnancy). Some potential health effects such as changing the frequency of behaviours more common in boys or girls (dimorphic behaviours) due to environmental estrogens still remain unexamined.

It is beyond this scope of this discussion to outline the burden of illness related to environmental hypersensitivity. This illness has been increasingly attributed to physical environments (Ashford and Miller, 1991) but is likely associated with specific social environments as well. A set of psycho-social impacts (stress, anxiety, worry) may not be recognized as "disease" but may be significant in experiencing an environmental exposure (Edelstein 1988; Taylor et al. 1993). Other interpretive models than traditional epidemiological ones are required to understand the linkages between such experienced "illnesses" and ecosystem parameters. Other investigative methods, based on qualitative traditions, are also required (Eyles et al. 1993).

Indicators of Environmental Burden of Illness

It would be useful to determine the magnitude and trends in the impact of environmental factors on human health outcomes. A wide variety of morbidity and mortality statistics are kept, which are useful in health care service planning. These data do not, however, reveal the cause of the health effect. All health outcomes have a multitude of causes or risk factors; environmental agents are but one contributing factor. Several approaches have been tried to isolate the attributable risk associated with the environment (Walters 1983).

Cancer and birth defect data have been mapped in atlases (Gilman et al. 1992; Johnson et al. 1992; Mills and Semenciw, 1992). Geographic patterns do emerge in these atlases, but it is not only environmental risk factors that vary geographically. Rather than the atlas giving answers that the high rate of cancers or birth defects in a particular area is likely due to particular environmental conditions, we usually can explain the variation on the basis of what we already know about the risk factors for the specific health effects. Atlases, however, can at times be useful to generate a hypotheses to test by other means.

Cancer outcomes are poor indicators of environmental effect because the latency between exposure and outcome is usually several decades. The exception to this general rule is the use of childhood leukemia as an endpoint for exposures to radionuclides. The latency for some leukemias is two to ten years. Studies of the association between proximity to nuclear power plants and leukemia have shown a slight (but not statistically significant) trend toward increased leukemias (Clarke et al. 1991).

Birth defects (minor and major) occur in three to four percent of all pregnancies in Ontario (Mills and Semenciw 1992). Some of this effect is related to background exposure to teratogens, including radiation in the environment and naturally occurring chemicals in food. Although birth defects are relatively common, they are not good indicators of effect related to toxic agents added to the environment by human activities. There are a wide variety of birth defects and the effect of any specific agent will be only at critical stages in the development of the embryo. Individual types of birth defects have a low incidence in any geographic area. An environmental exposure over a relatively small geographic area, even if it were a strong teratogen, would produce few specific birth defects over a short period of several years. The increase in outcome will be less than the chance variation in outcome and thus not be detectable by epidemiological methods.

In some situations the environmental effect of a pollutant is the major source of variation in the health outcome. Thus a clear association between hospital admissions for asthma and respiratory problems has been demonstrated related to particulate, ozone and sulphate pollutants in the air (Burnett et al. 1994; Dockery and Pope, 1994). Indeed this effect varies directly with air pollution levels without evidence of a threshold. Hospital admissions for children under one year show the effect most clearly, and thus these hospital admissions would make a good indicator of the respiratory burden of illness. The lag time for the effect is up to three days. Compare this to several decades' latency for lung cancer and it is clear why trends in lung cancer do not give a good indication of effects related to those air pollutants that clearly do add to the burden of lung cancer.

Although the increased exposure to uv-B in the Great Lakes basin because of thinning of the ozone layer should result in increased skin cancers(squamous and basal cell carcinomas) and cataracts, this effect may also be moderated by measures individuals take to reduce their exposure. Skin cancers and cataracts have long latency periods, so that today's trends represent the effect of environmental and behaviour changes several decades ago. Trends in these outcomes deserve study, but they do not serve well as indicators of how our environment is doing today.

The practical reality is that the association of low-level environmental exposures to health effects can rarely be established by epidemiological methods. Risk assessment methods can give reasonable estimates of risk at levels of exposure in the ambient environment. The limitations of science, however, do not mean that health effects related to ambient environmental exposure are not occurring or are not of concern (see Chapter 2.4). For some toxic substances like lead, very good evidence from well-controlled epidemiological studies and/or risk assessments indicate that health effects are or very likely are occurring within the range of ambient exposure. In these situations, the most practical way of determining the trend in the environmental burden of illness then becomes measurement of the change in exposure, not measurement of the health outcome. Blood lead surveys have routinely been done for this purpose. The neurobehavioural impact of low levels of blood lead has been established in cohort studies (Needleman and Bellinger, 1991). Population surveys of blood lead levels in children can then establish the likely environmental health impact from lead. Population surveys of children's IQ and measurement of environmental concentrations of lead (air lead, soil lead) would never be able to establish the environmental burden of illness. Blood lead is a much better indicator of actual received dose than measures outside the body. Children's IQ is influenced by a wide variety of factors that, in general population monitoring would override any clear indication of a lead effect. Monitoring of other persistent toxic substances (such as PCBs in human tissues) would similarly be useful.

Blood lead is one example of a bioindicator, a measure of exposure. Bioindicators can also measure physiological changes as a result of exposure. Environmental agents are, however, not specific in producing these changes, so that the actual application of bioindicators of effect in Great Lakes basin studies has not proved to be useful (Kearney and Cole, personal communication).

What can summarize the best measures to monitor the potential of environmental exposures to produce human health effects are the actual monitoring of the agents known to produce the direct effects. Further studies of toxics in food similar to Davies (1988) are warranted. Blood lead surveys are appropriate, but with the elimination of lead in gasoline, lead exposure has become a less serious issue in the Great Lakes basin. A case can be made for creating a database to monitor persistent organochlorines in the population, but this recommendation may be influenced by the outcomes of current ATSDR-funded studies on PCBs and neurobehavioural effects (whether or not the results of the Michigan fisheater cohort studies are confirmed). New research on endocrine modulators is needed (see Chapter 2.4). Until there is a much clearer understanding of the effects of these chemicals, better characterization of exposure (serum total PCBs likely being the most cost effective and representative measure) is warranted.

In terms of actual effects of toxic agents in the environment on the health of humans in the Great Lakes basin, hospital admissions for children under one year of age for asthma/respiratory disease is the only precisely measurable indicator at this time.

2.2.4 Indicator Selection Criteria

Various attempts have been made to establish lists of criteria for indicators, recognizing that no single indicator is likely to meet all the criteria. The Council of Great Lakes Research Managers developed 16 criteria for indicators of ecosystem health (IJC 1991; see Table 2)Developed by the Council of Great Lakes Research Managers. In the report, *Bioindicators as a Measure of Success for Virtual Elimination of Persistent Toxic Substances* (1994) submitted to the IJC's Virtual Elimination Task Force (VETF), four criteria are suggested: specificity to the substances; placement in appropriate scales; ease and cost of measurement; and social relevance/public perception. This is a sensible short list. Eyles and Cole (1995) in their monograph use a simplified but more generic approach to indicator criteria applicable to ecosystems and human health. They propose two sets of indicator criteria: science based and use based, with the caveat that all indicators are goal directed and that good indicator selection is dependent on specifying the problem to be measured and managed. The science-based criteria are:

- **Data availability and suitability.** It is likely because of cost constraints that existing datasets must be used where possible, but it must be remembered that those data may have been collected for different purposes than now required.
- **Validity and reliability.** To be valid, an indicator must measure the phenomenon or concepts it is intended to measure. There are four types of validity:

  -Face validity (after evaluating the rationale behind indicator selection, is it a reasonable measure?)

  - Construct validity (does the measure behave as expected in relation to other variables in the scientific model in which it is being used?)

  - Predictive validity (does the measure correctly predict a situation which would be caused by the phenomenon being measured?)

  - Convergent validity (do several measures collected or structured in different ways all move similarly over time?)

  Reliability depends on the amount of error variance in an indicator measurement, and is determined by carrying out repeat measures of the same indicator.

- **Indicator representativeness.** Questions of data representativeness are quite easy to recognize, based as they are on sampling procedures, and size and population characteristics. More troublesome is the issue of indicator representativeness. Is it possible to select one or several indicators that cover the important dimensions of concern? Indicator representativeness may be enhanced by developing an index, combining indicators. However, even if the problems of combining indicators can be overcome, if the index rises or falls, it remains unstated which of its constituent indicators are rising or falling.
- **Indicator comparability.** Not only must data be available for several time periods, they must also mean roughly the same thing at those times. The sensitivity of measurement procedures or the nature of the population being studied may change.
- **Disaggregating indicators.** To be informative, indicators must be related to other variables such as age, sex, locale and various characteristics of the involved individuals or communities. If an indicator can be broken down by several variables, it tells us a great deal more, so long as the numbers do not become too small.

The use-based criteria for indicator selection are:

- **Goal oriented.** There should be as much clarity as possible in the definition of the relationship between the indicator and the goal (purpose, use, state) that it is meant to monitor.
- **Feasibility.** Are the data already collected? If they are, are they available for the right time periods and at the desired geographical scale? If they are not, how feasible is it to create surrogate or indirect indicators of the phenomenon of interest? If this is carried out, what happens to scientific validity? If the data are not collected, how expensive would it be to alter the information-gathering system?
- **Desirability.** Do the indicators inform on the state of the ecosystem or of health in ways that are perceived as important by those affected? Do the indicators enable residents of a particular region or the members of a particular population group to assess their needs and risks? Do the indicators enable them to make meaningful comparisons with similar groups of residents or populations members? A feature of desirability is in fact credibility (a user-version of validity).
- **Gameability.** If there is to be a link between public perceptions and indicators, then we must ensure that indicators are not gameable, i.e. that they cannot be "gamed" or altered by those with something to gain (while others lose) from the indicator being pushed in a certain direction at a particular pace. For example, if resources for improvements in water quality are dependent on a particular level of microorganisms, it may pay a municipality to defer reporting improvements until budgetary allocations are made.
- **Manageability.** The ability of human beings to process information is limited. Therefore, the number of indicators to be used should be as small as possible.
- **Balance.** There should be a rough balance among all of the phenomena of interest.
- **Catalyst for action.** We may choose to distinguish indicators that more or less act as catalysts for action, whether on the part of industry, government, communities or individuals. This criterion is also important in that it relates indicators firmly to the goals of monitoring.

These criteria act as criteria for the suitability of indicators in themselves and as criteria for specific indicator selection. They enable those concerned with monitoring ecosystems and human health in the Great Lakes basin to consider matters of proof (primarily, but not exclusively the scientific list) and of prudence (primarily, but not exclusively the use list) together.

2.2.5 Summary

It is necessary to ask continuously: how is human health relevant to the specific ecosystem issues under consideration? What "evidence" (scientific or philosophic) underpins the connection of human health and ecosystem health? How might we judge the significance of any identified connection? In answering such questions through identifying plausible indicators, we must always be aware of the normative basis and power of science.

We must recognize in our efforts to "measure" ecosystem health and human health as an integral part of it that "ecosystem," health and similar terms are abstracted notions with implications not only for what but also how we measure things. The notions that become powerful, that have resonance, take on metaphorical significance, hence the need for value clarification. We must also recognize that adoption of a prudent or precautionary stance towards the evidence of health effects must be open to scientific evidence. In our use of the metaphor ecosystem health, we must exercise caution concerning the connectionist view of the world contained in the metaphor. The utility of the connectionist, network approach to human health in relation to ecosystem is a frame-work -- an overarching recognition that warns of possible trade-offs, side effects, possible unintended consequences and unanticipated events. It should not be so overarching that it limits our capacity to act in subsystems or among subpopulations. For this, we must battle the power of metaphor.

Although it is difficult to attribute a specific proportion of overall burden of illness to the environment or ecosystem degradation, human health is a vital consideration in the ecosystem health paradigm. Ecosystem health internalizes human wellbeing as part of the environment, while a human health focus internalizes environment for individual and community wellbeing. The strength of the metaphor or paradigm is clear. Ecosystem health sees humans as integral parts of nature. The metaphors resonate strongly with core values about ourselves, our identify and our place in the world.

2.2.6 Recommendations

- **The Science Advisory Board recommends that the Commission, in its priority activities and its advice to the Parties, support further research to determine ambient levels of exposure to toxic chemicals in the Great Lakes basin and incorporate the following general principles for further development of environmental burden of illness indicators:**
    - continued monitoring of toxins in media, including trihalomethanes, nitrates, microbial contaminants in drinking water, PM-10, ozone and sulphates in air, and toxic bioaccumulative chemicals in general
    - systematic synthesis of water sampling results for microbial contaminants that result in beach closings. Consider complementing these with information on symptoms among beach users
    - inclusion of relevant ambient exposure factors (e.g. time outdoors, based on activity record) and consumption factors (e.g. freshwater fish and wildlife) in population-based health surveys. General population-based measures of body fluid levels of key contaminants (e.g. PCBs or DDE for the organochlorines in serum and breast milk, mercury and lead in whole blood for the metals) could be linked with these and other relevant social factors
    - surveillance of established environmental health outcomes, such as asthma, such that these conditions may be considered as sentinels for pollution effects
    - recognition that some human illness indicators are poorly suited to provide useful information on the impact of environmental matters on human health, e.g. most morbidity and mortality data that are routinely collected, including cancer rates
    - development of longitudinal designs around exposures and conditions of interest to enable stronger inferences concerning relationship between exposure and health outcomes.

It is also recommended that the Commission:

- **support actions that would lower human exposure to persistent toxic substances such as PCBs and lower concentrations of these substances in human tissues.**

- **support the development of indicators and scales that measure the environmental component of illness and wellbeing and indices of environmental stress and environmental condition**

- **continue to monitor state of the environment and sustainable development reporting in order to inform its recommendations to the Parties, regarding Great Lakes basin indicators. As these reports often take a broad-based approach to indicator selection, this monitoring is necessary to help ensure the integration of human exposure considerations into assessments of contamination in relevant fish and wildlife species.**

2.3 Weight of Evidence: Approaches to Decisionmaking in the Face of Uncertainty

2.3.1 Introduction

> *As more and more scientists venture into the arena of public policy, they are proving a valuable point: scientists, no matter how expert at their craft, are no wiser than anyone else when it comes to public policy.*
>
> *David Sarokin*, Washington, D.C. (From: "Letters," *Science*, Vol. 261, September 10, 1993, commenting on the editorial, "Pathological growth of regulations")

The *Sixth Biennial Report on Great Lakes Water Quality* of the **International Joint Commission** (IJC), in 1992, proposed as its first recommendation the application of a "weight of evidence" approach to identify and virtually eliminate persistent toxic substances. In that context, weight of evidence referred to considering together the many studies that indicate (or refute) injury or the likelihood of injury, to determine if the evidence is sufficient on which to base conclusions and policy decisions. The Commission elaborated on this proposal in its *Seventh Biennial Report* in 1994, suggesting a "pragmatic" definition drawn from both science and law. This definition noted that the cumulative weight of the many studies that address the question of injury or the likelihood of injury to living organisms should be considered. It was noted that this approach draws on formal science, logic and common sense. Many methodological and definitional questions remained, however. During a workshop at the 1993 Biennial Meeting, Commission members committed to making a priority for the 1993-95 cycle an analysis of how to proceed to clarify these questions. This report is a response to that priority.

Twenty years of experience with very diverse persistent, toxic and bioaccumulative hazards in the Great Lakes basin suggests the need for a systematized approach to evaluating the range of health and ecological effects putatively linked to these environmental exposures. Decisions as to possible measures to prevent or mitigate require explicit methods for dealing with the considerable uncertainty that often exists. Sometimes there is clear evidence of causation, in the form of "mature" epidemiological studies of human health outcomes. These studies can be analyzed by existing or new epidemiological criteria for assessing the quality of evidence on causation, such as those that Sir Austin Bradford Hill first proposed some 30 years ago. Typically, such studies estimate the strength of association between measured exposure to the contaminant and a specific, well-measured human health or natural resources outcome. One example is the evidence in the Great Lakes basin that the organochlorine family of PCBs has induced effects on wildlife. In this case harm to wildlife was observed first, and efforts to identify environmental agents associated with such harm and appropriate abatement measures followed.

However, experience in the Great Lakes also has required consideration of threats to biological diversity from factors other than conventional toxic substances. For these a more systematic and predictive approach is needed. All of the hazards have worrisome features, despite the fact that we do not yet fully understand them. Many toxic substances can lead to cascading complex effects in the Great Lakes Basin Ecosystem, with unpredictable but potentially severe outcomes after a long latent period. Effects can occur at the molecular or cellular level rather quickly, as in the case of estrogen-imitating compounds and we cannot yet evaluate the societal significance of such effects. More often in the past we have waited many years until reproductive failure is widespread among prominent species in the food chain, and at that point mitigation is problematical. Early detection and action are preferable, but that is also the period of greatest uncertainty. In these situations, we have only non-epidemiological evidence (i.e. laboratory studies or modelling) to consider potential harm to humans, animals and/or plant populations. Considerable potential exists for serious problems if longer-term ecological or human health effects are underestimated, and no action is taken to control the substances involved.

To develop criteria that could address these issues, a subgroup of the Workgroup on Ecosystem Health was formed in 1993, to undertake the weight of evidence priority set by the Commission. This term describes a synthetic integration to consider collectively all of the scientific evidence used in decisions to limit the risks from toxic substances. However, in the process of meetings held during 1994, the study group has come to realize that the expression "weight of evidence" is confusing in its similarity to legal scholars' approach to the adjudication of evidence in general, a rather different subject. As a result, the subgroup has, with support of the Workgroup on Ecosystem Health, adopted the subtitle shown above, "Approaches to Decisionmaking in the Face of Uncertainty."

Specific Objectives

Given the above background, this report has the following objectives:

- To review critically the current methodologies for assessing evidence of potential harm to humans or wildlife from putative toxic substances or other environmental interventions as the first step toward decisionmaking
- To identify those characteristics of environmental/human harm from putative toxic or other hazards that warrant adoption of broad, protective decisionmaking approaches
- To recommend, on the basis of this review, appropriate methodologies for assessing current and future Great Lakes environmental hazards as the first steps toward their control or remediation.

2.3.2 Three Methodologies

Three major methodologies have evolved, each of which in its own way systematizes the collection and use of scientific information and assists decisionmakers in the appropriate use and interpretation of that information. These are:

- inference as to causality
- risk assessment
- reports by interdisciplinary expert panels or study commissions.

We examine, comparatively, the strengths and weaknesses of each of these approaches as applied to water quality protection issues in the Great Lakes, particularly in how well a finding can be determined and the uncertainty quantified. The following sections discuss three contexts through which the information is reviewed and incorporated into decisions. This process is referred to in general as risk management.

Inference as to Causality

The steps required to infer causality have been understood since Koch's postulates were developed a century ago for assessing the microbial causation of infectious disease. More recently, Hill's criteria (1965) have been developed for a broad class of health studies. These criteria can be used by scientists not only to identify causal linkage, but often to describe the dose/exposure - response relationship in a mathematical way.

The basic principles of Hill's criteria of causality were developed for human epidemiology. They require that an association between a hazard and effect have most or all of the following characteristics:

Strength of Association. The rate of disease or other health effect in the exposed group of organisms must be higher, in a statistically significant sense(see Footnote 1), than in a control unexposed group -- preferably matched for age, sex, calendar year, etc. The actual strength of the association between hazard exposure and health outcome is measured by **relative risk** (RR): the proportionate increase in the risk of the outcome in question, in the exposed compared to an unexposed group. "Strong" associations have RRs of four or five or more, and are almost always causal in some sense; "moderate" associations (with RRs of two to four) and especially "weak" associations (relative risks of one to two) are often either due to imprecise identification of the exposed group or a non-causal association due to other confounding factors.

Consistency of Association. The same exposure/disease association is found in studies of other populations of the same species separated by geography, time and circumstances. In other words, the observed association is reproducible.

Specificity of Association. The uniqueness of the exposure's health effect is such that it strengthens one's confidence in causality. For example, Minimata disease occurs specifically following mercury poisoning. However, with environmental and other ubiquitous agents, specificity is often difficult or impossible to prove, since so few adverse health effects are caused by only one hazardous exposure. Thus, specificity is helpful when present, but is to be expected rarely.

Temporal Association. Exposure to the hazard must precede the disease or health effect. Latency periods for carcinogenesis (e.g. from smoking) and some other exposure-effect sequences, however, may extend over decades.

Dose-(Risk)-Response Relationship. Exposure increases should lead to stepwise increases in disease incidence or risk. In environmental epidemiological studies, this is often a crucial basis for inferring causation. This criterion can be modified in certain circumstances by competing causes of death, "all-or-nothing" biological responses that cannot be repeated, and resonance-related phenomena such as electromagnetic radiation, in which the dose-response relationship can change depending on frequency and field strength. In environmental studies it is often possible only to achieve an ordinal scale for dose, cf. "more" or "less," rather than a more accurate, continuous scale. Note here that the use of the term response relationship is an analog of, but not the same as, its use in toxicology/pharmacology where the response is not a population-based *risk* measurement, but rather some biological phenomena inside an organism.

Biological Plausibility of Association. The disease mechanism should be observable in animal models using the methods of laboratory disciplines (e.g. pathology, microbiology). Unfortunately, laboratory models do not exist for some human (and animal/plant) diseases. There should, however, be a plausible biological mechanism by which the exposure-effect sequence could conceivably occur.

Coherence of the Relationship. This criterion broadly implies that the hazard-exposure effect should be compatible with the known distribution of both the hazard and the health outcome over space and time. Thus childhood acute lymphocytic leukemia could not be primarily caused by electromagnetic fields if that condition is most common in rural developing countries where few strong electromagnetic fields are found. Similar studies should confirm the relationship, including studies in other branches of science and bioscience, such as those showing similar exposure-effect phenomena in animals or plants in the wild. The latter are often added as an analogy of additional criterion for inferring causation.

Experimental Confirmation. Laboratory studies on animals can test the cause of relationships between hazards and human disease. This obviously requires, however, that appropriate animal models are available to test the relationship. For those hazard-exposure effect sequences without such models, it is generally unethical and infeasible to conduct experiments in which humans are randomly exposed to a possible hazard, to see if the putative effect ensues. Thus environmental epidemiology is virtually always bereft of this most potent of Hill's criteria for causation. Some observers think of the demonstration of "reversibility" of health effects, after hazard abatement, as equally good "experimental" evidence of causation. However, many health effects are simply not easily reversed, or have long latencies after hazard exposure and before full expression, so one may not be able to so readily demonstrate "reversibility" in many situations.

In practice the inference of causality provides the framework on which to base decisions on elimination of harmful biophysical effects in contained situations such as a workplace. It is widely used in occupational health and is necessary to investigate less well-defined situations in an environment or ecosystem.

Scientific information generated through the study of humans in the workplace has provided one avenue for understanding the broader impact of such agents in the environment (air, water, soil or food chain) or the biota (living plants and animals), which together form the ecosystem. However, human health studies alone have proven insufficient to protect fixed ecosystems for one or more of the following reasons:

- Some routes of nonhuman exposure do not exist for humans
- Some routes of human exposure do not exist for nonhumans. Humans are exposed to all sorts of commercial products that are biologically active
- Chemicals are likely to be more toxic to some nonhuman organisms simply due to interspecies differences in sensitivity, physiology, biochemistry and/or lifestyle
- Mechanisms of action at the ecosystem level may not have human analogues
- Any environmental pollution is likely to result in much higher exposure to some nonhuman species than to humans, since humans have access to air conditioning, and food and water imports that protect them from local environmental hazards
- Most birds and mammals have a higher metabolic rate than humans so they may receive a larger exposure or dose per unit body mass of some hazards

- Some chemicals released into the environment are designed to kill nonhuman organisms (pests) and result in nontarget toxicity
- Nonhuman organisms are highly coupled to their environments and therefore may experience severe secondary effects such as loss of food or physical habitat.

As in human disease, it is not always easy to identify and distinguish natural ecological changes from those potentially attributable to human action. A clearly defined biological end point with one or more associated environmental factors gives important evidence of causation, but by itself does not prove causation. Therefore in defining causality in ecological epidemiology both careful epidemiological research design and scientific supporting data from related fields is important.

In conclusion, the Inference of Causality is a methodology to synthesize epidemiological research on human, animal or plant populations and biochemical/physiological/microbiological knowledge of mechanisms. Thus the great value of the Inference of Causality lies in its integration of two disparate types of empirical evidence: the synthesis of multiple sorts of "basic science" evidence, and evidence from well-designed epidemiological studies. It represents careful scientific building of knowledge and leaves little uncertainty, **but only where there has been a large enough population of organisms with measurable exposure to a well-defined hazard to generate sufficient cases of ill-health effects to allow a statistically significant relative risk compared to control unexposed populations.** Unfortunately, all of these conditions fail to apply in many circumstances of health effects due to environmental hazards. And even when these conditions do apply, and the application of Hill's criteria is useful, the fact that one has waited until there is an actual human "body count" of affected individuals means that exposure to environmental hazards has obviously been allowed to go too far.

Limitations to this Approach: The Inference of Causality is used most appropriately with a single, well-defined and measured hazardous exposure, such as lead or methyl mercury, and a single biological effect, such as the neurotoxicity or Minimata disease. It begins with a null hypothesis, that the hazard does not cause the biological effect, and tests that hypothesis against observations using recognized statistical methodology, within the framework of particular epidemiological study designs (e.g. case-control or cohort).

While the research goals and experimental design are subject to choice, the Inference of Causality is generally considered value-free. It is also considered limited in its applicability. It usually does not, for example, include the study of mitigative activities, or the socio-economic consequences of such activities. However, when a full set of epidemiological studies and basic science information exists of relevance to a putative environmental hazard exposure and observed health effect, the application of Hill's criteria is invaluable for assessing this information impartially. Unfortunately, such full evidence is often missing in environmental hazard assessment, as has been noted above.

More frequently than not, epidemiological studies attempting to infer causality are inconclusive or have negative results, i.e. no adverse health effect is observed. This is often due to test design, the requirement of large samples, testing only one biological endpoint such as cancer death, or the effects of multiple toxic interactions. The human or ecosystem integrates all of the negative exposures received, and the resulting ill health may not be directly attributable to any one of the exposures taken in isolation. It is not possible for the science of inference, which deals best with single effects, to meet fully the challenges of multiple hazards, e.g. toxic chemicals such as occur in the Great Lakes basin.

Finally, as an approach to decisionmaking, the use of Hill's criteria is data-intensive and requires scientific products of a long period (often decades) of study. Thus, it is usually available for retrospective analysis, and less appropriate for new problems or other prospective decision situations.

Risk Assessment

The science of risk assessment addresses and quantifies, where possible and appropriate, hazard identification, dose-response (or exposure-response) relationships and exposure determination, which lead to risk characterization. Risk characterization is the primary scientific input into risk management, which will be discussed in the next section. These relationships are shown in Figure 1, taken from the International Joint Commission's (IJC) Workshop on Risk Assessment, Communication and Management, held February 1-2, 1993. Ecological risk assessment is defined as a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

[Figu Figure 1.

Environmental Risk Characterization. The Relationship Between Risk Assessment and Risk Management (After Farland 1993)

A risk does not exist unless: (1) the stressor has the inherent ability to cause one or more adverse effects, and (2) it co-occurs with or contacts an ecological component (i.e. organisms, populations, communities or ecosystem) long enough and at sufficient intensity to elicit the identified adverse effect. While some ecological risk assessments may provide true probabilistic estimates of both the exposures and the adverse effects, other assessments may be deterministic or even qualitative in nature. In these cases, the likelihood of adverse effects is sometimes expressed through a semiquantitative comparison with other more familiar exposures, risks and effects. Such assessments require sensitivity to important differences in the situations, for example, voluntary vs. involuntary risks.

The paradigm now used by the **U.S. Environmental Protection Agency** (U.S. EPA) for most human health risk assessment was developed by the U.S. National Academy of Sciences and published in 1983. Hazard identification is a part of the risk assessment process. Hazards to health or to ecological systems are those interactions with human products, activities or interventions at sufficient intensity to alter the functioning of human or ecological systems at some level of organization (including the cellular and molecular). Hazard identification depends on the collection of all relevant information derived from laboratory experimentation, epidemiology, toxicology and cytotoxicology, embryology, physiology, anatomy, biology and other relevant disciplines. From this hazard identification process, gaps in research can be identified and studies undertaken that would permit more confident statements to be made about the significance of the hazard.

Hazards other than persistent bioaccumulating toxic chemicals are recognized as sources of harm to the Great Lakes Basin Ecosystem. These hazards include recreational uses of the lakes, construction and dredging operations, invasion by exotic species, and other stressors. In 1993, the U.S. National Academy of Sciences updated its 1983 report on risk assessment to include a broader definition of hazard to include those to the ecosystem as well as hazards to human health. They cited the Georges Bank Fishery Assessment as "most complete." This assessment contained a determination of the qualitative effects of fishing on fish populations. While the assessment developed in this case was incorrect, the community dynamics described are clearly analogous to the determination of contaminant effects and can legitimately be called "hazard identification." Estimates of fishing effort and models of population response to exploitation are comparable to exposure or dose-response assessments of chemicals. The expression of outcomes in terms of future population sizes and yields carries risk characterization several steps further than was done in any of the contaminant studies in the 1983 report.

The most recent developments in hazard identification are in more broadly defined "adverse effects." Ecological risk assessments do not have an equivalent to the lifetime cancer risk estimate used in most health risk assessments. The ecological risks of concern differ qualitatively between different stresses, ecosystem types and locations. The value of avoiding these risks is not nearly as obvious to the general public as is the value of avoiding exposure to established carcinogens. Because few risk managers are trained as ecologists, effective communication between risk managers, technical staff and the public is essential in sound risk management decisions. Stressors of human health are also being identified in categories other than fatal cancers, for example endocrine disruptors or chemicals causing neurotoxicity. Often it is the public, e.g. native people, hunters and mothers, who perceive hazards first and call attention to them.

The second component of the risk assessment process is the evaluation of the dose response relationships. Valid data sets should be presented with the plausible models for extrapolation from high to low dose, and from tests in laboratory species to evaluate hazards and risks in humans. In ecosystems a more generalized relationship between exposure and response must be established. Dose response has medical-human connotations, and also is more correctly applied to chemical pollution. Exposure in an ecological sense may be episodic, such as invasion by exotic species, cyclical, for example, summer recreational boating, or continuous, like the chemical runoff from agricultural land. Exposure usually has a time dimension and a magnitude or concentration dimension. These will modify the assessment of ecosystem harm. The range of hazard potency should be included in risk assessment, and general uncertainties inherent in the assessment reflected.

Response may be direct or indirect. A secondary poisoning of raptors due to accumulation of pesticide residues in their prey, or the effects of harvesting on fish community structure, would be considered indirect adverse effects. The Science Advisory Board's Subgroup on Decisionmaking in the Face of Uncertainty has identified some more subtle indirect effects which are normally understood by scientists before they become apparent to the public, and also before changes are likely to be irreversible. It is the scientist's responsibility to sound an alarm when the probability of any of these effects is in question. A stressor may be of special concern not because its characteristics pose a current risk, but because its pathways or potential host responses do, which are not immediately apparent. For example, although a chemical pollutant appears to be isolated from the biosphere in its current state, economic activities of future generations may unwittingly release it. Furthermore, adverse human reactions may occur only at sensitive points in the human life cycle, for example, the embryonic period, whereas responses are studied for the adult organism. The ecological response may be environmental collapse due to a cascade effect in the environment or food web, whereas the exposure-response examination focuses on the first link in the chain of consequences. Detailed considerations for expanding the list of indirect adverse effects of concern to society are detailed in Appendix I. These adverse effects entail further identification of stressors, detailing uncertainties, and communicating the potential harm to risk managers and decisionmakers, even if the indirect effects are difficult to predict. There is an ethical imperative to explore the long-term consequences of our activities. Social scientists must be involved more directly in the predicting of human interference and/or interruption of predicted behaviours.

The third element of the risk assessment process is exposure assessment. This aspect has taken on a large role in the past few years, in that it focuses on the populations or subpopulations that the data indicate may be particularly exposed. The potential routes of exposure from particular pathways and sources must be identified and the uncertainties and relative importance of the assumptions, exposure models and confidence in the data must be described.

It is now well recognized that exposures vary widely by habitat, niche, food web and other considerations. Humans disperse their foods globally, and exposures to toxics may occur many miles away from the point of harvesting. Species with limited range and who are locally dependent on air, water and food make good sentinels for the local ecosystem. For humans, lifestyle, hobbies and non-traditional uses of the environment also must be considered when assessing exposure. The average adult exposure may prove inadequate to describe the significant response of children or Native people. Social science can identify and quantify these factors. Exposure assessment may be influenced by temperature, acidity, humidity or other factors influencing bioavailability and/or uptake.

Exposure assessment can incorporate the physical, chemical, pharmacokinetic and metabolic data for a chemical mixture polluting an ecosystem. It must consider chemical interactions, environmental transformations (fate, transport and degradation) of complex molecules. Examining biomarkers and biomonitoring data where available and revisiting the list of "adverse effects" of public and scientific concern are all recent developments to expand and clarify this part of the risk assessment process. Biomarkers serve as indicators of exposure and help to elucidate pathways and effects.

Risk characterization is the process of combining and integrating the information and analyses derived from the three stages of risk assessment to describe the likelihood that humans or the ecosystem will experience any forms of toxicity or biophysical harm associated with the hazard. The major components of the risk are presented, along with quantitative estimates, where appropriate, to give a combined and integrated view of the evidence.

Although impact on human health is still a major focus of risk characterization, there is increased recognition that environmental sustainability is essential to human survival and an important end point for human planning. Risk characterization describes the nature and often the magnitude of risk to the ecosystem, including any uncertainties expressed in understandable terms to decisionmakers and the public. Further extension of the risk characterization definition provided in the 1983 U.S. National Academy of Science report is needed to focus on uncertainty, to facilitate expression of risks in management-relevant terms (including valuation), and to emphasize the importance of communication between scientists and managers. Risk characterization synthesizes the results of technical analyses and expresses them in a form suitable for valuation studies or other policy analyses carried out as part of risk management.

Formal analysis of uncertainty is another major subject needing improvement in ecological risk assessments of all types. The "uncertainties" discussion group at the IJC workshop in 1993 identified three general categories of uncertainty that affect all types of risk assessments:

- Measurement uncertainties, e.g. low statistical power due to insufficient observations, difficulties in making physical measurements, inappropriateness of measurements, and natural variability in organic and population response to stress
- Conditions of observation, e.g. spacio-temporal variability in climate and ecosystem structure, differences between natural and laboratory conditions, and differences between tested or observed species and species of interest for risk assessment

- Inadequacies of models, e.g. lack of or knowledge concerning underlying mechanisms, failure to consider multiple stresses and responses, extrapolation beyond the range of observations, and instability of parameter estimates.

Measurement uncertainties can be reduced by making more and better measurements. These uncertainties cannot be reduced but they can be communicated to decisionmakers and the public. It may be possible to incorporate some uncertainties in formal model uncertainty analysis, but inadequacies in the models themselves or scientific ignorance in general are much more difficult to quantify. Each of these uncertainties and associated assumptions, however, should be explained as explicitly as possible for those who must use and interpret the risk characterization conclusions.

From this discussion, and the report summarized in the IJC 1993 workshop on risk assessment, the strengths and weaknesses of this methodology for decisionmaking are clear. The strengths are: (1) risk assessment is designed to organize scientific information specifically for decisionmaking and policy purposes and is rapidly becoming reproducible in its applications; (2) because it is capable of formalizing uncertainties, it can be quantitative in those areas where other approaches are largely qualitative (i.e. where the pathways by which laboratory outcomes are observed can also be expressed in field conditions); (3) it is designed to be prospective and as broad and interdisciplinary as the problem. By design, it complements valuation studies and implementing cost-benefit studies when those are appropriate.

Some weaknesses limit the prospects for applying risk assessment: (1) its applications are generally data intensive, expensive and long-term in nature; (2) it can appear to be dissociated from risk management in the absence of full communication and transparency o the process by which judgements are reached; and (3) it can give the impression that physical and biological sciences are the sole determinants of policy, often in practice neglecting the social sciences and ethics. As in all human undertakings, risk assessment involves human values in the choice of adverse outcomes considered, numbers and types of indirect outcomes included interpretations of data used and other parameters. By making the process as clear as possible to everyone, these value judgements are more apparent to decisionmakers and to the public.

Scientific or Expert Panels

Because decisionmaking should rest on "good science," an interdisciplinary expert panel may be needed to judge the quality and appropriateness of research, mediate arguments between scientists, evaluate negative studies (i.e. those which find no association between an exposure in question and a response of concern) and generally clarify the scientific basis of certain projected findings. It is normal for scientists to disagree, and the inability of a particular research project to reject a null hypothesis is not unusual when dealing with a rare biological effect. These situations are, however, disconcerting for decisionmakers and courts.

Scientific disputes may be a stepping stone to a refined understanding of the phenomenon, to identifying new research needs, to broader recognition of conditions causing effects, or to focusing attention on previously unnoticed pathways, biological mechanisms or biophysical effects. Scientific understanding of our complex world is now expanding into non-linear models and chaos theory, a world less comforting to decisionmakers than that of predictable linear models. Yet these new models appear more realistic to the biophysical interactions of the ecosystem. As with other methods, the use of expert panels has strengths and weaknesses. Generally, scientific panels have greater flexibility than risk assessment as a method for recognizing and accommodating information on the ecosystem impacts in a specific location. Risk assessment looks more to effects of hazards on an idealized ecosystem. The principal strength of expert panels lies in the finding's comprehensiveness and relative immediacy. Unlike either inference of causality or risk assessment, an expert panel can review all relevant information at one point in time, evaluate the uncertainty, and reach findings appropriate for the decision process. It also can identify biomonitoring appropriate to the situation and nature of the uncertainties, which could be implemented when the decision is taken to guard against untoward or unexpected effects. Thus, it can set a course "for now" with proper safeguards for subsequent review of policy and early warning of potential negative outcomes. The weaknesses of the expert panel lie in its tendency to deal with uncertainties qualitatively rather than quantitatively, and with the inherent nature of the selection process. The same findings may not be arrived at by another panel. Reproducibility is the most powerful element of the two quantitative approaches discussed previously, and although it is not lost entirely from an expert panel, it is not an inherent part of the process.

2.3.3 Risk Management

Once the scientific process, inference of causality, risk assessment or expert panel has determined the scientific basis of the decisionmaking together with uncertainties, other disciplines contribute to the decision within the constraints of the legal, social and moral systems of society. Collecting and integrating this further input into decisionmaking can be formal or informal. In Canada, it is evolving as **Risk Acceptance**. The public tolerance for risk is modified by past experience, by other risks they are currently carrying, by their knowledge, by socio-economic aspects of the problem and by the community's ethical beliefs. Some aspects of this societal input into the decisionmaking process are discussed under the headings of civic science and prudent avoidance. Both are societal attitudes brought to decisionmaking, and which colour the risks which are seen as acceptable and ethical for a particular population at this time in its history.

More formalized inputs into the assessment process, which are currently recognized in Canada, include briefs on the social equity implications of the proposal, the socio-economic impact of the proposal on culture, jobs and future plans of the community, and cumulative impact assessment which analyzes prior harm experienced by the community being asked to assume the risk, or other risks currently being carried by the community. The reality of Risk Acceptance was recognized in the U.S. when setting radiation standards for the people of the Republic of the Marshall Islands who were returning to their Atoll, contaminated earlier by nuclear testing in the Pacific. Radiation Standards more restrictive than those in the United States were used because of the prior damage the population had suffered from nuclear exposure.

While risk characterization tends to be more universal, risk management addresses a particular project or intervention at a specific time and place.

Civic Science

At the Tripartite Meeting held at the International Joint Commission's 1993 Biennial Meeting, the Great Lakes Water Quality and Science Advisory Boards, and the Council of Great Lakes Research Managers addressed the question of how to make policy decisions in the face of uncertainty, given the implications of making a decision without a proven cause and effect. Dr. Henry Regier examined the approaches used to address uncertainty in the physical sciences through the social sciences, and the transdisciplinary initiatives that are characterized by some as "new science" and "civic science." Civic science reflects the complex input from individuals in society, with their professional and disciplinary orientations, often called informed public opinion.

Central to his thesis was the need to differentiate between those uncertainties related to understanding a problem (scientific facts) and those uncertainties related to policy (what can be done about it). Resolution involves attributing the uncertainty appropriately so that methodologies and decisions can be applied within the realms of science or politics. If a scientific consensus cannot be achieved and a political decision must still be made, democratic tradition requires that a range of views be expressed by experts and the public so the decision to act may be based on societal values and ethics, rather than expert calculation (Figure 2).

[Figu Figure 2.

Scientific and technical professionals commonly balance their work among a number of mindsets. Transdisciplinary initiatives may iterate and integrate among all types of disciplines and professions, as well as mindsets and methodologies (After: H. Regier, Managing on the way to ecosystem integrity, IJC Tripartite Meeting, October 22, 1993, Windsor, Ontario).

The challenge of incorporating societal values within the two realms of uncertainty, scientific understanding and policy formulation, lies at the heart of the concept of civic science. This is the public domain where facts are interpreted, and societal questions emerge as part of a great iterative process systemized by governmental and educational institutions. Although science does provide a fallible but increasingly accurate description of the world, its limits are widely acknowledged by many philosophers of science. The strength of civic science occurs when there is doubt, since it derives from all of the sciences, including social sciences and ethics, the humanities and the varied experiences of members of the community. These multiple points of view enrich the dialogue (as is shown schematically in Figure 2) with professional input from the broader community, as well as their common values. Such concepts as the precautionary principle and reverse onus have arisen from communities recognizing responsibility for future generations when the consequences of actions are perceived as potentially catastrophic when the burden of proof placed on the victims of pollution has become unbearable or impossible to address within the constraints of the present system. Animals have no voice in environmental assessment hearings and human victims of pollution cannot commission a million-dollar epidemiological research project.

These strong principles in civic science are beyond the scope of the scientific risk assessment process. They imply a need for broader consultation for the decisionmaking or risk management phase of policymaking. It is important to recognize that the scientific basis of risk characterization does not dictate policy. Even when a risk is "acceptable" to scientists, it may well be unacceptable to the public. The tension between so-called "hard science" and "soft science" will no doubt help society to mature in its deliberations. Neither has a monopoly on truth.

The need for concepts such as the precautionary principle and reverse onus lies in the widespread mistrust of expert opinion, particularly when it is applied to political decisionmaking processes. While some may know everything about grammar or automobiles, there is hardly anyone who, as noted by Hoyos (1987), is "fully conversant with the present and future effects of prevailing dangers on nature and society." When experts go beyond the available data to express their opinions, they should be viewed with the same caution as would be applied to the speculations of others. In addressing future research needs to address this problem, Fischhoff et al. (1981) recommended that uncertainty be assessed by bounding it as four broad areas of knowledge:

- definition of the problem

- determination of the facts
- assessment of the human elements
- evaluating the quality of decisions that occur

Although uncertainty can be reduced through rational analysis, human judgement and decisionmaking (even by experts) becomes distorted by the tendency for people to use "rules of thumb" to simplify complex subjects. This arises from the often observed need of the human mind to rationalize and complete a thought process, i.e. if an event cannot be explained, a possible solution is invented to explain what's happened (Ingram 1994). The use of these techniques, or heuristics(see Footnote 2), is well established in social science research with three predominating heuristics:

- In assessing the probability of a specific event, people often resort to the heuristic procedure of availability. That is, their probability judgement is driven by thinking about previous occurrences of the event, or the case with which they can imagine the event occurring. Research indicates that use of the availability heuristic will yield reasonable results when a person's experience and memory of observed events corresponds fairly well with the actual event being considered. It is likely to lead to underestimates if recall or imagination is difficult (e.g. there is no recent experience, concept is abstract, or it is not encoded in memory).
- Representativeness is a second heuristic procedure often used in judgements about uncertain events. In judging the likelihood that a specific object belongs to a particular class of objects, or that an event is generated by a particular process, people expect the details of the object or event to reflect the larger class or process. For example, people judge the string of coin tosses HTHTTH to be more likely than either the string HHHTTT or the string HTHTHT because they know that the *process* of coin tossing is random. While all three sequences are equally likely to occur, the first string looks more random than the other two outcomes. This phenomenon, of expecting in the small behaviour that which one knows exists in the larger set, gives rise to "belief in the law of small numbers" and is frequently used by those with formal statistical training.
- Finally, a frequently used heuristic is anchoring and adjustment. Under this heuristic, a natural starting point, or anchor, is selected as a first approximation to the value of the quantity being estimated and this value is then adjusted to reflect supplementary information. For example, when asked to estimate causes of death, respondents will produce overall lower estimates for all causes when they are given an initial reference that occurs less frequently, such as accidental electrocution (approximately 1,000 people/year in the U.S.), as opposed to a more frequent cause such as traffic accidents (approximately 50,000 people/year in the U.S.) (Morgan 1990).

In other studies contrasting expert and non-expert judgement, effects such as "motivational bias" have been noted whereby legal liability associated with professional responsibilities result in cautious, or risk averse decisions. Some examples from medical, engineering and auditing professions appear in the literature. In complex subject areas involving uncertainty, research shows that some experts have not generally performed better than their secretaries in estimating some results. While experts tend to use their knowledge of processes and actual quantitative values, the non-expert typically works backward from familiar examples and includes values that are known and that can be easily estimated. If the familiar quantities produce correct approximate values, a "best guess" can be elicited that corresponds to expert judgement.

In those areas where accurate judgements are possible, success does not depend on some unusual judgement power by practitioners. Rather, it is primarily based on the availability of a well-developed science that provides established theory, precise measurement techniques, and prespecified procedures and judgement guidelines. Thus, less reliance is placed on cognitive capacities, and the need to make large inferential leaps. When the scientific facts are known, experts do not need to rely on any intrinsic superiority in their cognitive abilities, and can simply apply their knowledge to achieve accurate judgements (Faust 1985).

In Chapter six of their book on "Uncertainty," Granger Morgan and Max Henrion conclude:

> "Although the experimental literature is not sufficiently refined to allow accurate predictions, problems appear more likely to arise in fields involving complex tasks with limited empirically validated theory. There is some evidence that asking for a carefully articulated justification and reasons for and against judgements may improve the quality of judgements. . .
>
> "The experimental evidence provides no basis for believing that the problems of cognitive bias that can arise in the elicitation of expert subjective judgement are necessarily any less serious than those that have been documented with non-expert subjects. The experiments we have reviewed clearly show the need for and importance of further studies of expert elicitation involving complex technical judgements of the sort regularly required in engineering-economic policy analysis. Until these studies are performed, one can only proceed with care, simultaneously remembering that elicited expert judgements may be seriously flawed, but are often the only game in town."

To gain a better understanding of how problems of uncertainty are addressed when judgement is applied, it is useful to consider a past problem, DDT, and a potential future problem, **recombinant bovine somatotropin** (rbST).

The case of DDT, banned in 1972, represents an early exemplar of a weight of evidence approach arising from public concern, together with scientific inquiries and hearings, which resulted in the decision to ban. The final decision taken by the Administrator of the U.S. EPA was contrary to the conclusions of a hearing, based on 9,300 pages of testimony, 300 technical documents, and 150 expert scientists over seven months. It was recommended that "no more extensive ban of DDT was necessary or desirable, based on the evidence presented at the hearings." The Administrator, however, also had to consider the outcome of state hearings and a decision by Wisconsin for immediate termination of the registration for DDT (Loucks 1971).

What methodology might be employed - given our cumulative experience and knowledge - to address the uncertainty related to the use of rbST to boost milk production in cows; a scientific issue with potential implications for human and animal health and with only a few experts available to inform the debate? A thorough analysis of the scientific literature published in *Science* magazine (Juskevich and Guyer, 1990) concluded that there was no increased health risk to consumers using a weight of evidence approach, notwithstanding that a 90-day test on a small group of rats at a given dose was the longest single test cited. Having received regulatory approval in the U.S., rbST use has now become an economic and an ethical decision to be made by farmers and consumers. Some clearly oppose rbST because they oppose biotechnology in general, while others base their conclusions on perceived risks and benefits. In the U.S., the majority of farmers are not using rbST despite the assurance of its safety by the developer, and the varied experiences reported as demonstrations (Stoneman 1995).

What conclusions can be made with respect to the foregoing?

- The concept of civic science involves more than simply public participation, and is essential to guide decision-making in a democratic society. This concept emerged from the Tripartite

Meeting and the Ann Arbor workshop, "Our Community, Our Health," September 14-15, 1992, and is an emerging field for students of science and public policy. Its implications require further reflection by the Council of Great Lakes Research Managers and the Science Advisory Board.

- Experts and scientific methodologies are essential to reduce uncertainty, i.e. the negative effects of change. Ultimately, decisions are made by people constrained by knowledge, culture and values. Uncertainty can be perceived as a positive element of change embracing both innovation and opportunity, as opposed to a state of certainty which implies regression in terms of stagnation and inertia.

Precautionary Principle

How does one know that there is sufficient evidence or accumulated knowledge or potential for harm so that the reasonable person would assume scientists should sound warnings and policy makers should act?

Commissioner Gordon Durnil
"Applying the Weight of Evidence: Issues and Practice session in Windsor, October 24, 1993"

The **precautionary principle,** sometimes called prudent avoidance is an ethical imperative to prevent catastrophic damage which has a credible probability of resulting from current choice.

As was noted under risk acceptance, alarms relative to environmental deterioration raised by hunters or fishers, Native communities, mothers or others living in the Great Lakes basin are part of the "evidence" and guidance used in policy formation. Critiques by scientists who are part of the general community but who have not prepared the scientific risk assessment or been part of an expert panel may serve a special role in identifying the most worrisome characteristics, environmental pathways or ecological/human responses of potentially hazardous agents, the implications of which are not sufficiently understood by the general public or explicated by the scientific basis developed for the decision-makers. Appendix I more fully discusses the subtle aspects of hazards more easily identified by scientists, than by the general public.

It is clear from the previously discussed examples that there is potential for arbitrary use of prudent avoidance to prevent all effective decisionmaking, as well as neglect of prudent avoidance in decisions where it would be relevant. In the case of DDT, decisionmaking was contrary to the preponderance of hearing evidence and in the case of rbST the opposite happened, proceeding wit a proposal without sufficient scientific support.

The precautionary principle was stated in the 1992 Rio Declaration as follows:

> "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."
>
> Principle 15, Rio Declaration, August 12, 1992 U.N. Conference on Environment and Development

This principle requires the use of prudent avoidance when there is "sufficient evidence," "sufficient accumulated knowledge" and the risk of "sufficient potential harm." Sufficiency requires human judgement of the available evidence.

Because the scientific evidence and accumulated knowledge presuppose a sufficient exposed population/ecosystem and an adequate period of followup to observe long-term effects, the harm may be irreversible and unacceptable before "proof" of harm is sufficient for policymakers to act. Therefore, the third criteria is especially important because it alerts the policymaker and the public of the magnitude of the risk. Whether or not a risk is "acceptable" is a political and not a scientific decision.

The role of science in support of decisionmaking in the face of uncertain evidence is to generate theories and produce evidence that contribute to policy formation. The validity, relevance and limitations of such evidence must also be communicated.

However, democratic policy incorporates not only scientific inputs but also the ethics, aspirations, opinions and values of the society. Jack Weinberg and Joe Thornton of Greenpeace expressed the concerns of many of the people of the Great Lakes basin when they said:

> "The current condition of the Great Lakes suggests a failure in past environmental policy, a failure that was aided and abetted by limitations or failures in the science that informed that policy. It is time to re-evaluate policymaking methodologies that are based on these conceptions of "assimilable capacity" and "acceptable harm" - particularly risk assessment and risk/benefit analyses. As currently practised, these exercises never provide a meaningful prediction of real risks or real benefits. The simplified, narrow models used to "quantify" health and environmental threats bear little resemblance to the complex and unpredictable phenomena that occur when chemical mixtures enter integrated natural systems.
>
> "The societal decision to establish a particular standard of proof in some sphere of concern reflects a societal value judgement about that sphere of concern under circumstances when the data is incomplete and there is uncertainty. A policy of reverse onus protects society from the abuse of power by industry and also from corruption, arbitrary action, and even honest judgement errors.
>
> "Weighing evidence in order to decide upon a course of action under circumstances of uncertainty is not a value-neutral exercise. Precaution must be built into the rule of inference. The goal is to make inferences that can inform a course of action that will minimize the likelihood of significant harm. When the harm is large, the uncertainty is great, and our ability to predict the future is limited, we adopt a precautionary standard of judgement and inference. The use of precautionary context changes both the purpose and the practice of weighing evidence."

In order to set some criteria for identification of hazards which may potentially lead to significant harm, the Workgroup has extended the IJC criterion of persistent bioaccumulative toxic chemicals to other characteristics of hazards, namely the pathways by which they are dispersed and the nature of the human/ecological responses. These are contained in Appendix I. By so identifying the worrisome properties of potential hazards we hope to further the rational basis for policy decisions in the Great Lakes basin. When these worrisome properties are scientifically ascertainable, the ethical scientist must raise an alarm and policymakers may reasonably be expected to take some action. Minimally the response to disclosure would be:

- to **fully inform the public debate**
- to **reverse the onus of proof,** so that the burden of proving no harm must be on the polluter
- to **apply prudent avoidance** to protect the ecological/public good potentially at risk.

In an encouraging development, some industries are using their own scientific and technological resources to identify and protect against indirect negative health/ecological outcomes of human activity or products. Stewardship of the earth and good corporate citizenship are demanding responses at all levels of decisionmaking and management in our interconnected world.

The potential irreversible harm resulting from uniformed decisions about the consequences requires further development of the risk management process of decisionmaking to include explicit analysis of risk acceptance. Further developments of civic science and the policy of prudent avoidance can be expected. Management needs to consider the risk from the perspective of the actual ecosystem/human community being asked to accept the risk. Such particularization is beyond the scope of risk assessment or inference of causality, and is only partially met through the use of expert panels. Formalizing equity considerations, socio-economic impacts and cumulative impacts would go a long toward making risk management decisions transparent. For example, when such factors are not considered in planning, an already degraded area could become a sacrifice area because it is consistently chosen as the area for less desirable projects, having no "valuable assets" to lose.

2.3.4 Weight of Evidence

As outlined in the *Seventh Biennial Report,* the Commission's use of weight of evidence has been in relation to reaching conclusions and making recommendations by the Commission itself. The Commission receives input on risk assessment from inference of causality, risk assessment and scientific panels. It is also in a pivotal position to receive the input on risk acceptance both from civic science and from scientists concerned with long-term effects or more subtle indirect effects of hazards not ordinarily considered in risk assessments. As was stated in the report, the Commission takes into account "the cumulative weight of many studies that address the question of injury to living organisms."

The above description stems from recognition of the responsibilities of judges and juries to weigh the evidence and decide. In courts, expert evidence can be given a weight based on the witnesses' qualifications and credibility. The basis of a judge's choice between conflicting statements is normally stated. The phrase need not always be read and understood so narrowly, of course, and past-chairman Durnil counselled the participants at the 1993 Biennial Meeting workshop to forget the traditional legal meaning, which is the preponderance of credible evidence. Accumulating evidence means accumulating harm and tolerating processes which may become irreversible. He encouraged, instead, application of weight of evidence in the evaluation of potential for adverse effects, and suggested that the real issue was how and when do we know "there is sufficient evidence or accumulated knowledge" so that a reasonable person will conclude that policymakers should act? *The Seventh Biennial Report* notes that the decision is "made on the basis of common sense, logic and experience as well as formal science."

This brief summary of how the Commission has proposed to use the term "weight of evidence" suggests the need to resolve several issues. We need to answer the public's question: how do we proceed? One major issue is whether *assembling information*, and its weight in regard to a policy action, should all be done in one document or report. In none of the scientific assessment approaches, nor in judicial proceedings, has this been the case. Indeed, there are overwhelming precedents for the clear separation of prosecutor, judge and jury in their responsibilities for different aspects of information to be weighed. Similarly, there are many precedents for the separation of processes having to do with scientific findings (as in the three previous methodologies), and processes having to do with public policy and related decisionmaking. The questions the Commission seeks to address in its Biennial Report are, indeed, something of a hybrid among the above: The Commission is not a decisionmaking body in the usual sense, and it does not make policy (although its recommendations to the Parties can lead to policy). At the same time, the Commission is confronted with a broad range of scientific assessments and findings, often conflicting, and it sees a need for adjudicating between conflicting scientific findings. The real issue then becomes, is weight of evidence an appropriate term for such scientific adjudication? Moreover, the Commission recommendations respond not only to the risk characterization flowing from the scientific input, but also from the legal, social, economic, ethical and other inputs which are reflected in risk management decisions.

Many points of view were expressed in the October 1993 Biennial Meeting workshop, and all of the above problems were outlined. Glen Fox, of the Canadian Wildlife Service, expressed concern for applying scientific principles to determine causal explanation; Margaret Berger of the Brooklyn Law School described concern with recent U.S. Supreme Court decisions requiring the courts in general to become more sophisticated in the criteria by which they judge conflicting experts, scientific data and references from laboratory animal studies. Especially interesting is the case-study presented by William Owens, Procter and Gamble Company indicating that a weight of evidence approach (including a three-year, $3 million study) had led to successful resolution of conflicting indications of risks to fishery resources at a Canadian pulp mill. The process led to withdrawal of proposals for a potentially crippling level of proposed effluent regulation. Here, the process was designed to build consensus and resolve legitimate scientific differences as to significance, causality and interpretation. Our experience on scientific panels designed to produce recommendations for policymakers is that the transparency in the weighing and decision process is critical. These examples, and the workshop report itself, bring us back to the basic values question posed by past-Chairman Durnil at the beginning of the workshop: How and when do we know there is sufficient evidence or knowledge that we should expect a policymaker to act? The Workshop could not answer this profoundly value-laden question, but important aspects were discussed in the paper by Jack Weinberg and Joe Thornton of Greenpeace USA. They recognize that science is a continual process of seeking truth, rather than a collection of ultimate truths, and that in the frequent absence of appropriate scientific data, risk assessments are blind - sometimes even serving as evidence of safety. They also note the continuum in weight of evidence criteria used in court: "beyond reasonable doubt" in the case of capital crimes, versus "preponderance of credible evidence" as applied to certain contracts or in administrative proceedings. Ethics and societal values are reflected in this scale of weighing, as they should be in weighing evidence for environmental risk. Thus, these authors argue for a strong precautionary standard, or reverse onus, when data are absent or sparse, and there is a potential for serious harm, rather than a weight of evidence, based on preponderance of current information, as described above.

The differences summarized here suggest the need for consensus-building in regard to societal values and tolerance of risk, in addition to methodologies for assessing the science and decisionmaking. It also calls for clarification of degree of certainty demanded of decisionmakers faced with varying degrees of threat of harm and implies the need to carefully monitor the consequences of decisionmaking when the information base is uncertain.

2.3.5 Synthesis and Findings

The approaches described in the previous sections do not exist exclusively of one another. To a great extent, they function all at the same time. To answer the questions posed at the beginning about how we should proceed, however, a goal should be that all stakeholders see for themselves how they contribute to the aggregate process. Comparisons among the approaches are useful, and can be facilitated by the summary in Table 3.

The left side of the table lists nine considerations relevant to a comparison, most of which have been discussed briefly in the preceding sections. More comparisons could be suggested. Among those shown, one of the most informative compares the kinds of information used in each of the approaches. Some approaches, such as causal explanation and risk assessment, involve intensive, long-term development of quantitative information, while civic science incorporates clearly articulated general information. Civic science incorporates general information and interdisciplinary understandings of an informed public built up over a long period of time. Causal explanation has advantages in regard to retrospective assessments, while others, such as expert panels and the precautionary principle, are more useful for problems that are arising (prospective situations). Other considerations raise questions as to the scale of the problem appropriate for each approach, inherent requirements for interdisciplinary information, documenting and reporting of uncertainty, and the different kinds of users or audiences principally concerned with each approach.

The table summary also summarizes that the finding that the cause-effect science, risk assessment and civic science are all long term, often excessively so for many of the decisions required in protecting Great Lakes water quality. To the extent that policy questions are paramount, risk assessments and expert panels can be planned, managed and designed specifically for a policy purpose, while cause-effect science is best designed for assessments used by scientific audiences. Causal relationships, when available, are incorporated into hazard identification and dose-response estimates used for risk assessment. Assessments using study groups or panels usually avoid the problems of major costs and long-term analysis, but they lack the capacity to commission critical new data, as is often required to resolve differences among studies. Findings reported by panels often reflect large uncertainties, the result not only of measurement and modelling uncertainty, but also differences among individuals in their interpretation of data. A goal of several of the approaches, including especially risk assessment and expert panels, is to make explicit: (1) the uncertainties; (2) the likely public tolerance for risk; (3) the cost to society either of not acting (and potentially incurring otherwise avoidable damage), or of acting inappropriately or too soon (and potentially incurring unnecessary harm or costs); and (4) other aspects of practical action help to inform the risk management decisions.

The three contexts for developing a risk management policy in Table 3, namely precautionary principle, civic science and weight of evidence, all must be viewed in relation to broad public interest in health, ecological integrity, resources, morality and economic wellbeing, not incorporated formally into risk management methodology, which describes the scientific base. Civic science judgements are descriptive of real-world public processes. Although they suggest that a decision or consensus is made by the public, the process is not decisionmaking in the usual sense. Rather, the policies and practices of public institutions come eventually to reflect this civic judgement. The SAB report on *Our Community, Our Health: Dialogue Between Science and Community* (IJC 1994) illustrates the process in action.

The precautionary principle probably applies best to situations where little information is available for civic science or risk assessment, but where the public agrees on a very low tolerance for the risk of future damage. The emerging public consensus that "zero discharge" should be applied as soon as possible in the Lake Superior basin illustrates a precautionary approach to protecting this ecosystem, while the efficacy of implementing similar on-land restrictions around the other Great Lakes remains part of a broader debate.

Weight of evidence, narrowly interpreted, is a shorthand term for law-related conventions guiding the judging and weighing of evidence, leading to decisions based on a broad scientific and public values evidentiary record. Thus, weight of evidence as a term describes both a process, weighing, and the decisionmaking. It also includes the context of being the endstep in the process. However, all the assessment steps, scientific as well as public, include weighing of evidence, and making personal or constituency-interest decisions based on it, but within the Great Lakes community these generalized input processes need not be blended in with the major determinations on behalf of the Water Quality Agreement, as can only be done by the Commission.

These observations or findings as to the process itself, and the end-step decisions, should be seen in relation to the different levels of proof society accepts for different kinds of judgements or decisions. We use "beyond any reasonable doubt," essentially removing uncertainty, for capital punishment decisions. But we use a simple "preponderance of credible evidence," which tolerates much uncertainty, for many administrative law decisions. Should the Commission use "beyond a doubt" for recommendations that may cost society hundred of millions of dollars in pollution abatement? Or, can such decisions (or those by scientists, or expert panels) be based on a "preponderance of credible evidence"? Conversely, is "beyond-a-doubt" evidence needed to act prudently and quickly to prevent large-scale, subtle, irreparable alteration of human health or natural resources? These choices are open, and involve critical expression of societal values that this report has sought to enlighten, but on which we make no recommendation. We simply state that the basis of the decision be made clear.

If a summary recommendation can be drawn from the information presented here, it is as follows: The weight of evidence approach outlined for policymaking in two Biennial reports of the International Joint Commission, and into which many stakeholders have been invited, is too generalized and all-inclusive to function for the entire IJC community. To the extent that it refers to the Commission's own determinations, based on the full range of inputs provided biennially to the Commission, then it is an appropriate use of a well-established term. It would be consistent with prior usage if it were reserved for the Commissioners, well-documented processes. The large IJC family, who do weigh technical evidence and interpret public values, provides important input to the Commissioners' weighing of evidence, but these inputs and the processes involved should be distinguished from the final determinations by the Commission. A more satisfactory overall concept requires that two different functional elements be distinguished: scientific and public interest assessments (of all kinds) by scientists, businesses, nongovernment organizations, and the public as input; and weighing the full record and determining of policy recommendations by the Commission itself.

2.3.6 Recommendations

- **Whereas decisionmaking relative to human and ecosystem health must frequently be made on the basis of scientific and policy uncertainty, and whereas the consequences of wrong decisionmaking vary from trivial to catastrophic, and whereas a weight of evidence approach incorporates risk characterization and risk management phases of decisionmaking, the Science Advisory Board recommends that:**

  - scientific risk characterization formally include disclosure of: (1) choices embedded in the design of supporting research; (2) modifiers of risk factors used; and (3) all relevant uncertainties
  - risk characterizations prepared for environmental decisionmaking explicitly examine the potential indirect consequences resulting from the characteristics of the hazard, pathways and host response as outlined in Appendix I of this section
  - decisionmakers seek out or recommend relevant valuation assessments, legal and regulatory analysis, socio-economic assessments, equity analysis, ethical analysis and cumulative impact assessments as necessary inputs into risk management decisions.
- **Whereas the Commission recommendations of environmental policies to the Parties require broad societal understanding and support, and whereas uncertainties and potential negative outcomes of either action or non-action accompany weight of evidence decisionmaking, and whereas the priorities of human health and of ecosystem integrity may at times be in conflict, the Science Advisory Board recommends that:**

  - Commission weight-of-evidence decisions be clear as to evidence used, assumptions, values, uncertainties, and consequences involved
  - the level of proof required (beyond a reasonable doubt, or more likely than not) be clearly stated
  - the risk of non-action be included in deliberations on risk management
  - Commission recommendations and decisions based on weight of evidence include parallel decisions on reasonable monitoring needed to serve as a measure of progress toward the desired goal, or conversely as an indicator of a wrong decision
  - Commission recommendations and decisions based on weight of evidence, because tentative, incorporate clear strategies for ongoing cooperation between scientists and managers
  - further development of an ethical basis for ordering and prioritizing goals of human health and/or environmental integrity, when there is a potential conflict between those goals, be undertaken.

Appendix I.

Threats of Serious or Irreversible Damage

In order to provide clear guidelines for identifying threats of serious or irreversible damage, we have pointed out key features of the hazard, of the exposure or pathways and of the biological effects which would serve as identifying characteristics.

Justification of Use of the Precautionary Principle Based on the Toxic Chemical or Hazard Characteristics

Those features of the environmental hazard itself - such as the specific characteristics of the toxicant being evaluated in terms of its adverse effects for both the ecosystem and human health or of its presence in the environment, its kinetics in the environment and within host species, etc. - may justify prudent avoidance efforts on the part of decisionmakers before all scientific uncertainties are resolved.

Key Features of the Hazard

- **Toxicity:** the traditional definition of the hazard's ability to produce adverse effects in a host species at very low exposure doses. As a more qualitative but often critical consideration, the full span and profundity of effects must also be considered at the cellular and sub-cellular, and multi-organ-system levels that have been attributed to the hazard, often primarily in laboratory and animal studies. In other words, some environmental hazards are particularly "worrisome" not simply because they have specific health effects at very low exposure doses, but because they appear to "turn on" cellular and sub-cellular mechanisms throughout the body. Examples include some organochlorine compounds on endocrine receptors in a wide range of mammalian body cells and organ tissues, or of radionuclides at low doses which have an ability to trigger an inflammatory cascade effect. Other hazards such as invasion by exotic species or dredging of waterways may be gauged by the scale of impact as an analog to toxicity.

- **Persistence in the environment:** the tendency of the compound not to degrade to harmless substances over long periods of time, and its continued bioavailability in the sense that it is not sequestered in harmless locales, so that ongoing exposure to various biota are likely.
- **Non-remediability of environmental loading:** Related to the above, but separate, is the notion that some environmental hazards cannot be sequestered by artificial intervention or deliberate actions designed to prevent further harmful effects of their presence in the environment. On the other hand, if it is both feasible and economical to completely "seal over" a chemical contaminant (e.g. in a particular layer of lake bottom sediment) in a very local circumstance, it obviously generates much less concern.
- **Global dispersibility:** Related to the above but again somewhat separate is the capacity of some environmentally hazardous contaminants, such as PCBs or carbon 14 releases from nuclear plants, to disburse throughout the globe by virtue of specific chemical and bioaccumulation characteristics - such as their low vapour pressure, their tendency to move into food chains where some species are widely migrating, or their function as an essential chemical in all living systems. Carbon, for example, is a basic element of life and will be incorporated into organisms in both its radioactive and non-radioactive form.
- **Tendency to bio-magnify:** Again somewhat separate, but related to the above, is the notion that some compounds bioconcentrate as one sees them moving up the food chain into higher predator levels. This often has important implications for humans, who are rarely very far down the food chain, but it also has important implications for broader ecosystem effects such as "food chain" effects - cf. below.
- **Uncertain interactions with other environmental or widespread exposures:** the well-known concept of the "environmental soup of mixed contaminants of partially unknown natures and concentrations." One rarely has much information on this, but there can sometimes be basic science evidence to suggest that the interactions are likely to be biologically important and widespread.

Features of the Pathways or Exposure which call for use of the Precautionary Principle

The features of the specific exposure circumstances or pathway characteristics that lead to putative ecosystem and/or human health effects - such as the duration of exposure necessary to produce effects, the extent of deliberate versus involuntary exposure to human beings, etc. - can be important considerations in determining whether there is enough potential harm to warrant intervention on behalf of prudent avoidance.

Features of the Exposure Itself or the Pathway

- **The capacity of short-term ("one hit"/"bolus") exposure to cause significant effects:** Particularly worrisome hazards are those that appear to have the capacity to cause disproportionate adverse effects, in an individual or an ecosystem, despite very time-limited exposure, which may occur at sensitive points in the development of the individual or the species community. An example of this would be the apparent sensitivity of the rat fetus (and that of other species) to dioxin levels transmitted in utero after even one low-dose dioxin meal. In a different example, a construction project during fish spawning season might be significantly more damaging to the ecosystem than at another time because of PCBs resuspended from the sediment.
- **The widespread existence of involuntary exposure pathways that lead to the "helpless victim" phenomenon:** Exposures that are ubiquitous but poorly known to the general public are necessarily of greater concern because they prevent the individual from reducing their personal hazard voluntarily. It is therefore both a quantitative concern when the exposure is, for example, mediated through ordinary nutritious foodstuffs, as well as an ethical concern. Many contaminants fit this description, including the many pesticides that are used on fruit and vegetable crops.
- **The existence of complex multiple exposure pathways:** This characteristic of an environmental contaminant causes concern because it suggests the infeasibility of reducing overall population exposure by any simple public health or health protective measure. Again, polychlorinated biphenyls would seem to represent such an environmental hazard at the global level. Similarly tritium released to both air and water, and capable of being incorporated into the DNA molecules of all living tissue, presents a complex multiple exposure pathway.
- **The tendency for humans themselves to facilitate exposure by ongoing economic or other activities:** While some might regard this as an increased opportunity for preventive efforts, if such activities can be reduced, they raise the spectre of increasing exposure in the future when these activities expand for economic or other reasons. Thus the dredging of water channels, setting free contaminants that have previously been sequestered away from various susceptible biota, represents a potential for additional exposure and consequent harm to susceptible populations.

Significant Biological Effects Which Call For Use of the Precautionary Principle

The features of the putative or established biophysical effects that have been linked to the environmental exposure in question - such as their inherent nature, dose-response relationships, etc. - may also require action of prudent avoidance. These features also serve to define situations posing enough potential harm to warrant a deliberate decision to act or not act.

Significant Biological Effect Features in Any Population

A. Intra-Organism Effects

- **The severity, reversibility and "nastiness" of the effects themselves (including their tendency to be treated to a limited extent, or not at all):** Public policy must respond to concerns about health effects that are particularly pernicious and untreatable. Cancers of the solid tissues in children or adults is a clear example. Subtle neuro-developmental effects in children that may compromise their ability to perform as an adult, particularly their ability to perform as productive citizens and parents of the next generation, would be another example. A closely related notion not separated here is the notion of "irreversibility" of effects.
- **The presence of poorly understood non-linear/non-threshold dose-response curves:** The doses at which effects begin to occur are poorly understood for many environmental hazards,

suggesting that we may have misjudged the ambient concentrations of these hazardous substances.

- **The possible presence of a dose-response relationship where there is no "no-effect" dose:** A subject of considerable controversy in the cancer literature for some decades, it is arguable that there are dose-response curves for some hazardous substances and physical phenomena that continue to show adverse effects even at micro-doses we cannot measure, so that there is no threshold below which exposure is strictly "safe."
- **Particularly "protean" or "pleiotropic" effects on organisms' functioning:** By this is meant the reduction in the capacity to perform basic metabolic or bodily defence functions, such as occurs in immunosuppression. The difficulty here is that one may misjudge mild effects of this sort because they can be signalled only through rather non-specific symptoms and signs, such as the increase in opportunistic infections, in the case of immunosuppression (witness the early days of the AIDS epidemic) - cf. below "opportunistic pathogens."
- **The bioaccumulative persistence of body burdens of the toxicant with the probability of delayed or latent effects over a lifetime:** This suggests we may only be seeing the tip of the iceberg of the effects of the exposure in short-term studies, without decades of followup in large numbers of subjects. A closely related notion is the presence of primary, secondary and tertiary "cascades" of biochemical, physiological and functional effects of hazardous exposure.
- **The extent to which reproductive or survival implications arise for the individual organism, as a result of the specific health and behavioural effects of the hazardous exposure:** In line with the considerations described below, there is more concern if the effects of the exposure in any organism compromise its reproductive success, or capability of surviving as a species.

B. Inter-Organism, Intra-Species Effects

- **Potential for population failure of whole species:** Picking up the point listed immediately above, even near-extinction of a species can often have massive cascade effects inside an ecosystem.
- **The presence of transgenerational effects:** This is mediated through a variety of mechanisms and perhaps best exemplified by mammalian species' potential to affect their offspring through germ cell and genomic changes, transplacental exposures, breastfeeding changes (in either chemical content or lactational nature), and the implications of altered parental competence to raise offspring.

C. Inter-Species/Whole Ecosystem Effects

- **Unanticipated, disproportionate cascading effects throughout a whole ecosystem:** Examples of these could be food chain effects, such as major alterations in other species' populations or densities occasioned by the disappearance of a top predator. More worrisome because of the profound "metabolic" level at which it operates inside a community of organisms, are subtle changes in nutrient cycling, such as have been demonstrated for nitrogen in polluted forests, which cause insidious nutrient "leakage" in the local ecosystem, with serious implications for its long-term sustainability.
- **The presence of "false signals" that might suggest ecosystem viability to naive observers, but in fact portend the opposite:** Examples include the overwhelming of immunodeficient species by opportunistic pathogens where the immunodeficiency itself has been caused by environmental contaminants. The tendency may be for some observers to claim that "a new germ has evolved," when in fact the pathogen that has taken advantage of the situation is merely responding to subtle changes in host defence capabilities. An example may be the

current decimation by pathogens of yellow locust trees in the Appalachian region. Another example could be the explosion of certain populations, which naive observers might regard as a sign of a healthy ecosystem; for example, gulls in the Great Lakes. Exotic species population explosions may also be viewed in this way by naive observers.

A third example are situations where the inherent dose-response curve of health effects for a contaminant in the environment is "hermetic," in that small amounts of the agent appear to be necessary for health, but larger amounts cause toxicity, as with many micro-nutrients (vitamins and minerals).

2.4 Toxicological Mechanisms: Environmental Exposure to Chemicals Acting As Endocrine Modifiers

2.4.1 Statement of the Problem

There is clear evidence from animal studies that many chemicals present in the environment can alter reproductive function mediated by the endocrine system. A partial list of such chemicals is shown in Table 4.

These and other chemicals have been shown in wildlife and laboratory animals to have widespread effects on the endocrine system. In fact, almost all of the endocrine organs have been shown to be affected. Effects include enlarged thyroid glands in Great Lakes fish, decreased reproductive capacity in fish-eating birds, and shortened penises and altered sexual maturation in alligators in Florida. For a more complete listing and discussion of these endocrine effects in the Great Lakes, the reader is referred to the 1992 book edited by Theo Colborn and Coralie Clement: *Chemically-Induced Alterations in Sexual and Functional Development: The Wildlife/Human Connection.*

Humans accidently exposed to high levels of some of these chemicals also exhibit altered endocrine function. For example, in boys and girls accidently exposed to high levels of PCBs and PCDFs, preliminary studies (Guo et al. in press) have shown that the exposed boys have shortened penises. The boys and not the girls have decreased ability to comprehend spacial relationships, a function that is normally better developed in males than in females.

If animals exposed to these chemicals in the wild have altered endocrine/reproductive function, and if humans exposed to these chemicals at high levels have altered neuroendocrine, endocrine and sexual maturation, what if any are the effects of these chemicals on the general public? The concept that the general public may be experiencing alterations in endocrine and reproductive function, as seen in the wildlife, is very troubling. Several observations indicate that the general public may have altered endocrine function from unknown or unrecognized sources. These reports include the disputed claim that sperm counts in the adult male have fallen over the last few decades (Carlsen et al. 1992; Olsen et al. 1995; Auger et al. 1995; Sherins 1995), the observations of an increase in sperm abnormalities (Auger et al. 1995), an increase in incidence rates for testicular and prostrate cancer, and an increase in the incidence of undescended testes in children. The cause of these observed changes in humans has not been identified, but the possibility exists that these effects are due to environmental exposure to chemicals.

One recent study supports the concept that environmental exposure to chemicals is having an effect on endocrine function in the general public. Koopman-Esseboom et al. (1994) studied the thyroid function of infants and mothers living in an industrialized part of the Netherlands. They found a correlation between the estimated body burdens of PCBs and dioxins and altered thyroid function in the mother and infant.

The mechanisms by which environmental exposure to chemicals exhibit endocrine effects have been studied. While there are many possible mechanisms of action, the most common mechanism may be the ability of many chemicals to act as an agonist or antagonist of the natural hormones, and binding their receptors. For example, some PCBs can act as estrogens or anti-estrogens, depending on the level of exposure to a particular PCB congener.

2.4.2 IJC-Sponsored Wingspread Symposium

In recognition of the emerging data, the complexity of the endocrine system and the potential impact that altering the endocrine system can have on other organ systems and on the incidence and manifestations of diseases, the **International Joint Commission** (IJC) sponsored a Wingspread symposium on endocrine modulators. The symposium explored the state of knowledge on the interaction between disease states and other organ systems and the endocrine system. The meeting was also designed to identify the most important studies to undertake, the sensitive parameters to be used in these studies, and the critical populations to be studied.

The topics of concern explored were the following: the effects of endocrine modifiers on endocrine sensitive cancers and cancers of the endocrine glands; immune function; neurobehavioural function; reproduction; sexual maturation development; and on the endocrine system itself. Animal and human studies were compared. Human populations were identified as useful to study for the benefit of scientific knowledge, but to benefit the subjects themselves. In addition, the potential interaction of stresses on a population and endocrine function were discussed, as well as the molecular biology of estrogen receptors.

The full report and overview of each topic area, and a summary statement of the symposium, are to be published in a special supplement to the international, peer-reviewed journal, *Toxicology and Applied Pharmacology,* this fall or early winter. However, two pieces of information from the Wingspread symposium are included in this chapter. The first is the overview statement of the hormonal effects on neurobehavioural function. This overview is presented to demonstrate the complexity of the science and the many factors which must be entertained in designing the appropriate animal and human studies.

The second piece of information from the symposium is a set of research recommendations, which are supported by the Workgroup on Ecosystem Health and the Science Advisory Board.

2.4.3 Overview Statement from Wingspread Symposium, January 13-14, 1995: Hormonal Effects on Neurobehavioural Function: Priorities for Future Research

Overall, a symposium Subgroup See Footnote 3 concluded that the highest priority for future work on the endocrine effects of environmental exposure to chemicals should be to develop research strategies based on more sophisticated analysis of behavioural and endocrine endpoints that might be expected to be influenced by developmental exposure to hormonally-active agents.

Much of the work to date has focused on a limited set of strongly sexually-dimorphic responses (e.g sex behaviour and patterns of gonadotrophin release) in small animal model systems. These model systems offer significant advantages: they are standardized, involve well-characterized cellular mechanisms, and are relatively inexpensive. However, they also suffer from major drawbacks that have limited the scope and interpretation of the work. They are highly dependent on gonadal steroids (particularly estrogens) and are less sensitive to effects that may involve other hormonal mechanisms. Perhaps most important, effects on sex behaviour and gonadotrophin release in laboratory rodents cannot easily be extrapolated to higher mammals, including humans. The most commonly used endpoints of sexual differentiation in rodents - the ability to support cyclic gonadotrophin release and sex behaviour reflexes, such as lordosis - have no obvious parallels in primates. The nature and extent of the developmental risks that hormonally-active environmental agents pose for humans are thus questioned. This issue is, however, largely one of semantics. There is no question that hormonally active substances have the potential to influence human development; the challenge is to identify experimental endpoints that can give meaningful data in terms of assessing the true clinical and environmental risks of exposure to potential endocrine-active chemical pollutants.

The Subgroup considered these issues with respect to three specific areas of research: animal physiology; reproductive ecology, and human psychoneuroendocrinology.

- **Animal Physiology**

  The highest priority should be to examine the effects of environmental chemical exposure using sexually-differentiated behavioural endpoints that are sensitive to changes in the integrated activity of the brain, as opposed to simple endocrine and reflex-behavioural endpoints. More complex behaviours, involving higher **central nervous system** (CNS) centers, appear to be more consistently affected by developmental hormone exposure across mammalian species than is the case with simpler reflex functions. For example, there is compelling evidence that juvenile play behaviour is sexually differentiated, with the male exhibiting more high-energy, rough-and-tumble play than females, in species as diverse as rats, rhesus monkeys, and humans. Similarly, lateralization of the brain - the preferential association of functions with either the left or right cerebral hemisphere - is affected in rodents as well as primates by early gonadal steroid exposure.

  The Subgroup identified several types of behavioural tests that could potentially be used as more sensitive indices of possible endocrine effects of environmental exposure to chemicals:

  - maternal behaviour
  - preference/motivational behavioural tests of sexual differentiation, as opposed to the simpler standardized tests of male and female sex behaviour used in the majority of studies
  - open-field behaviour (sensitive to both gonadal and adrenal steroid effects).
  - cognitive tests using paradigms that show differences between normal males and females (particularly tests based on acquisition and use of visuospatial information)

  Similar considerations apply to assessment of neuroendocrine function. The relatively "all-or-nothing" ability to support an **ovulatory luteinizing hormone**See Footnote 4 (LH) surge is normally only observed in females and hence has been widely used as an endpoint for sexual differentiation, but it is an endpoint with relatively low discriminatory power with respect to the possibility of subtle disturbances of masculinization and/or defeminization. Other aspects of neuroendocrine function that are sexually differentiated and which might be expected to show more "graded" effects of environmental hormonal exposure include circadian rhythms in motor and feeding activity, which in turn are related to serum corticosteroid levels, as well as patterns of glucocorticoid secretion in response to standardized stress stimuli.

Finally, the Subgroup recognized that for all of the available test paradigms, there is a pressing need to extend previous work to analysis of more complex mixtures of chemicals, such as those present in the environment. Because of the possibility of synergism or antagonism between different compounds in the environment, laboratory data obtained on individual compounds may not be meaningful in terms of risk assessment.

- **Reproductive Ecology**

  The Subgroup felt that considerable opportunities remain to obtain valuable data from field studies of reproductive fitness. Obviously greater problems exist in accurate data collection than is the case in the laboratory setting, but these are offset by the opportunity to assess the impact of "real-world" mixtures of environmental contaminants. Comparisons between the reproductive and general health of the same species living in contaminated, as compared to non-contaminated sites, could be very useful. In addition to assessments of total animal numbers and the obvious parameters of reproductive function (e.g. litter size, gonadal size, and morphology at autopsy), such studies should also include assessment of parameters that might be sensitive to subtle environmental, endocrine or metabolic effects, (e.g. sex ratios at birth and in surviving offspring, time of the onset and offset of breeding seasons, and numbers of litters per season).

- **Human Psychoneuroendocrinology**

  The availability of human cohorts with defined environmental exposure provides a potentially invaluable research resource. A major problem in designing potential studies of human CNS effects of environmental chemical exposure, however, is that it is extremely difficult to eliminate potential confounding effects. Even in the case of normal sex differences, it has proven difficult to tease development hormonal responses out from the extensive contributions of social and educational factors. Testing for possible effects of endocrine active environmental contaminants on human cognitive function presents even greater challenges. It may be impossible to adequately control for the effects of differences in socio-economic background, education opportunities and biases introduced by study population expectations. Simply being aware of developmental exposure to a potentially harmful environmental chemicals may introduce confounding effects that could influence tests of human cognitive function to an even greater extent than the actual exposure to the chemicals themselves.

  For this reason, attempts to detect possible effects of hormonally-active chemicals from environmental exposure on human brain development should probably be focussed on sexually dimorphic endpoints that are robust, objective and relatively easy to measure. Play behaviour in childhood is one such variable. It is normally strongly sexually differentiated, with males showing more high-energy expenditure, "rough-and-tumble" play than females. This sex difference is a consequence of developmental androgen exposure; girls with excessive prenatal androgen exposure resulting from the syndrome of congenital adrenal hyperplasia show play behaviour patterns resembling those of normal males. Therefore, environmental exposure to chemicals that interfere with sex differences in either steroid hormone secretion or action might be expected to affect play behaviour patterns. Another robust sex difference is in the extent of lateralization of brain function; males are generally considered more lateralized than females. Relatively simple, objective measures of lateralization can be achieved using methods such as dichotic listening tests. Cerebral hemispheric lateralization and other sexually-differentiated structural features of the brain (e.g. in the hypothalamus-preoptic area) could also potentially be studies using either **magnetic resonance imaging** (MRI) or at autopsy, in patients exposed to endocrine-active chemicals from environmental exposure as compared to control populations. Both approaches have demonstrated sex differences in brain structure in normal human populations and therefore could presumably be used to test for possible modulating effects of environmental chemical exposure.

Sex differences also exist in humans in the prevalence of various developmental disabilities. Mental retardation is twice as common in males as in females, while autism and other pervasive developmental disorders show a male:female sex ratio of 3-4:1. The relatively low base rates for these disorders must be considered in any epidemiological investigation of the effects of environmental toxicants. For instance, autism occurs with an incidence of 4.5-4.8/10,000 children and mental retardation ranges from one to three percent of the general population. A more common phenomenon is that of learning disabilities. These are detected in 10 to 15 percent of the school-age population and exhibit a male:female ratio of 2-5:1. Sex differences in the incidence and type of psychiatric disorder is another domain in which the potential influence of environmental toxicants could be assessed. Depression, for instance, is diagnosed twice as often in women as in men. Estrogens have been implicated in the etiology of depressions, possibly through their effects on enzymes involved in biogenic amine metabolism as well as on neurotransmitter receptor systems.

2.4.4 Conclusions and Recommendations

In animals, certain chemicals in the environment can cause a range of effects on the endocrine and endocrine responsive organ systems. An important subsequent question is to determine if these effects are observed in, or can reasonably be extrapolated to humans under environmental exposure conditions.

The Science Advisory Board recommends that:

- **cooperative efforts occur between the governments, academia, the general public and industry to focus research:**

1. to identify which, if any, environmental exposures to chemicals are or have the potential to be endocrine modulators in humans. For those chemicals identified, what are the exposure and dose-response relationships that define the potential for adverse effects?
2. to identify what effects and disease state in humans may be linked to endocrine modulation as a result of exposure to chemicals in the environment, and at what stage of development is the human most susceptible to these effects
3. to identify the mechanisms of action of environmental exposures to chemicals relative to endocrine modulation, and how such knowledge can be factored into the risk assessment process
4. to determine if structure/activity relationships can be developed to accurately predict which environmental exposures to chemicals have the potential to modulate the endocrine system

5. to determine if sensitive biomarkers of endocrine modulation can be developed and validated for use in animals and humans exposed to chemicals in the environment
6. to determine in animals if environmental exposures to chemicals that are endocrine modulators can be differentiated from other environmental stressors, such as loss of habitat, malnutrition, or changes in ecosystem dynamics that can similarly exert effects on the endocrine system
7. to determine in humans if environmental exposures to chemicals that are endocrine modulators, can be differentiated from endocrine effects that are caused by endogenous, dietary or other lifestyle stressor factors (loss of jobs, etc.). How can their interactions be studied?
8. to identify chemically-exposed cohorts that can be used to study the potential for environmental exposure to chemicals to alter endocrine function or endocrine responsive organ function
9. to identify if technologies can be devised to control the release of endocrine modulators. Can more effective technologies be developed?

2.5 Federal and Provincial/State Toxic Reduction Programs And Related Activities in the Great Lakes Basin: A Preliminary Evaluation

2.5.1 Introduction

The overall goal of the **Great Lakes Water Quality Agreement** (GLWQA) is to maintain and preserve the physical, chemical and biological integrity of the waters of the Great Lakes Basin Ecosystem. To further this goal, Article II and Annex 12 oblige the Parties to reduce discharges of toxic chemicals to the Great Lakes.

In 1994, the Science Advisory Board's Workgroup on Parties Implementation investigated the status of toxic reduction programs and related activities by federal and provincial/state governments in the Great Lakes basin. It is assumed that these programs would provide some indication as to the progress being made in implementing the goals stated in the Agreement.

The Workgroup contracted with two investigators, one in Canada and one in the United States, to provide an inventory of the federal and provincial/state programs in this regard. This report is a brief synthesis of the findings of these two reports (Sadek 1994; Scheberle et al. 1994), with Workgroup member commentary. The detailed studies, including any comments received from the various agencies, are available from the Board on request.

2.5.2 Terms of Reference

In fashioning the Terms of Reference for the inventory studies, the Workgroup asked that the following questions be investigated:

- Are there laws in place requiring the collection of data and reduction in discharges pertaining to toxic chemicals?
- In addition to, or apart from, the laws identified above, are there programs in place to reduce discharges of toxic chemicals?
- In light of the laws and programs, what measurable results have been achieved and what gaps have been identified, if any?

2.5.3 Summary of Background Studies

Agency personnel in all eight Great Lakes states (Illinois, Indiana, Michigan, Minnesota, New York,Ohio, Pennsylvania, and Wisconsin) and the Province of Ontario and in both federal governments were contacted in this study. A list of laws, programs and data relevant to toxic chemicals was then compiled, and an attempt was made to make this inventory as complete as possible. The inventory included information from 37 major databases in the United States and 56 in Canada. Personal interviews were conducted with 75 U.S. federal and state agency staff and 24 Ontario provincial and Canadian federal agency staff.

Two caveats about this work should be noted. First, some programs are not specifically targeted at toxics but may collect small quantities of data as an adjunct to other work. Although the Workgroup tried to include all such programs, some may have been missed unintentionally. The Work-group, however, believes these to be a small proportion of the total effort. Second, the inventory necessarily represents a snapshot in time. Laws, programs and databases change constantly, so the findings reported below should be considered representative of conditions that prevailed in late 1994.

2.5.4 General Findings

The Workgroup found an abundance of activities of many types in both countries. Indeed, the number, diversity and incomplete cross-referencing of these programs proved a major challenge in compiling a "complete" inventory. Several general findings emerged, however, as follows:

Are there laws in place requiring the collection of data and reduction in discharges pertaining to toxic chemicals?

> All jurisdictions had laws in place to reduce discharges of toxic chemicals. Few of these laws require data collection, and few address all environmental compartments. For example, Ontario's **Municipal-Industrial Strategy for Abatement** (MISA) Program will develop regulations for municipal and industrial effluent discharges of toxic chemicals, but does not target air or solid waste emissions of those toxics. Data sets collected by statutory authority under U.S. legislation such as the **Comprehensive Environmental Response, Compensation and Liability Act** (CERCLA), the Clean Air Act, the Clean Water Act and the **Resource Conservation and Recovery Act** (RCRA) contain compliance information and therefore may be limited to certain types of substances. As a final example, the 305(b) reports required under the Clean Water Act, intended to provide a basis of comparison across a region, in fact vary considerably from state to state in terms of detail, data collection techniques, and timeliness.

In addition to, or apart from, the laws identified above, are there programs in place to reduce discharges of toxic chemicals?

> Multi-media toxics reduction programs have been initiated through a number of voluntary industrial agreements. Examples of this are the federal Canadian **Accelerated Reduction/Elimination of Toxics** (ARET) program and individual agreements with sectors such as the Canadian Motor Vehicle Manufacturers' Association. Some voluntary programs exist in local and regional municipalities to control household hazardous wastes, and rural nonpoint source reduction activities are sponsored by a number of agricultural agencies as part of farm environmental planning. The Responsible Care

program introduced in the mid-1980s by the Canadian Chemical Producers' Association is an important industry initiative directed at reduction of toxics use and emissions by member companies. The U.S. EPA's "33-50" program is another example of a voluntary initiative directed at reducing toxics.

The vast majority of data collection efforts underway in the states, provinces and federal governments, however, relates to tracking compliance of point source controls. Many toxics reduction programs have a specific media or contaminant focus and thus are difficult to compare across jurisdictions. Little effort is directed to discharges of toxic chemicals from nonpoint sources. A good example of this is the wellhead (groundwater) protection programs (see Table 5). Despite Congressional mandate, some states have taken almost ten years to submit their wellhead protection programs for U.S. EPA approval and most do not have the data from which to make determinations about nonpoint source contributions to groundwater. Additionally, recently passed House of Representatives property rights legislation is a serious blow to national wellhead protection efforts.

In light of the laws and programs, what measurable results have been achieved and what gaps have been identified, if any?

Despite the mountains of data that have been collected by the various agencies over the past ten or fifteen years, very little historical information is available on basinwide ecosystem conditions in the Great Lakes basin. Available data comprises detailed information about localized problems and conditions, but efforts to integrate these isolated databases into a regional framework are rare. The resulting data pool is fragmented, incomplete, and lacks a temporal or spatial perspective within the context of basinwide evaluation. Further complications relate to changing standards for measuring progress, including shifting benchmarks from water quality to bioaccumulative effects to resuspension/reactivation potential, and so on.

Databases may be unreliable; for example, databases such as STORET in the U.S. accept data with little internal error checking; the user may therefore have difficulty determining the quality and reliability of the data of interest. Data are often, perhaps usually, inaccessible to the general Great Lakes research community for prolonged periods because of proprietary rights and difficulties in searching and access. Some databases, such as the U.S. Toxic Release Inventory and the Canadian National Pollutant Release Inventory, may change every year as new chemicals are added to the reporting list and new facilities are required to report their emissions.

Finally, the available data have been collected for different purposes, whether to track compliance with statutory or voluntary requirements, or to assess ambient conditions in local "hot spots." It is therefore almost impossible to assess progress on a basinwide basis, as there is simply no accepted standard of comparison; there is little comparability among data sets; and the data in general lack the temporal and spatial contexts essential for such an analysis. Few agencies contacted used any formal method or criteria to evaluate the effectiveness of toxics management activities. This makes it difficult for agencies to assess the current status of programs and to establish a baseline against which future progress can be judged.

As a result of this fragmented database,

- Few agencies had sufficient data to make a comprehensive assessment of ambient water quality with respect to toxic chemicals.
- Few agencies had sufficient data to identify the relative contribution of toxic chemicals made by type of source (for example, agricultural nonpoint sources vs. industrial point sources).
- Few agencies have sufficient data to assess toxic chemical discharges or receiving water impact trends over time.

Finally, it is clear from the review that the Parties have not succeeded in developing joint or binational approaches to toxic reduction programs or data inventories. A major obstacle to a common assessment methodology is the differing legal frameworks in the two countries, which lead to different approaches to toxics management issues, different requirements for data collection, different ways that databases are used, and so on. The **State of the Lakes Ecosystem Conference** (SOLEC) provided an initial step in this direction but is still an evolving process that should be closely integrated with IJC activities and the Parties' commitments under the Great Lakes Water Quality Agreement.

2.5.5 Recommendations

It is evident that current toxic chemical management programs and data collection activities are not well coordinated between the U.S. and Canada. This situation has arisen because of a variety of factors, including differing legal frameworks and an evolving policy agenda. Nevertheless, the Workgroup concluded that current fiscal restraint initiatives make it imperative that Great Lakes jurisdictions improve the compatibility of their laws, programs and databases with respect to the management of toxic substances. This is not to say that the Parties programs should be identical, but rather that they need to improve their ability to compare progress on a basinwide basis. The Science Advisory Board recommends that:

- **the Commission consider toxics reduction programs as a priority for further action within the next biennial cycle. To further this priority item, the IJC should establish a special task force of the Science Advisory Board, in cooperation with the Water Quality Board and the Council of Great Lakes Research Managers, with a mandate to:**

  (a) develop standardized binational mechanisms and criteria to assess toxic chemical management laws, programs and data collection activities;
  (b) provide advice to the Commission on the design and implementation of such activities in order to assess toxics loadings to the Great Lakes basin.

- **the Commission reiterate and re-emphasize to the Parties the recommendation from the Commission's *Seventh Biennial Report on Great Lakes Water Quality,* which stated:**

  - Governments adopt a specific, coordinated binational strategy within two years with a common set of objectives and procedure for action to stop the input of persistent toxic substances into the Great Lakes environment, using the framework developed by the Virtual Elimination Task Force.

2.6 Followup on the Virtual Elimination Task Force

The issue of persistent toxic substances has remained one of the focal points for the work of the **International Joint Commission** (IJC). Since the 1970s, the Commission, with the assistance of its advisory boards, has proposed policy directions and action steps to address this problem, as demonstrated in its recommendations to the governments. One of the key recommendations in the *Seventh Biennial Report* (IJC 1994) was the endorsement of the Virtual Elimination strategy proposed by the **Virtual Elimination Task Force** (VETF), as a framework for action to implement a central policy of the Agreement.

The Workgroup on Parties Implementation addressed the role and importance of planning efforts related to implementing the proposed strategy and achieving progress toward the virtual elimination of persistent toxic substances.

The Workgroup has examined dioxin and furans as interesting examples for virtual elimination, because they raised a range of social, economic and technical issues. The Workgroup is not recommending that action proceed on any specific group of compounds. Rather, the intent is to examine the practical implications of transition to virtual elimination.

2.6.1 The Evolution of the Policy Framework for Persistent Toxic Substances

The **Great Lakes Water Quality Agreement** (GLWQA) provides the overall policy direction for toxic substances. Article II of the Agreement states that the "discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated." In addition, Annex 12 further provides direction to governments in dealing with persistent toxic substances, such as the principle that new regulatory programs must be designed in the "philosophy of zero discharge."

While the Agreement provides a framework to address persistent toxic substances, successive IJC Biennial Reports to the Governments of Canada and the United States have expanded and evolved the thinking with respect to the nature, scope and application of the Agreement goals.

Building on much of the work of the Science Advisory Board in its previous three reports to the Commission, the IJC in its *Sixth Biennial Report* provided a policy framework to address persistent toxic substances. The Commission recommended to the governments a process to further the phaseout of persistent toxic substances. The process, labelled "sunsetting," was defined by the Commission in the following way:

> "Sunsetting" is a comprehensive process to restrict, phaseout and eventually ban the manufacture, generation, use, transport, storage, discharge and disposal of a persistent toxic substance. Sunsetting may require consideration of the manufacturing processes and products associated with a chemical's production and use, as well as of the chemical itself, and realistic yet finite time frames to achieve the virtual elimination of the persistent toxic substance.

In its *Sixth Biennial Report,* the Commission recommended that specific substances be targeted for sunset (such as DDT, dieldrin, toxaphene, mirex and hexachlorobenzene). It also recommended that, in consultation with industry and other affected interests, timetables be developed to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks and that the means of reducing or eliminating other uses be examined.

The sunsetting concept was further elaborated upon, and indeed, highly refined, in the report of IJC's **Virtual Elimination Task Force** (VETF), titled *A Strategy for Virtual Elimination of Persistent Toxic Substances* (1993). The VETF report traced the history of efforts to address persistent toxic substances. It noted the progression of approaches to address these substances, evolving from pollution control that manages individual substances through prevention that seek to avoid the use and generation of such substances, to environmentally-sustainable production processes. The report then developed a strategy to achieve virtual elimination, including the articulation of ten principles to guide the strategy. The premise of the strategy is that there may be a need to use specific chemicals and other raw materials, and at times, a need to evaluate whole classes of chemicals or industrial processes. The VETF propose a use-tree analysis to assist in identifying chemical sources and where and how to intervene to more effectively address the problem. The Commission formally adopted the VETF report and endorsed its conclusions and recommendations in its *Seventh Biennial Report.*

The VETF also developed its decisionmaking process and recommended that the process be used to determine which substances should be candidates for virtual elimination, what indicators would measure progress and what approach should be taken to achieve virtual elimination.

2.6.2 Implementing the VETF Strategy - Toward Sustainable Industry

The Commission's use of the sunsetting concept, and the knowledge and elaboration added to it by the VETF, responds to the question of how, and the basis for, the identification of those substances subject to phaseout.

While there was considerable development in the policy framework on what (or if) substances should be identified for action, an equally perplexing set of issues has arisen as to how to sunset or phaseout substances once the strategy as proposed by VETF is applied. The how question, indeed, has been the growing subject of discussion and dialogue among many stakeholders. At the 1993 Biennial Meeting in Windsor, Ontario, representatives from labour, the environmental community and industry all agreed that if substances are to be phased out, the technological, social and economic issues that may arise in the implementation of such phaseout decisions must be explicitly anticipated and addressed. In effect, there was a recognition of the need to plan for the transition to cleaner production processes.

In its *Seventh Biennial Report*, the Commission recognized that an effective virtual elimination strategy would respond to the issue of how the sunset concept should be carried out in light the technological, social and economic components that might arise. Indeed, the Commission noted in its *Seventh Biennial Report* (page 29):

> Sunsetting and eliminating the many persistent toxic substances in use will take time, even with a broadly-ascribed and determined effort by all governments and industry. The scale of this effort will be massive and in some cases cause ripples throughout the economy. The continued viability of the orderly transition of the economy is also in everyone's best interest.

The Commission went on to recommend that a "consensus-building approach is essential which addresses the concerns of labour, industry, municipalities and other interests to ensure an orderly transition to an economy without persistent toxic substances." [p. 15]. Further, recommendation 20 stated that "Governments, industry and labour begin devising plans to cope with economic and social dislocation that may occur as a result of sunsetting persistent toxic substances."

While the concept of planning is important, it is acknowledged that several of the substances on the IJC list of 11 **persistent toxic substances** (PTSs) have been taken out of commerce without the help of transition plans. The political process ultimately addresses societal transitional issues on the basis of policy, regulation and legislation. Under the market system, new technology is continually being developed and introduced that facilitates the phasing out of products and processes that are detrimental to the ecosystem. The role of planning in the context of the policy of virtual elimination of PTSs is to enhance these mechanisms for broad social change, by providing a forum for all those affected to evaluate progress, identify alternatives and agree on priorities. The successful implementation of any strategy requires planning and coordination from all sectors of society. While government is often traditionally viewed as having a leadership responsibility toward planning activities, all stakeholders share responsibilities for implementation of the strategy for PTS elimination as developed by the VETF, and for the necessary planning that it entails.

2.6.3 Workshop Sponsored by the Workgroup on Parties Implementation

To further the assigned priority, the Workgroup hosted a facilitated Workshop on Transition to Virtual Elimination on March 30-31, 1995 in Ann Arbor, Michigan. The purpose was to identify roadblocks and opportunities to achieving virtual elimination. The issue was how to plan for a transition, not if phaseout of targeted persistent toxic substances should occur. The workshop was centred around a case study using **polychlorinated dioxins** and **furans** (PCDD/F) as specific virtual elimination candidates.

Dioxin is used here as a case study for a number of advantages. Not all members of the Science Advisory Board believe it is the most important substance for action, and it is not used for that reason. It is used as a case study because the IJC has recommended action on this substances in past Biennial reports; it is a difficult substance to address since it is a byproduct. As a difficult substance, it clearly brings to light some of the important issues in the transition to virtual elimination; and there are a multitude of sources that will allow research to look at different applications of the concept to different sources.

To facilitate discussion, the Workgroup commissioned a set of papers from various stakeholder groups, including industry, environmentalists, labour and government. In the case of industry and environmentalists, each formed a consortium so that one paper from each of these constituencies could incorporate the views of a number of perspectives from that interest group.

The presenters were asked to consider the following elements in a binational perspective:

- provide a working definition of "transition planning"
- refer to existing data on loadings and sources of dioxin-like compounds from anthropogenic sources to the Great Lakes
- identify legal, economic, social and technological/scientific impediments to the elimination and "sunsetting" of these compounds
- identify stakeholders that would be economically, socially or otherwise affected by the implementation of virtual implementation strategies and need to be included in transition planning processes
- discuss mechanisms that can be used in transition planning to minimize adverse impacts, promote the maximum benefits and ensure fair and equitable distribution of the benefit and detriments of the transition among stakeholders.

The workshop also benefited from a detailed presentation on the recent U.S. EPA report, *Dioxin Re-Assessment Study* (U.S. EPA 1994) and a study on the *Quantitative Estimation of the Entry of Dioxins, Furans and Hexachlorobenzene into the Great Lakes from Airborne and Waterborne Sources* (Commoner and Cohen, 1995). As well, presentations were made on economic perspectives and green technologies. These studies are available on request. Papers were also presented from representatives of labour, environmental and industrial groups.

It is not possible to relay, even in a summary way, the wealth of information and insight of the presenters and participants of the workshop. However, a number of interesting, thought-provoking and relevant issues were raised. An inventory of issues subject to dialogue and debate, and remain so, include:

Overarching Issues

- the need not only for a transition planning process, but the need for a transition policy for North America
- the development of a suitable definition for "transition planning"

Principles for Transition Planning

- the need for clear targets and sunset mandates as a precondition to triggering of the transition process
- the need to have all relevant stakeholders involved, that is, labour, industry and communities
- the adoption of a "no net loss for workers" policy in the transition process
- a review of how to incorporate a cost/benefit analysis

Developing a "Transition Planning" Process

- develop a systematic framework for planning for orderly transition, including identifying targets and principles, establishing appropriate institutions, undertaking background research review, selecting transition mechanism and implementing the mechanisms
- apply the process to the largest contributors first (either sector or plant)

Examining Mechanisms for Transition

- the establishment of a transition fund to assist workers and communities
- examine economic, legal, voluntary and other such mechanisms to assist in the transition

The Institutional Framework for Transition

- the need for new or enhanced international, regional or local bodies to assist in the design, development and implementation plans.

2.6.4 Recommendations

There seems to be a general agreement that, in the process of sunsetting substances, planning for the transition to cleaner production processes is both necessary and advisable. Moreover, it is a concept that naturally evolves from the policy developments of the Commission. For present purposes, no specific definition of transition planning is being adopted, since no doubt the concept will evolve over time with a broader dialogue on the subject. **However, a working definition can simply be that it is a process that includes a variety of economic, legal, voluntary or other such measures intended to anticipate the transition to cleaner technologies and products by assessing the impacts to employees, communities and other affected interests. In effect it asks, what are the societal implications associated with the sunset of a substance or class of substances?** Hence, the Science Advisory Board recommends that:

- **the Commission consider planning for the transition to virtual elimination as a priority for further study and research within the next biennial cycle. Components of this research should include:**
    - a study researching a number of case histories of where there were specific efforts to facilitate the transition of an industrial sector owing to some change in circumstance (such as the downsizing of the military establishment or the phaseout of certain substances such as CFCs) to determine the lessons learned from those experiences
    - an investigation to identify the major contributors of dioxin to the Great Lakes
    - the development of a transition plan, with the participation of the important stakeholders, for the virtual elimination of dioxin inputs from one of the major contributors. The development of the plan would serve as a forum for a discussion on both the general framework and the key components of transition plans. The terms of reference of the study would include:
        1. the definition of transition planning
        2. important principles that would be included in fashioning a plan (such as who should participate in the plan design, when it is necessary, among many others)
        3. identification and feasibility of transition mechanisms (such as a transition fund) and the potential and obstacles for them to work in practice
        4. the need to establish, if at all, an institutional framework for the development, implementation and monitoring of the transition process, whether at a local, regional, national or international level.
- **the Commission sponsor one or more roundtables to engage the dialogue of stakeholders in the topic, and to further elaborate on how the term should be interpreted and applied.**
- **the Commission actively seek avenues to participate in international dialogue both within North America and beyond on transition planning.**
- **the International Joint Commission reiterate recommendation 20 in its *Seventh Biennial Report* to the governments in particular, which stated that governments, industry and labour begin devising plans to cope with economic and social dislocation that may occur as a result of initiatives designed to promote virtual elimination.**
- **Further to this recommendation, that the Commission recommend to the governments within the Great Lakes basin that:**
    - transition planning components, when deemed necessary in the sense that there is a risk of significant worker or community dislocation, be included into the specific commitments to those substances that are already candidates for phaseout, such as those identified under the Canada-Ontario Agreement (1994), and the Lake Superior Binational Program
    - governments report back to the IJC biennially on progress made in furthering these transition mechanisms.

2.7 Impacts of Climate Change on the Great Lakes: Progress Towards A Binational Strategy

2.7.1 International Aspects

Introduction

The anticipation of climate change as a result of anthropogenic influence has been a matter of speculation in scientific literature at least since 1896 (Bolin 1994). An international assessment of its significance was initially completed in 1985, under the auspices of the **United Nations Environment Program** (UNEP) and the **World Meterological Office** (WMO) (Bolin et al. 1986). The prospect for climate change, within the broader context of global change, was addressed by the United Nations Commission on the Environment and Development (1977). This led to the formation of the **Intergovernmental Panel on Climate Change** (IPCC) in 1988 as a technical body for the scientific assessment of climate change and its first assessment report was completed in 1990. A 1992 IPCC Supplemental Report preceded the adoption of the U.N. Convention on Climate Change in May 1992 on the occasion of the U.N. Conference on Environment and Development held in Rio in that year. The ratification of this international convention resulted in the first meeting of the Conference of the Parties held in Berlin, March 31, 1995. The objective of the Framework Convention on Climate Change is "... to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, which level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." To assist the Conference of the Parties in its work, the IPCC is preparing a second assessment report to be released in early 1996. A summary report for policymakers addressing "Radiative Forcing of Climate and Review of Global and Regional Greenhouse Gas Emission Scenarios" was published in November 1994, with the complete scientific report publication planned to coincide with the Berlin Conference of the Parties.

The work of the IPCC is organized under three working groups:

- Working Group I addresses the function of the climate system, including natural and anthropogenic factors
- Working Group II assesses potential impacts, adaptation strategies and mitigation measuring, including the potential to reduce greenhouse gas emissions and the role of technology
- Working Group III focuses on economic implications, including methodologies for cost-benefit analysis, e.g. Is prevention better than adaptation? Which is the most cost effective?

The second assessment by the Intergovernmental Panel on Climate Change will include chapters with some relevance to the Laurentian Great Lakes.

Assessment

The role of the IPCC is one of assessment, similar to the role of the **International Joint Commission** (IJC) under the **Great Lakes Water Quality Agreement** (GLWQA). This assessment function is supported internationally primarily through an international framework for research on the earth's system. These programs share an institutional linkage through the **International Council of**

Scientific Unions (ICSU), as well as the interpersonal involvement of some of the world's most eminent scientists. The ICSU was established in 1931 to:

- encourage international scientific activity
- facilitate coordination among the unions and national members
- design and implement international interdisciplinary scientific programs
- act as a consultant to governments and others on scientific issues that have an international dimension.

It currently comprises 23 international scientific unions, 20 interdisciplinary bodies, and national scientific members from 92 countries. The national members are typically the academics or research councils from the various countries.

Research

Earth system research is organized under four areas, all related to climate:

- the **physical climate system,** including the atmosphere, oceans, ice and snow (World Climate Research Program)
- the **interactive processes**; physical, chemical and biological, that regulate the Earth system (International Geosphere-Biosphere Program)
- the **biological diversity** of plant and animal life (DIVERSITAS See Footnote 5)
- the **human dimensions** of environmental change, i.e. how human society interacts with its environment (HDP).

Within the IGBP goal to address the nature of the earth system, its past changes and uncertain future, six key questions have been identified to guide research:

- How is the chemistry of the global atmosphere regulated, and what is the role of biological processes in producing and consuming trace gases?
- How will global changes affect terrestrial ecosystems?
- How does the vegetation interact with physical processes of the hydrological cycle?
- How will changes in land use, sea level and climate alter coastal ecosystems, and what are the wider consequences?
- How do ocean biogeochemical processes influence and respond to climate change?
- What significant climatic and environmental changes occurred in the past, and what were their causes?

Other IGBP activities relevant to increasing the understanding of the chemical, physical and biological integrity of the earth include a Task Force on **Global Analysis, Interpretation and Modelling** (GAIM); a **Data and Information System** (IGBP-DIS); and a **System for Analysis, Research and Training** (START) (Williamson 1992).

The Hydrological Cycle

One IGBP core project particularly relevant to the Great Lakes is addressing how ecosystems and their components affect the water cycle, freshwater resources and partitioning of energy on earth. The hydrological cycle is a key component of the earth's climate system which links the atmosphere, oceans, land and the biosphere. Improved understanding of the hydrological cycle is essential in order to resolve uncertainties in predicting future climate change. While modelling efforts have become more dynamic and integrative since 1990, present knowledge is still largely based on the results of **General Circulation Models** (GCMs) which formed the basis of the early assessment report. Current modelling efforts seek to couple the ocean and the atmosphere (CGCMs) and have generally confirmed IPCC 1990 estimates of future warming of about 0.3 deg/decade (range 0.2 to 0.5 deg C/decade) (WMO/UNEP 1992). By accounting for the influence of the hydrological cycle, climate researchers hope to improve the certainty of predictions related to the timing, magnitude and regional patterns of climate change.

The hydrological cycle influences climate in a variety of ways. The exchanges of moisture and heat between the atmosphere and the earth's surface fundamentally affect the dynamics and thermodynamics of the climate system. In the forms of vapour, clouds, liquid, snow and ice, as well as during phase transitions, water plays opposing roles in heating and cooling the environment. Fifty percent of surface cooling results from evaporation. Water vapour in the atmosphere acts as a powerful greenhouse gas and nearly doubles the effects of greenhouse warming caused by carbon dioxide, methane and all similar gases (Chahine 1992). Clouds control climate by altering the earth's radiation budget. The release of latent heat of condensation in clouds provides 30 percent of the thermal energy that drives the earth's atmospheric circulation.

Conclusions

Other important factors related to the future prediction of climate change are determining future anthropogenic emissions of greenhouse gases and other climate-forcing agents, such as aerosols. Greenhouse gases increase the radiative effect, while aerosols reduce it by increasing the reflection of solar radiation to space. Recent studies on the effect of "dirty" clouds on climate as a result of aerosol particles mediating cover and vapour density suggest that their effect could be comparable in magnitude to the effect of greenhouse gases (Stephens 1994).

Progress since 1990 has resulted in a better appreciation of climate change uncertainties, and is driving an international research agenda aimed at their reduction. This includes (WMO/UNEP 1990):

- development of improved models, which include adequate descriptions of all components of the climate system
- improvements in the systematic observation and understanding of climate-forcing variables on a global basis, including solar irradiance and aerosols
- development of comprehensive observations of the relevant variables describing all components of the climate system, involving as required new technologies and the establishment of data sets
- better understanding of climate-related processes, particularly those associated with clouds, oceans and the carbon cycle
- improved understanding of social, technological and economic processes, especially in developing countries, that are necessary to develop more realistic scenarios of future emissions
- development of national inventories of current emissions
- more detailed knowledge of climate change that have taken place in the past
- sustained and increased support for climate research activities which cross national and disciplinary boundaries; particular action is needed to facilitate the full involvement of developing countries
- improved international exchange of climate data.

It is not expected that the conclusions of the IPCC will change significantly in their second assessment report, to be released in early 1996. This conclusion, in part, stated that (WMO/UNEP 1990):

- Global mean surface air temperature has increased by 0.3 deg C to 0.6 deg C over the last 100 years, with the five global mean warmest years being in the 1980s. Over the same period, global sea level has increased by 10-20 cm. These increases have not been smooth with time, nor uniform over the globe
- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus, the observed increase could be largely due to this natural variability; alternatively, this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more
- There is no firm evidence that climate has become more variable over the last few decades. However, with an increase in the mean temperature, episodes of high temperatures will most likely become more frequent in the future, and cold episodes less frequent
- Ecosystems affect climate, and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct. Enhanced levels of carbon dioxide may increase productivity and efficiency of water use by vegetation. The effect of warming on biological processes, although poorly understood, may increase the atmospheric concentrations of natural greenhouse gases.

With the scientific certainty of rising global average temperature, including the highest year on record in 1990, the June 1991 eruption of Mount Pinatubo in the Philippines emitted large quantities of sulphate aerosols into the upper atmosphere, which reflected incoming sunlight back into space, enough to exert a cooling effect that confirms climate models. By early 1994, however, almost all the aerosols had settled out, clearing the way for a resumption of the warming trend (McCormick et al. 1995). The year 1994 brought renewed evidence of global warming with record temperatures in many countries. Recent estimates project cumulative emissions of CO_2 from energy and industry of 3-1/2 to 10 times larger in the coming century than in the past, unless significant efforts are made to reduce emissions, and confirm the IS92 emission scenarios developed as input to the GCMs for modelling future climates (Bruce, personal communication).

2.7.2 Regional Assessment of Freshwater Ecosystems and Climate Change in North America

This symposium, held in October 1994 in Leesburg, Virginia, was organized by the American Society of Limnology and Oceanography and the North American Benthological Society and sponsored by the U.S. Environmental Protection Agency and the U.S. Geological Society. Drs. Diane McKnight and Alan Covich chaired the conference. For analysis North America was divided into eight regions, one of which was the region of glacial lakes, including the Laurentian Great Lakes. Three products are expected. These are: (1) eight regional assessments of the potential effects of global climate change to be published in the journal, *Hydrological Processes,* (2) an early summary of these eight assessments, and (3) a special issue of *Limnology and Oceanography* containing the peer-reviewed papers presented at the symposium. A summary of the assessment for the region of glacial lakes is provided below:

Laurentian Great Lakes and Precambrian Shield (Magnuson et al. 1995)

> This region is water-rich with low relief, cool to cold in winter and warm to cool in summer. A multitude and diversity of lakes and associated WETLANDS and streams

dominate the area. Included are the Laurentian Great Lakes, smaller glacial lakes, streams, and wetlands south of the permanent permafrost to the southern extent of the Wisconsin glaciation. Lakes are emphasized in our analysis owing to the existing breadth and intensity of lake research. Physical and biological processes and conditions of these systems are sensitive to potential climate change as are associated human values. Paleo analyses of lake sediments and time series of weather data and ice phenologies indicate that the region is warmer and wetter now than several thousand years ago. Observed air temperatures, summarized from 1911 for the Great Lakes - St Lawrence area, have been increasing at a per decade rate of about 0.11 deg C (spring) and 0.06 deg C (winter) with little change observed in summer and fall. Similarly annual precipitation has been increasing at a per decade rate of 2.1%. Ice thaw dates on selected lakes indicate that late winter temperatures have warmed by about 2.5 deg C since the mid-1800s. **Carbon dioxide doubling** ($2XCO_2$) scenarios from the Canadian **General Circulation Models** (GCM) generated warmer temperatures of 6-10 deg C (winter) and 4-5 deg C (summer). Scenarios for summer are dryer in western Ontario (-20%) but show little change or slight increases elsewhere. Scenarios for winter are wetter in western Ontario and northern Minnesota, Wisconsin and Michigan (+20%) but show little change or slight decreases elsewhere.

Two overarching considerations shaped our thoughts: 1) the wide array of expected changes, and 2) differences in expected responses within the region. Potential changes include changes in physical limnology; hydrology in respect to water levels, weathering, and residence times; solar radiation in respect to changes in cloudiness, **dissolved organic carbon** (DOC) concentrations, and deep water oxygen concentrations; and distribution, growth, and persistence of fishes. Watershed and lake-specific factors were identified as key considerations.

Various limnological models have been used to extend climate scenarios from the General Circulation Models to physical limnological scenarios. With a doubling of carbon dioxide, these models generate stream temperatures that track air temperature, summer lake temperatures that are 1 to 7 deg C warmed in the epilimnion and 6 deg C cooler to 8 deg C warmer in the hypolimnion, deeper or shallower thermoclines by up to 4m, sharper thermoclines, and reductions in duration of ice cover by several months, including the absence of ice cover at some latitudes. To the south, the loss of ice for some lakes in some years indicates that dimictic lakes would become monomictic and mix through the winter; summer stratification would become longer. To the north, some lakes that presently are monomictic and mix during summer would stratify in summer and become dimictic. Dimictic deep lakes would be less likely to mix completely. All of these changes would influence the lake ecosystems.

Hydrologic scenarios with a warmer and dryer climate produce lower lake water levels which should change WETLANDS, alter spawning opportunities for fishes and substrates for littoral benthos, and increase demand for water for agriculture and other uses. For Lake Michigan various $2XCO_2$ scenarios produce a decrease in water level of 1.25 to 2.5m. For the Illinois shoreline of the Chicago area, increased costs for dredging, extending water intakes, relocating beach facilities, and extending storm water outfalls have been estimated at $280 million to $540 million. Other direct economic impacts include increased costs of shipping in the Laurentian Great Lakes and reduced production of hydroelectric power at Niagara Falls.

Lower runoff under a dryer and warmer climate would affect biogeochemical processes, such as slowing the weathering of silicate rocks and decreasing solute fluxes to lakes. Conversely, concurrent increases in water residence time would cause higher solute concentrations and greater internal alkalinity generation. Lower wetland water tables could decrease the extent of reducing environments, increase acidic flows, and decrease DOC and trace metals in inflows. The decrease in DOC should increase water clarity, deepen the thermocline, increase benthic algae and invertebrates. Such logically predictable changes have been observed in the Experimental Lakes Area of western Ontario during the recent 20-year period of progressively warmer and dryer weather.

Fishes are aerobic ecotherms and would respond strongly to changes in temperature and oxygen concentrations. Generally, simulations driven by climate scenarios, both for large and small lakes, increase thermal habitat for warm water, cool water and even cold water fishes if oxygen is not depleted in deep water. Scenarios also generate increased body growth if there is sufficient food to meet the higher metabolic demands at warmer temperatures. For some more extreme scenarios and latitudes, there is an increased probability that temperatures would reach lethal levels both for cool water and warm water fishes. Simulations also suggest that deep water anoxia is more probable which could eliminate cold water fishes. Warmer groundwater and stream temperatures would cause habitat reductions and loss of some cold water and cool water fish populations.

Local lakes and streams do not necessarily exhibit coherent responses to the same climate changes and variability. Lakes integrate changes over different timescales because their water residence times as influenced by lake size and inflows differ. Specific spatial factors that alter hydrologic responses of lakes to climate changes are regional climate, geomorphic setting and substrates, mean depth, ratios of lake/drainage area, and lake volume/total basin storage. Differing hydrologic responses can interact with differences in ecosystem structure and function. The reduction in ice cover can decrease winterkill of fishes in a shallow forest lake, but increase winter mortality of whitefish eggs in bays of the Laurentian Great Lakes. This results not only from the physical differences between tiny lakes and great lakes, but also from differences between their species in life history and physiology.

Five broad research needs were identified:

- Long-term research and monitoring be maintained and expanded at key locations
- Models of aquatic system behaviour be improved and tested against long-term data and manipulative field experiments
- Climate models be improved to include outputs of wind and clouds and at temporal and spatial scales more suitable for subregional analyses
- Heterogeneity of potential responses should be recognized and a predictive understanding of this heterogeneity be developed
- Laboratory studies on the response of fishes to altered temperature regimes.

2.7.3 Binational Approach for the Great Lakes

The **Great Lakes - St. Lawrence Basin** (GLSLB) Project on "Adapting to the impacts of climate change and variability" is an integrated climate impact assessment lead by the Atmospheric Environment Service of Environment Canada (Mortsch 1994). The project objectives are to determine the impacts of climate variability and change in four theme areas: water management, land use and management, ecosystem health and human health, and to demonstrate how activities can develop adaptation strategies to reduce vulnerability.

Several study concepts were developed during two 1993 consultation workshops, cosponsored by **l'Association de climatologie du Quebec** (ACLIQ), Health Canada and Environment Canada in Quebec City and Montreal (Mortsch et al. 1993; ACLIQ 1993). Eight collaborative research projects are presently in various stages of completion (Mortsch 1994).

A Global Climate Change Workshop was convened on December 6-8, 1993 in Ypsilanti, Michigan, by **National Oceanic and Atmospheric Administration's** (NOAA) **Great Lakes Environmental Research Laboratory** (GLERL), the **Cooperative Institute for Limnology and Ecosystems Research** (CILER) and the Great Lakes Commission. The Administrator of NOAA had charged GLERL with developing the United States component of a binational Great Lakes global climate change study. The objective of the workshop was to link the study with the ongoing initiative coordinated by the Canadian Atmospheric Environment Service. Thus, the workshop agenda included:

- assess the current status of global change research and impact assessment in the Great Lakes
- identify unmet needs in these areas
- develop a United States Great Lakes Climate Change Research Plan to address these unmet needs and lay the foundation for basinwide adaptive strategies.

The workshop (Ryan et al. 1994) included nine formal presentations and five breakout discussion groups focussing on issues related to: economic/social assessment and impacts; ecosystem and public health; landscape/long-term measurements; physical/climate systems; and water policy and management.

The main conclusions and recommendations can be summarized as follows: potential effects of climate change and variability could have several consequences for the economic, environmental and social fabric of the Great Lakes basin, such that:

- a study should be undertaken to investigate the potential impacts of climate change and adaptive and mitigative strategies to address the potential consequences
- the proceedings of the workshop should be used as a basis for a United States Plan of Study.

A Canada-U.S. committee met fall of 1994 and spring 1995 to plan a binational symposium to be held in 1996, and to develop a Binational Implementation Plan as a terms of reference for the Great Lakes - St. Lawrence Basin Climate Change Project.

The Board notes that NOAA's participation in this project responds to its recommendation from its 1993 report that the "Parties develop and implement a binational program to address global climate change through the integrated study of the Great Lakes basin as a regional pilot project." Such an approach, lead by NOAA and Environment Canada, and involving state and provincial agencies epitomizes the benefits that can occur when binational cooperation and scientific consensus are achieved on an important issue.

Research Objectives and Framework

The goal of the Binational Implementation Plan is to undertake research that will improve understanding of the complex interaction between climate change and variability, the environment, and our social and economic systems so that informed regional adaptation responses can be developed for the regional sustainable management.

To achieve this goal, the research agenda is directed to achieve the following objectives:

- develop indicators of climate change to identify sensitivities and thresholds
- identify in a measured, quantitative way, how activities and systems respond and adapt to direct/indirect impacts of climate change and variability
- identify and evaluate adaptation strategies
- "integrate" (link and coordinate) biophysical and socio-economic impact assessments and potential adaptation responses
- communicate impact and adaptation results to targeted decisionmakers and affected groups as well as the public and scientific community.

These objectives will be addressed through a comprehensive research program combining scientific and policy concerns, according to a framework comprising themes and crosscutting topics.

Four specific climate-sensitive theme areas were identified and five cross-cutting research topics were developed to focus and integrate the binational research agenda. The research framework is a matrix (Figure 3) which links the theme areas with the range of research topics that should be incorporated into studies associated with the project. The matrix also indicates that the climate-sensitive issues are integrated and linked and that impacts and adaptation strategies in these areas affect each other.

Figure 3

Integration Framework for Binational Project

In particular, a major research project proposed by the Great Lakes Commission will strengthen understanding of climate-human interactions and in so doing, identify policies and management procedures to promote human adaptation to climate fluctuations and the development of a Great Lakes Water Resources Management Program. The latter is a policy framework to establish a process by which government jurisdictions in the Great Lakes basin can anticipate and adapt to the impacts of climate change through the informed use, development and protection of their shared water resources.

Research Opportunities

The research framework is flexible and comprehensive and provides a basis for further research initiatives to add to the knowledge base of the binational project as opportunities arise. Specific study areas that would benefit from additional research include:

- assessment of the human health impacts of climate change impact of climate variability and change on Areas of Concern and implementation of remedial efforts
- impact of climate variability and change on groundwater, ecosystem processes, wetlands, biodiversity, lake circulation and water quality
- impact of changing agroclimatic conditions on agricultural practices
- impact of climate change on long-range transport and atmospheric loadings of toxics.

Much of the current climate impact assessment research has focused on the southern portion of the basin, while Lakes Superior and Huron, the St. Lawrence River, and inland waterbodies have received less research.

2.7.4 Conclusions and Recommendations

The Science Advisory Board congratulates the Parties for developing a comprehensive and integrated research program that addresses many of the major issues concerning climate change relevant to the Great Lakes. It is noted that a symposium is planned for 1996, as a followup to the binational meeting initially held in Chicago in 1988. This symposium will provide a major opportunity for researchers to discuss and incorporate current global and regional efforts in order to develop the 1988 proposal for an integrated study of the Great Lakes basin as a regional pilot project for an international response to global climate change. This recommendation was recently reiterated by the IJC in their *Seventh Biennial Report.*

The proposed Binational Implementation Plan develops such an integrated study, providing it receives the Parties' support through to its completion in 2001. Accordingly, the Science Advisory Board recommends that:

- **the Parties be encouraged to support the completion of the binational implementation plan through to 2001 according to the scheduled timeline as indicated in Table 6.**
- **a quinquennial symposium on climate change in the Great Lakes basin be sponsored by the Parties and sustained following the event planned for 1996, as an important scientific forum for discussion and to measure progress towards climate change assessment and adaptation.**
- **the recommendation from the 1993 Science Advisory Board report, that the Parties make a long-term commitment to climate change research under Annex 17 of the Great Lakes Water Quality Agreement, and report progress in a holistic and systematic fashion within the context of a State of the Great Lakes Basin Ecosystem report, receive further consideration and emphasis in the IJC recommendations to the Parties.**

2.8 Identification and Assessment of Emerging Issues

2.8.1 Introduction

The Workgroup on Emerging Issues conducted an inquiry and analysis of potential emerging issues, both within the Great Lakes region and more widely from sources around the globe. The goal was to identify issues that were important to the **Great Lakes Water Quality Agreement** (GLWQA), but that were not yet explicitly developed or being addressed. The results are presented here to provide material for thought and discussion, as well as provide a basis for proposals for the priority-setting process of the International Joint Commission.

2.8.2 Survey Within the Great Lakes Region

This study was directed by the Workgroup on Emerging Issues during the spring and summer of 1994. The three-stage process and its findings are presented more briefly below:

- A survey of members of the Water Quality Board, the Science Advisory Board and the Council of Great Lakes Research Managers was undertaken to identify issues, to indicate their importance, and to provide recommendations on how they should be addressed. The initial list of 31 topics from the respondents was evaluated in terms of the perception of each topic as emerging and whether it was already being addressed by current research efforts. Eleven topics were retained for followup by the Workgroup.
- All original respondents were sent a subset of eleven items and asked to rate each as high, medium or low priority as an emerging issue. Responses were ranked by two methodologies: on the basis of the consensus of respondents rating each topic high, medium or low; and by overall scoring. The two approaches yielded slightly different results, and were generated to test different analytical approaches, rather than to provide a comparative assessment.
    - Approach 1. This approach accommodated minority views when a topic was rated by some respondents as high, and others as medium or, by some as medium, and others as low. No single issue fell into all three categories.
      - *High group* had the highest of rating from all respondents
      - *High/medium group* were rated by respondents as either high or medium
      - *Medium/low group* were rated by respondents as either medium or low
    - Approach 2. Assigned scores of: high = 3, medium = 2, and low = 1, were summed to give a total score from all respondents (.Table 6)
- Each topic was then assessed in terms of the current research effort determined by the 1991/92 Research Inventory by the Council of Great Lakes Research Managers (included on Table 7). The Workgroup understood the inventory's limitations acknowledged in this report and viewed the research categories as broadly indicative of the level of effort associated with each category. No attempt was made to relate specific research projects within the categories to the emerging issues. Topics identified as receiving significant funding are related to toxic chemicals, exotic organisms, the ecosystem approach and human health. These results indicate that respondents had a difficult time separating important items for the Great Lakes from emerging items for the Great Lakes. An important item was posited to be one that was highly rated and also received significant research funding, while an emerging item was rated high to medium and even as low, but received little or no research funding.

Conclusions

This assessment identified several possible emerging issues, i.e. items that were judged to be important at some level but which have received little or no attention based on the level of research funding identified in the Great Lakes Research Inventory (IJC 1993). The issue of sustainable development was clearly evident as an emerging issue warranting further study. In summary, the emerging issues were:

1. sustainable development
2. stability of water levels
3. uv-B effects on biota
4. various implications of the **North American Free Trade Agreement** (NAFTA)
5. lifestyle choices as a factor in ecosystem integrity
6. incidence of endometriosis in women who eat fish from the Great Lakes

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2.8.3 Global Survey of Priorities Beyond the Great Lakes Region

Introduction

This survey reviewed general goals or future issues in policy documents from around the globe that might be relevant to emerging issues for the Laurentian Great Lakes. Information was obtained from various international and national boards, commissions, organizations or institutes and the documents were reviewed and assessed. The approach was indicative, rather than comprehensive, however it did generate ideas and increase Workgroup awareness of issues that may be important to the International Joint Commission.

Findings

Issues, especially those identified by international organizations are often broader than those under the GLWQA or the binational research and program agendas of the Parties. At the national level, priorities are more defined and provide ideas for consideration. Collectively, global issues and priorities provide a useful context for ideas on emerging issues in the Laurentian Great Lakes.

The goals of the organization or issues identified in the documents are tabulated briefly in Table 8. As might be expected many issues are identified, while others are contained at lower levels in the hierarchy in the names or acronyms of further goal-setting or issue-oriented documents.

Three organizations are cited sources of information available in further detail as an indication of priorities, goals and issues:

- The **Scientific Committee on Problems in the Environment** (SCOPE) within the International Council of Scientific Unions

SCOPE 1993 includes projects that are either underway or in preparatory phases in the current program. Projects are proposed by member nations or international organizations and are approved and launched by decision of the General Assembly. The present program is in five clusters:

- Sustainability is a broad, new subject area that includes major interdisciplinary efforts to utilize ecological and socio-economic knowledge needed to identify options for ensuring sustainability of the biosphere. Sustainability overlaps widely with all four of the other clusters.
- Biogeochemical cycles concentrates on essential elements and toxic substances, including radionucleotides. Examples are: phosphorus cycles and its interaction with other element cycles in terrestrial and aquatic ecosystems; groundwater contamination; particle flux in the oceans; nitrogen transport and transformation; and radiation from nuclear test explosions.
- Global changes assesses effects of various systemic or cumulative global environment changes in liaison with the **International Geophysical Biological Program** (IGBP), which implements research programs. Two research projects of note are: effects of increased uv-B on biological systems and effects of human activity on surficial earth processes; and the sustainability of land uses.
- Ecosystems and biodiversity focuses on ecosystem processes affected by environmental change and on losses in biological diversity, especially in relation to ecosystem functions. There are five projects: organic matter budgets; climate change in coniferous forests and grasslands; ecotones in a changing environment; the ecosystem function of biodiversity; and the dynamics of mixed tree/grass systems.

- Health and ecotoxicology develops methodologies to assess chemical risks to humans and other organisms, as well as case studies of environmental contamination. There are three projects: methods for assessing the effects of chemicals on ecosystems; methods and risk assessment for neurobehavioural toxicology; and mercury cycling in ecosystems.
- World Health Organizations **Global Environmental Monitoring System** (GEMS)

GEMS designs and develops global water-quality monitoring, relying on the following priorities:

- drinking water quality
- recreational water quality
- eutrophication
- microbiological pollution
- urban water management

Table 9 provides a list of general major water-quality issues on a global scale as developed by GEMS.

- The **World Conservation Union** (IUCN) joint report with the **United Nations Environmental Program** (UNEP) and the **World Wildlife Fund** for Nature (WWF)

The IUCN (IUCN/UNEP/WWF 1991) provides a strategy for sustainable living. Their priorities for the sustainable use of fresh waters are as follows:

- improve information and training
- improve awareness of how the water cycle works in respect to land use
- wetlands and other ecosystem units
- manage water demand for effective and fair allocation
- integrate water and land managemen t
- increase international cooperation on water issues
- improve the institutional and community capabilities to manage and use fresh waters in a sustainable manner
- conserve the diversity of aquatic species and genetics stock

Conclusion

These documents provide a list of issues that are or are not already being addressed by the IJC, but could be relevant to the Great Lakes. Several of the issues from the global survey are in common with our Survey of the Great Lakes Region (Table 9). Perhaps the most noticeable are various issues related to sustainable use and development expressed in the various documents. The biological effects of uv-B was also evident in both surveys. Several broad issues were apparent in the global survey that did not show up as high priority emerging issues in our Great Lakes survey. Two of note are: the broad issue of biodiversity and especially in relation to ecosystem function; and global climate change. The first, biodiversity, is closely related to a more specific issue being addressed in the Great Lakes and to some extent may be subsumed within it, i.e. invasions and effects of exotic organisms. The second is being addressed at an information level by the Workgroup on Emerging Issues and in previous Science Advisory Board reports, and is not a specific responsibility under the Great Lakes Water Quality Agreement.

2.8.4 Recommendation

The Workgroup on Emerging Issues recommends that:

- **the issues identified as potentially important for the International Joint Commission be considered as priorities for serious deliberations during the next biennium. They are complex issues, especially the issue of sustainability that reappeared in each survey, that would require IJC resources to address in terms of implications for progress under the Great Lakes Water Quality Agreement. The issues assessed as most salient include:**

    1. sustainable development
    2. stability of water levels
    3. uv-B effects on biota
    4. various implications of the **North American Free Trade Agreement** (NAFTA)
    5. lifestyle choices as a factor in ecosystem integrity
    6. incidence of endometriosis in women who eat fish from the Great Lakes.

2.9 References

ACES (Advisory Committee on Environmental Standards). 1994. *A Standard for Tritium.* A Recommendation to the Minister of the Environment and Energy, Toronto, Ontario. ACES Report 94-01. 102 pp.

Agency for Toxic Substances and Disease Registry (ATSDR). 1994. *Great Lakes Human Health Effects Research Program.* United States Department of Health and Human Services, Atlanta, Georgia. 60 pp.

Allen, T.F.H. and T.W. Hoekstra. 1992. *Toward a Unified Ecology.* Columbia UP, New York. 384 pp.

Allen, T.F.H., B.L. Bandurski, and A.W. King. 1993. The *Ecosystem Approach: Theory and Ecosystem Integrity.* International Joint Commission, Report to the Science Advisory Board, Windsor, Ontario. 67 pp.

Ashford, N.A., C.S. Miller. 1991. *Chemical Exposures: Low Levels and High Stakes.* Van Nostrand, New York. 214 pp.

Auger, Jacques, Jean Marie Kunstmann, Francois Czyglik, and Pierre Jouannet. 1995. Decline in Semen Quality Among Fertile Men in Paris During the Past 20 Years. New England Journal of Medicine. Volume 332, Number 5, pp. 281-285.

Bandurski, B.L. 1994. Learning Panes, in Environmental Law Institute (ed.) *National Environmental Policy Act, Ecosystem Assessment and Environmental Impact Assessment.* ALI-ABA, Washington, DC.

Bateson, G. 1972. *Steps to an Ecology of Mind.* Ballantine, New York. pp. 541.

Bellar, T.A., J.J. Lichtinberg, R.C. Kroner. 1974. The Occurrence of Organohalides in Chlorinated Drinking Waters. Journal AWWA 66:703-6.

Black, J.S., P.C. Stern, J.T. Elsworth. 1985. Personal and Contextual Influences on Household Energy Adaptations. Journal of Applied Psychology 70:3-21.

Bolin, B., B. Doos, J. Jaager and R. Warrick. 1986. *The Greenhouse Effect, Climate Change and Ecosystems.* John Wiley and Sons, Chichester, England. 541 pp.

Bolin, Bert 1994. Science and Technology. Ambio, Vol. XXII, No. 1, February 1994 ISSN 0044-7447. pp. 25-29.

Bromwich, P., J. Cohen, I. Stewart and A. Walker. 1994. Decline in Sperm Counts: An Artefact of Change Reference Range of Normal? Br. Med. J. 309:19-22.

Brown, R.H. 1977. *A Poetic for Sociology.* Chicago UP, Chicago, Illinois. pp. 302.

Bruce, J., personal communication. WGIII Evaluation of 1592 Emission Scenarios. January 4, 1995.

Bruce, James P. 1994. The Intergovernmental Panel on Climate Change (IPCC) -- Second Assessment Report.New York. Delta: Canadian Global Change Program, Vol. 5, No. 2, Summer 1994, p. 7.

Burnett, R, R.E. Dales, M.E. Raizenne, D. Krewski, P.W. Summers, G.R. Roberts, T. Raad-Young, T. Dann, J. Brook. 1994. Effects of Low Ambient Levels of Ozone and Sulphates on the Frequency of Respiratory Admissions to Ontario Hospitals. Environmental Research 65:172-194.

Callicott, J.B. 1992. Aldo Leopold's Metaphor. In: *Ecosystem Health,* R. Costanza et al. (eds.). Island Press, Washington, DC. pp. 42-56.

Campbell, M. 1993. *Outdoor Air Quality in Toronto: Issues and Concerns.* City of Toronto Department of Public Health, Toronto, Ontario. 172 pp, plus appendices.

Canadian Public Health Association (CPHA). 1992. *Human and Ecosystem Health.* CPHA, Ottawa, Ontario. 31 pp.

Carey, P.M. 1987. *Air Toxics Emissions from Motor Vehicles.* A Technical Report prepared for the Office of Mobile Sources, Office of Air Radiation, U.S. Environmental Protection Agency, Ann Arbor, Michigan.

Carlsen, E., A. Giwercman, N. Keiding and N.E. Skakkebaek. 1992. Evidence for Decreasing Quality of Semen During Past 50 years. Br Med J 305:609-13. CGCP (Canadian Global Change Program). 1992. Prospectus. Glen Suter (ed.) The Royals Society of Canada, Ottawa, Ontario. ISBN 0-92-920064-43-4. 20 pp.

Chahine, Moustafa T. 1992. The Hydrological Cycle and Its Influence on Climate. Nature, Vol. 359, October 1, 1992.

Clarke, E.A., J. McLaughlin and T.W. Anderson. 1991. *Childhood Leukemia Around Canadian Nuclear Facilities, Phase II.* Final report to the Atomic Energy Board, Ottawa, Ontario.

Clements, Frederic E. 1905. *Research Methods in Ecology.* Lincoln, Nebraska.

Climate Groups Rejects Criticism of Warnings. Nature, Vol. 371, September 22, 1994. p. 274.

Colborn, Theo and Coralie Clement (eds.). 1992. *Chemically-Induced Alterations in Sexual and Functional Development: The Wildlife/Human Connection.* Advances in Modern Environmental Toxicology. Princeton Scientific Publishing, Princeton, New Jersey. 403 pp.

Colborn, T. F.S. vomSaal and A.M. Soto. 1993. Developmental effects of Endocrine-Disrupting Chemicals in Wildlife and Humans. Environ. Health Perspectives. 101:378-384.

Commoner, B., and M. Cohen. 1995. *Quantitative Estimation of the Entry of Dioxins, Furans, and Hexachlorobenzene into the Great Lakes from Airborne and Waterborne Sources.* Center for the Biology of Natural Systems, Queens College, Flushing, New York. 86 pp. plus appendices.

Costanza, R., H.E. Daly, J.A. Bartholomew. 1991. Goals, Agenda and Policy Recommendations for Ecological Economics. In: R. Costanza et al. op. cit. pp. 1-20.

Cotgrove, S. 1982. *Catastrophe or Cornucopia.* Wiley, New York. pp. 154. Daly, H.E. 1991. Elements of Environmental Macroeconomics. In: R Constanza et al. op. cit.

Davies, K. 1988. Concentrations and Dietary Intakes of Organochlorines, Including PCBs, PCDDs and PCDFs in Fresh Food Composites Grown in Ontario, Canada. Chemosphere 17(2):263:276.

Devall, B. and G. Sessions. 1985. *Deep Ecology.* Gibbs Smith, Salt Lake City, Utah. pp. 266.

Dockery, D.W., C.A. Pope. 1994. Acute Respiratory Effects of Particulate Air Pollution. Annual Rev Public Health 15:107-132.

Dubos, Rene. 1959. *Mirage of Health.* Anchor Books, Doubleday and Company, Inc. , Garden City, New York. 235 pp.

Ebert E.S., P.S. Price, R.E. Keenan. 1994. Selection of Fish Consumption Estimates for Use in the Regualtory Process. J Exposure Analysis and Environmental Epidemiology 4:373-393.

Edelstein, M.R. 1988. *Contaminated Communities.* Westview Press, Boulder, Colorado. pp. 217.

Ehrenfeld, D. 1992. Ecosystem Health and Ecological Theories. In: *Ecosystem Health,* R. Costanza et al. op. cit.

Environment Canada, Department of Fisheries and Oceans, Health and Welfare Canada. 1991. *Toxic Chemicals in the Great Lakes and Associated Effects.* Volume I and II. Ottawa. Ministry of Supply and Services Canada, Ottawa, Ontario. 755 pp.

Eyles, J. 1985. *Senses of Place.* Silverbrook Press, Warrington, Silverbrook. 162 pp.

Eyles, J. and D. Cole. 1995 (unpublished). *Human Health in Ecosystem Health: Issues and Meaning and Measurement.* Monograph prepared for the Science Advisory Board, International Joint Commission, Windsor, Ontario. 145 pp.

Eyles, J. 1990. Objectifying the Subjective. Social Indicators Research. 22:139-53.

Eyles, J., S.M. Taylor, J. Baxter, D. Sider and D. Willms. 1993. The Social Construction of Risk in a Rural Community. Risk Analysis 13:281-90.

Farland, William. 1993. Environmental Risk Characterization: In: *Risk Assessment, Communication and Management in the Great Lakes Basin*, Michael Gilbertson (ed.). Proceedings of a Workshop, February 1-2, 1993, St. Catharines, Ontario. Great Lakes Water Quality Board Report to the International Joint Commission, Windsor, Ontario. ISBN 1-895085-59-4. 43 pp.

Faust, D. 1985. Declarations Versus Investigations: The Case for the Special Reasoning Abilities and Capabilities of the Expert Witness in Psychology/Psychiatry. Journal of Psychiatry and Law (Spring-Summer):33-59. Fein, G. et al. 1984. Prenatal Exposure to Polychlorinated Biphenyls: Effects on Birth Size and Gestational Age. Journal of Pediatrics 105:315-20.

Fine, G.A. and K. Sandstrom. 1993. Ideology in Action. Sociological Theory 11:21-38.

Fiore, M.C., H.A. Anderson, R. Hong, R. Golumbjatnikov, J.E. Seiser, D. Nordstrom, L. Hanrahan and D. Belluck. 1986. Chronic Exposure to Aldicarb-Contaminated Groundwater and Human Immune Function. Environmental Research 41:633-645.

Fischhoff, B., S. Lichtenstein, P. Slovic, S.L. Derby and R.L. Keeney. 1981. *Acceptable Risk.* Cambridge University Press, Cambridge, U.K.

Fleisher, J.M., F. Jones, D. Kay, R. Stanwell-Smith, M. Wyer and R. Morano. 1993. Water and Non-water Related Risk Factors of Gastroenteritis Among Bathers Exposed to Sewage-Contaminated Marine Waters. Int J Epidem 22:698-708.

Foran, J.A., M. Cox and D. Croxton. 1989. Sport Fish Consumption Advisories and Projected Cancer Risks in the Great Lakes Basin. Am J Public Health 79(3):322-325.

Frank, J., B. Gibson, M. Macpherson. 1988. Information Needs in Epidemiology. In: *Information Needs for Risk Management* C. Fowle et al.(eds.). IES, Toronto, Ontario. pp 129-144.

Friberg, L. 1984. Cadmium and the Kidney. Environmental Health Perspectives 54:1-12.

Geertz, C. 1963. *Agricultural Involution.* Univ. California Press, Berkeley, California. pp. 231.

Gieryn, T. 1983. Boundary-Work and the Separation of Science from Non-Science. American Sociological Review 48:781-95.

Gilman A.P., Y. Mao, R. Burnett, R. Semenciw. 1992. Linking Administrative Databases Relating to Cancer Incidence and Environmental Contaminants in the Great Lakes Basin. Chronic Diseases in Canada 13(6 Suppl): S15-22

Goudie, A. 1994. *The Human Impact on the Natural Environment.* MIT Press, Cambridge, Masssachusetts, 4th ed. 454 pp.

Governments of the United States and Canada. 1978. *Great Lakes Water Quality Agreement,* Ottawa, Ontario and Washington, DC. 64 pp.

Government of Canada and the Province of Ontario. 1994. *The Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem.* 12 pp.

Guo, Yueliang L., George H. Lambert and Chen-Chin Hsu, in press. Growth Abnormalities in the Population Exposed to PCBs and Dibenzofurans.

Hardin, G. 1968. The Tragedy of the Commons. Science 162:1243-8.

Haskell, B.D., B.G. Norton and R. Costanza. 1992. What is Ecosystem Health and Why Should We Worry About It? In: Ecosystem Health, R. Costanza et al. op. cit.

Heberlein, T.A. 1972. The Land Ethic Realized. Journal of Social Issues 28:79-87.

Hengeveld, Henry. 1994. Modelling the Global Climate System, New York. Delta: Canadian Global Change Program. Vol. 5, No. 2, Summer 1994, p. 14.

Hertzman, C., M. Hayes, J. Singer and J. Highland. 1987. The Upper Ottawa Landfill Site Health Study. Environmental Health Perspectives 75:173-95.

Higginson, J. 1992. The Epidemiological Approach to the Causes of Human Cancer and the Implications for Cancer Control Policy. In: *Development of Environmental Health Status Indicators,* S McColl (ed.), Institute for Risk Research, Waterloo, Ontario.

Hill, Austin B. 1965. "The Environment and Disease Association or Causation." Proceedings of the Royal Society of Medicine. 58:295-330.

Hoyos, Carl Graf. 1987. Attitudes To and Acceptance of Uncertain Situations: The Viewpoint of Psychology. In: *Society and Uncertainty.* Verlay Versicherung-Wirtschaft, c.v. Munich, W. Germany. 239 pp.

Hunsaker, C.T. and D.E. Carpenter. 1990. *Environmental Monitoring and Assessment Program.* U.S. EPA, Research Triangle Park, North Carolina.

Ingram, J. 1994. Book review: The Burning House. "Using His Grey Matter," Windsor Star, December 3, 1994.

International Joint Commission. 1993. *Great Lakes-St. Lawrence Research Inventory, 1991/1992.* Council of Great Lakes Research Managers, Report to the International Joint Commission, Windsor, Ontario. ISBN 1-895085-73-X. 158 pp.

International Joint Commission. 1978. *The Ecosystem Approach.* International Joint Commission, Windsor, Ontario. 47 pp.

International Joint Commission. 1991. *A Proposed Framework for Developing Indicators of Ecosystem Health for the Great Lakes Region.* International Joint Commission, Windsor, Ontario. 47 pp.

International Joint Commission. 1994. *Our Community, Our Health: Dialogue Between Health and Science.* Proceedings of A Workshop, held September 14-15, 1992, Ann Arbor, Michigan. 58 pp.

International Joint Commission. 1994. *Seventh Biennial Report on Great Lakes Water Quality.* International Joint Commission, Windsor, Ontario. 58 pp.

International Joint Commission. 1994. *Bioindicators as a Measure of Success for Virtual Elimination of Persistent Toxic Substances.* A Report Based on a Workshop held April 28-29, 1992 at the Michigan League, Ann Arbor, Michigan. G.A. Fox (ed.) 37 pp.

International Joint Commission. 1993. *Applying Weight of Evidence: Issues and Practice.* A Report of a Workshop held October 24, 1993, Windsor, Ontario, Gilbertson, Michael and Sally Cole-Misch (eds.). International Joint Commission, Windsor, Ontario. 37 pp.

International Joint Commission. 1993. *A Strategy for Virtual Elimination of Persistent Toxic Substances,* Volumes 1 and 2. Washington, DC and Ottawa, Ontario. 72 and 112. pp.

International Joint Commission. 1993. *Risk Assessment, Communication and Management in the Great Lakes Basin,* Michael Gilbertson (ed.). Proceedings of a Workshop, February 1-2, 1993, St. Catharines, Ontario. Great Lakes Water Quality Board Report to the International Joint Commission, Windsor, Ontario. 43 pp.

International Joint Commission 1992. *Sixth Biennial Report on Great Lakes Water Quality.* Ottawa, Ontario and Washington, DC. 59 pp.

IUCN/UNEP/WWF. 1991. Caring for the Earth. A Strategy for Sustainable Living. David A. Munro and Martin W. Holdgate (eds.). English ISBN 2-8317-0074-4; French ISBN 2-8317-0075-2; Spanish ISBN 2-8317-0076-0; Earthscan edition 1-85383-126-3. 200 pp.

Jacobson, J. and S.W. Jacobson. 1988. New Methodologies for Assessing the Effects of Prenatal Toxic Exposure on Cognitive Functioning in Humans. In: *Toxic Contaminants and Ecosystem Health,* M.S. Evans (ed.). John Wiley, New York. pp 373-387.

Jacobson, J., S. Jacobson, P. Schwartz, G. Fein, J. Dowler. 1984. Prenatal Exposure to an Environmental Toxin. Developmental Psychology 20:523-32.

Johnson, K., J. Rouleau., C. Stewart. 1992. Atlas I. Birth Defects Atlas of Ontario: 1978-1988. LCDC, Health Canada. 21 pp and maps and appendices.

Juskevich, Judith C. and C. Greg Guyer. 1990. Bovine Growth Hormone: Human Food Safety Evaluation. Science, Volume 249, pp. 875-884.

Kay, J.J. 1991. A Nonequilibrium Thermodynamic Framework for Discussing Ecosystem Integrity. Environmental Management 15:483-95.

Kay, J.J. 1993. On The Nature of Ecological Integrity. In: *Ecological Integrity and the Management of Ecosystems,* S. Woodley et al. (eds.). St. Lucie Press, Delray Beach, Florida. pp. 201-212.

Kearney, J. and D.C. Cole. 1995. Personal Communication.

Kelly, J.R. and M.A. Harwell. 1990. Indication of Ecosystem Recovery. Environmental Management 14:527-45.

Kluckhohn, F.R. 1953. Dominant and Variant Value Orientations. In: *Personality in Nature, Society and Culture.* C. Kluckhohn et al. (eds.) Knopf, New York. pp. 142-157.

Koopman-Esseboom, Corine, Dennis C. Morse, Nynke Weisglas-Kuperus, J. LutkeSchiphoh, Cornelis G. Van der Paauw, Louis G.M. Th. Tuinstra, Abraham Brower, Pieter J.J. Sauer. 1994. Effects of Dioxins and Polychlorinated Biphenyls on Thyroid Hormone Status of Pregrant Women and Their Infants. Pediatric Research. 36(4):468-473.

Koshida, G., B. Mills, L. Mortsch, and D. McGillivray. 1993. *Climate Sensitivity, Variability and Adaptation Issues in the Great Lakes - St. Lawrence Basin: A Reference Document.* Climate Adaptation Bulletin 93-06, Atmospheric Environment Service, Downsview, Ontario. 5,920 pp.

Kreiger, Norman, Mary S. Wolff, Robert A. Kiatt, Marilyn Rivera, Joseph Vogelman and Norman Orentreich. 1994. Breast Cancer and Serum Organochlorines: A Prospective Study Among White, Black and Asian women. J. Natl. Cancer Inst. 86:589.

L'Association de climatologie du Quebec (ACLIQ). 1993. Le Climat. Special issue New York. Adaptation aux contraints climatiques des aspects socio-economiques et environment-taux due basin du Saint-Laurent.New York. Vol. II, Mai 1993, 100 pp.

Langlois, P., L. Smith, S. Fleming, R. Gould V. Goel and B. Gibson. 1995 (in press). Blood Levels in Toronto Children and Abatement of Lead-Contaminated Soil and Housedust. Arch. Environ. Health.

Last, J.M. 1993. Global Change: Ozone Depletion, Greenhouse Warming, and Public Health. Ann Rev Publ Health 14:115-136.

Loucks, Orie L. 1971. The Trial of DDT in Wisconsin. Chapter 7 In: *Patient Earth.* John Harte and Socoow, Robert (eds.) Holt, Rinehart and Winston, Inc. New York. pp. 88-111.

Lubin, J.H. 1994. Invited Commentary: Lung Cancer and Exposure to Residential Radon. Am J Epidem140:323-32.

MacKenzie, W.R., N.J. Hoxie, M.E. Proctor, M.S. Gradis, K.A. Blair, D.E., Peterson, J.J. Kasmierczak, D.G Addis, K.R. Fox, J.B. Rose, J.P. Davi. 1994. A Massive Outbreak in Milwaukee of Cryptosporidium Infection Transmitted Through the Public Water Supply. N Engl J Med Jul 21. 331 (3):161-7.

Magnuson, John J., Carl J. Bowser, Raymond A. Assel and Bart T. DeStasio, John R. Eaton, Everett J. Fee, Peter J. Dillon, Linda D. Mortsch, Nigel T. Roulet, Frank H. Quinn, David W. Schindler. 1995. Laurentian Great Lakes and Precambrian Shield. Working Group 1. In: *Symposium Report: Regional Assessment of Freshwater Ecosystems and Climate Change in North America.* D. McKnight (ed.) ALSO and NABS.

McCormick, M. Patrick, Larry W. Thomason and Charles R. Trepte. 1995. Atmospheric Effects of the Mt. Pinatubo Eruption. *Nature,* Review Article. Volume 373, 02 February, 1995. pp. 399-404.

McKay, D. and S. Patterson. 1992. *A Survey and Critical Review of Models to Assess Human Exposure to Chemicals.* A report to the Environmental Health Directorate, Health Protection Branch, National Health and Welfare. Minister of Supply and Services Canada, Ottawa, Ontario. 61 pp.

Miller, A.B. 1992. Planning Cancer Control Strategies. Chronic Diseases in Canada. 13(1Suppl):S1-40.

Mills, C. and R. Semenciw. 1992. *Atlas II: Cancer Incidence in the Great Lakes Region, Ontario: 1984-1988.* Health Canada Laboratory Centre for Disease Control, Bureau of Chronic Disease Epidemiology, Ottawa, Ontario. 46 pp.

Mitchell, M.F., E. Vavasour, P.B. Currie and J.R. Roberts. 1987. Quantitative Estimation of the Risk to Humans Resulting from Exposure to Chemicals. Monograph VI. In: *Strengths and Limitation of*

Benefit-Cost Analyses Applied to the Assessment of Industrial Organic Chemicals, Including Pesticides. Associate Committee on Scientific Criteria for Environmental Quality. Natural Research Council of Canada, Ottawa, Ontario. 90 pp.

Ministry of Environmental and Energy (MOEE). 1994. Science and Technology Branch 1994. *Windsor Air Quality Study: Executive Summary.* Queen's Printer of Ontario, Toronto, Ontario. 35 pp.

Moorehead, W.P., R. Guasparini, C.A. Donovan, R.G. Mathias, R. Cottle and G. Bayhalen. 1990. Giardiasis Outbreak from a Chlorinated Water Supply, Canadian Journal of Public Health. 81:358-62.

Morgan, M. Granger and Max Henrion. 1990. *Uncertainty -- A Guide to Dealing with Uncertainty in Quanitative Risk and Policy Analysis.* Cambridge University Press, Cambridge, U.K. 332 pp.

Morris, R.D., A. Audet, I.F. Angelillo, T.C. Chalmers, F. Mosteller. 1992. Chlorination, Chlorination By-Products and Cancer. American Journal of Public Health. 82:955-63.

Mortsch, L. 1994. Great Lakes-St. Lawrence Basin Project (GLSLB): An Introduction. In: *Great Lakes-St. Lawrence Basin Project,* 1994. What is the Great Lakes St. Lawrence Basin Project, Issue 1, Winter 1994, 4 pp.

Mortsch, L., G. Koshida, and D. Tavares (eds.). 1993. Great Lakes - St. Lawrence Basin Project: New York. Adapting to the impacts of climate change and variability, New York. Proceedings of the Great Lakes - St. Lawrence Basin Project workshop conducted on February 9-11, 1993 in Quebec City, Atmospheric Environment Service, Downsview, 88 pp.

National Research Council/National Academy of Sciences. 1993. *Issues in Risk Assessment.* National Academy Press, Washington, DC

Needleman, H.L. and D. Bellinger. 1991. The Health Effects of Low Level Exposure to Lead. Ann Rev Public Health. 12:111-140.

Nieboer, E., B.L. Gibson, A. Oxman. 1993. *Health Effects of Aluminum: A Critical Review with Emphasis on Aluminum in Drinking Water.* Institute of Environment and Health and Public Health Branch of Ontario Ministry of Health, Toronto, Ontario. pp. 110.

O'Neill, R.V., D.L. DeAngeles, J.B. Waide and T.F.H. Allen. 1986. *A Hierarchial Concept of Ecosystems.* Princeton UP, Princeton, New Jersey. 287 pp.

Olsen, Geary W., Charles E. Ross, Kenneth M. Bodner, Larry I. Lipshultz, Jonathan M. Ramlow. 1995. Have sperm counts been reduced 50 percent in 50 years? A statistical model revisited. Fertility and Sterility, American Society for Reproductive Medicine, Vol. 68, No. 4, pp. 887.

Olson, M. 1965. *The Logic of Collective Action.* Harvard UP, Cambridge, Massachusetts. 176 pp.

Ontario Task Force on the Primary Prevention of Cancer. 1995. *Recommendations for the Primary Prevention of Cancer.* Ontario Ministry of Health, Toronto, Ontario. 64 pp.

Parsons, T. 1972. Definitions of Health and Illness in the Light of American Values and Social Structure. In: *Patients, Physicians and Illness.* E. Jaco and E. Gartley (eds.) Collier-Macmillan, London, England.

Public Health Coalition. 1992. *Report Respecting the Health Effects of Ontario Hydro's Demand/Supply Plan.* Environmental Assessment Board, Toronto, Ontario.

Rapport, D.J. 1992. Evaluating Ecosystem Health. Journal of Aquatic Ecosystem Health. 1:15-24.

Rapport, D.J. 1989. What Constitutes Ecosystem Health? Perspectives in Biology and Medicine. 33:120-32.

Regier, H. unpublished. Managing Uncertainty on the Way to Ecosystem Integrity, International Joint Commission Tripartite Meeting, Windsor, Ontario, October 22, 1993. 5 pp.

Regier, H. 1993. The Notion of Natural and Cultural Integrity. In: *Ecological Integrity and the Management of Ecosystems,* S. Woodley et al. (eds.). St. Lucie Press, Delray Beach, Florida. pp. 3-18.

Richardson, G.M. and D.J. Currie. 1993. Estimating Fish Consumption Rates for Ontario AmerIndians. J Exp Anal Environ Epi. 3(1):23-38.

Rind, D., C. Rosensweig and R. Goldberg. 1992. Modelling the hydrological cycle in assessments of climate change. Nature, Vol. 358, 9 July 1992. pp. 119-122.

Ritter, L. 1994. Organochlorine Residues and Risk of Breast Cancer. Public Health and Epidemiology Report Ontario (PHERO). 5(8):176-183.

Ryan, C.B., F.H. Quinn, and M.J. Donahue, (eds.). 1994. *Great Lakes Climate Change Project: Research Priorities for Assessing the Impacts of Climate Change in the Great Lakes Basin.* National Oceanic and Atmospheric Administration, GLERL, Ann Arbor, Michigan. 159 pp.

Sadek, M. 1994 (unpublished). *An Inventory of Canadian Federal and Ontario Provincial Toxics Reduction Programs and Related Activities.* Consultant report prepared for the Workgroup on Parties Implementation, Science Advisory Board, International Joint Commission, Windsor, Ontario. 102 pp. plus appendices.

Sagoff, M. 1985. Fact and Value in Environmental Science. Environmental Ethics. 7:99-116.

Scheberle, D., M. Buttke and K. Boggiatto. 1994 (unpublished). *Survey of U.S. and Great Lakes States Toxics Reduction Programs, Laws and Database Inventory.* Consultant report prepared for the Workgroup on Parties Implementation, Science Advisory Board, International Joint Commission, Windsor, Ontario. 114 p. plus appendices.

Schrader-Frechette, K.S. and E.D. McCoy. 1993. *Method in Ecology.* Cambridge UP, New York. 328 pp.

Schwartz, J. 1991. Particulate Air Pollution and Daily Mortality in Detroit. Environ Res. 56:204-213.

Seedhouse, D. 1986. *Health.* John Wiley, Chichester, England. 104 pp.

Sherins, Richard J. 1995. Are semen quality and male fertility changing? New England Journal of Medicine. Volume 332, Number 5, pp. 327-328.

Stephens, Graeme, L. 1994. Dirty Clouds and Global Cooling. Nature, Vol. 370, August 11, 1994. p. 420.

Stern, P.C., T. Dietz and L. Kalof. 1993. Value Orientations, Gender and Environmental Concern. Environment and Behaviour. 25:322-48.

Steward, J. 1955. *Theory of Culture Change.* Univ. Illinois Press, Urbana, Illinois. 244 pp.

Steward, J. 1978. *Evolution and Ecology.* Univ. Illinois Press, Urbana, Illinois.

Stoneman, Don. 1995. Big herd operators question BST profit. Farm and Country Magazine. February 28, 1995. Vol. 59, No. 9, pp. 12.

Taylor, S.M., D. Streiner, J. Eyles and S.J. Elliott. 1993. *Psychosocial Effects in Populations Exposed to Contaminants in the Great Lakes Basin.* Report to Great Lakes Health Effects Program, Institute of Environment and Health, Hamilton, Ontario. 63 pp.

The Role of the Hydrological Cycle in Global Environmental Change. The Globe, Wiltshire, England. Issue 18, April 1994. 12 pp.

Todd, E.C. 1991. *Foodborne and Waterborne Disease in Canada.* Annual summaries, 1985 and 1986. Health and Welfare Canada, Ottawa, Ontario.

Tomatis, L. (ed.). 1990. *Cancer: Causes, Occurrence and Control.* IARC Scientific publications No. 100. International Agency for Research on Cancer, Lyon, France. 352 pp.

U.N. Conference on Environment and Development. 1992. Rio Declaration. United Nations, New York.

U.S. Environmental Protection Agency. 1994. *Estimating Exposure to Dioxin-Like Compounds, Vol. II: Properties, Sources, Occurrence and Background Exposures.* External review draft; Office of Health and Environmental Assessment. Office of Research and Development, U.S. Government Printing Office, Washington, DC, June 1994. EPA 600/6-88/005Cb

U.S. National Academy of Science. 1983; update 1993 (risk assessment paradigm; section 2.3.2.2)

U.S. Environmental Protection Agency. 1994. *Health Assessment Document for 2,3,7,8-Tetrachlorodiveno-p-Dioxin (TCDD) and Related Compounds, Vol. III.* External review draft; Office of Health and Environmental Assessment. Office of Research and Development, U.S. Government Printing Office, Washington, DC. EPA 600/BP92-001C. 121 pp.

U.S. Environmental Protection Agency. 1994. *Estimating Exposure to Dioxin-Like Compounds, Vol. I: Executive Summary.* External review draft; Office of Health and Environmental Assessment. Office of Research and Development, U.S. Government Printing Office, Washington, DC. EPA 600/6-88/005Ca. 128 pp.

United Nations/World Commission on Environment and Development. 1977. *Our Common Future.* Oxford University Press, Oxford, England. 383 pp.

Vayda, A.P. and R. Rappaport. 1976. Ecology-Cultural and Noncultural. In: *Human ecology,* P. Richardson and J. McEvay (eds.) Duxbury Press, North Scituate, England.

Walters, S.D. 1983. Effects of Interaction, Confounding and Observational Error on Attributable Risk Fraction. Am. J. Epid. 117(5):598-604.

Williamson, P. 1992. *Global Change, Producing Uncertainties.* IGBP, Royal Swedish Academy of Sciences, Stockholm, Sweden.

WMO/UNEP. 1992. Climate Change 1992. *The Supplementary Report to the IPCC Scientific Assessment.* J.T. Houghton, B.A. Callander and S.K. Varney (Eds.), Cambridge University Press.

WMO/UNEP. 1990. *Climate Change.* The IPCC Scientific Assessment. J.T. Houghton, G.J. Jenkins and J.J. Ephraums (eds.) Cambridge University Press. 365 pp.

Wolff, M.S., P.G. Toniolo, E.W. Lee, M. Rivera, N. Dubin. 1993. Blood Levels of Organochlorine Residues and Risk of Breast Cancer. J Natl Cancer Inst. 85:648-652.

World Health Organization (WHO). 1948. Text of the Constitution of the World Health Organization. Off. Rec. World Health Organ. 2:100.4.

World Health Organization (WHO)/ United Nations Environment Program (UNEP). 1991. *Earthwatch, Global Environmental Monitoring System: WHO/UNEP Report on Water Quality.* Progress in the implementation of the Mar del Plata Action Plan and a Strategy for the 1990s.

Worthington, E.B. 1983. *The Ecological Century.* Clarendon Press, Oxford, England. 206 pp.

Zimmerman, K.S. 1994. Human Geography at the New Ecology. Annals, Association of American Geographers. 84:108-25.

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2.11 The Joint Institutions and Other Advisory Entities Reporting to the International Joint Commission With General and Specific Mandates Related to the Great Lakes Water Quality Agreement: 1993-1995 Priorities

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