Environmental Health Surveillance: Indicators for Freshwater Ecosystems

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ABSTRACT

The relationship between the health of human populations and the state of the ecosystems in which they live is profoundly complex. As most environmental indicators relevant to human health depend on evidence of a direct cause and effect relationship, there are few indicators of the less direct consequences of environmental degradation on human health. Indicators of the direct consequence of contaminants in freshwater ecosystems on human health are highlighted in this paper and candidate indicators for environmental health are provided. Many of the indicators included here are from the State Of the Lakes Ecosystem Conference (SOLEC) program. SOLEC conferences in the past (1994 and 1996) examined the state of various components of the ecosystem through the use of ad hoc indicators, and provided subjective assessments of certain environmental conditions. At SOLEC 98, a comprehensive suite of 80 Great Lakes ecosystem health indicators was presented for review, refinement and acceptance. Candidate indicators for freshwater systems and environmental health presented here are organized following the "Pressure-State-Response" framework and cover the areas of drinking water, recreational water, freshwater food sources, and the availability of freshwater for economic activities.

RÉSUMÉ

La relation entre la santé des populations humaines et l'état des écosystèmes où elles vivent est très complexe. Même si la plupart des indicateurs environnementaux liés à la santé humaine dépendent de la démonstration d'une relation directe de cause à effet, il existe néanmoins quelques indicateurs des conséquences moins directes de la dégradation de l'environnement sur la santé humaine. Les auteurs traitent des indicateurs des effets directs des contaminants dans les écosystèmes d'eau douce sur la santé humaine et proposent des indicateurs d'intérêt potentiel pour l'hygiène de l'environnement. Nombre de ces indicateurs sont tirés du programme de la Conférence sur l'état des écosystèmes lacustres (CEEL). Les conférences CEEL de 1994 et 1996 ont porté sur l'état de diverses composantes des écosystèmes à partir d'indicateurs ad hoc et ont fourni des évaluations subjectives de certaines conditions environnementales. Lors de la CEEL 1998, on a présenté une série exhaustive de 80 indicateurs de l'état de l'écosystème des Grands Lacs en vue de les examiner, les raffiner et les approuver. Les indicateurs potentiels pour les écosystèmes d'eau douce et l'hygiène de l'environnement présentés dans cet article sont organisés d'après le cadre Pression-État-Réaction et couvrent les secteurs de l'eau potable, des eaux utilisées à des fins récréatives, des sources de nourriture en eau douce et de la disponibilité de l'eau douce pour des activités économiques.

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Contaminants in the Great Lakes can cause disease in humans because we drink or wash in contaminated tap water, because we ingest contaminated food, or because we swim in contaminated water. In suggesting indicators for environmental health, this paper considers each of these routes of exposure. As most health outcomes have multiple potential sets of causal factors, outcome indicators are of limited value and do not permit any direct inferences with respect to effects from environmental exposures. Nonetheless, those outcomes that are routinely recorded by state, provincial and federal agencies are relatively easy to track and unusual spatial and temporal distributions of disease may suggest emerging problems. Trends in disease rates may provide evidence relevant to interpretation of trends in contamination and thus some are included here. We also consider the less direct relationships between health and the environment such as those related to economics and food supplies in the Great Lakes basin. Finally, we delineate structural indicators that reflect the status of programs to protect human health from these risks.

DRINKING WATER

Overview

Few areas of environmental health have received as much attention for as long a time as the health risks related to drinking water. Contaminants may enter water supplies at many points before reaching the tap. The types and quantities of contaminants in drinking water at the point of consumption differ depending upon whether they result from contamination of the source water, arise as a consequence of treatment processes, or enter as the water is conveyed to the user.

Source water contaminants and associated health risks

Precipitation falling on the Great Lakes Basin literally washes over the air and the watersheds of the Lakes delivering a solvent load that contains, at some concentration, every chemical produced in the basin together with the pathogens that infect its human and animal inhabitants. Contaminants of concern are those that are either sufficiently potent to pose risks at extremely low concentrations or capable of causing local contamination at high concentrations. These contaminants may enter the water from naturally occurring sources of toxic elements, industrial discharges, agricultural runoff or domestic municipal waste discharges.

Naturally Occurring Chemicals and Pathogens

Naturally occurring chemicals, such as arsenic[1-3] and radon,[4,5] are established carcinogens that can pose significant health risks. These are primarily a concern for groundwater supplies and do not appear to pose a documented problem in the water of the Great Lakes. Furthermore, naturally occurring chemicals do not provide a useful indicator with respect to the State of the Lakes since their presence is usually independent of anthropogenic activities. Pathogens and algal toxins may enter source water from sources that are not a direct consequence of human activity (e.g., giardia). There is no clear evidence of health effects from exposure related to these contaminants in the Great Lakes, but they pose a plausible risk that should be considered in the development of indicators.

Agricultural Runoff

Farm runoff containing agricultural chemicals and manure may lead to local or regional contamination of source waters with pesticides, fertilizers and pathogens. Agricultural activities may also result in nutrient loading and suspended silt loads in the Lakes that can have secondary effects related to human health.

Most pesticides have documented effects on human health, but there is little evidence to determine whether long-term exposure to the low levels found in drinking water has significant health consequences. Water utilities regularly test for heavily used chemicals and highly toxic chemicals as specified by the EPA and Health Canada. It is possible that an index could be developed based on these data.

Nitrates in drinking water have the well-documented capacity to cause methemoglobinemia ("blue baby syndrome"). There is also limited evidence indicating that nitrates may have other effects.[6-8] Given that the presence of nitrates in surface water in rural areas is likely to be strongly correlated with the presence of animal wastes, the nitrate link should be interpreted cautiously.[9] Their levels are routinely monitored in drinking water and could provide not only a measure of potential risk associated directly with nitrates, but also an indicator of agricultural runoff.

Agricultural runoff can also contain a number of significant pathogens. Of particular concern are *Cryptosporidium* and E. coli:157. *Cryptosporidium* oocysts are resistant to chlorine disinfection and have caused many waterborne outbreaks. Routine monitoring for *Cryptosporidium* is limited and relies on insensitive methods, but more regular monitoring with more sensitive methods is likely to be required in the near future. Also, routine monitoring data for fecal coliform should identify possible contamination with this organism.

Industrial Discharges

Industrial waste includes a vast number of chemicals about which it is difficult to draw general conclusions about the risks they pose. Elevated cancer risks are difficult to detect because of the relatively low incidence of site-specific neoplasms and the small size of exposed populations in most situations.[10] However, some studies have found evidence of positive associations between some compounds in drinking water and some forms of cancer.[11-13] The wide variety of chemicals present in hazardous waste sites, the difficulties in assessing exposure, the obstacles to establishing links between exposure and cancer even when links are present, the small size of exposed populations and the uncertainties concerning future risks make it difficult to define an ideal indicator of risk associated with this group of chemicals. Currently, water utilities in Canada and the U.S. monitor a subset of these chemicals that could provide the basis for any such indicator.

Contaminants from Sewage

Municipal sewage, in treated effluents or in untreated combined sewer overflows, poses an obvious risk related to human pathogens, especially during periods of low flow when treated waste can constitute a substantial portion of the water entering the Lakes. This waste can include any pathogen present in the population including bacteria, viruses, or protozoa. Routine monitoring for pathogens is often limited to 3 indicators. Total coliform is used primarily to indicate the effectiveness of the disinfection at the treatment plant. Fecal coliform provides an indicator of contamination with fecal matter in the source or treated water and turbidity provides an indicator of filter effectiveness and is a surrogate for the presence of viruses and protozoa in the effluent.

Municipal sewage can also contain chemical contaminants as industrial wastewater is often combined with domestic waste entering the sewage system. It has recently been recognized that pharmaceutical products can contaminate domestic and hospital waste and may pose threats to ecological and human health. However, there is little hard data documenting this effect and immediate monitoring is not required, but the existence of data may provide a useful indicator with relevance to public health in the future.

Contaminants introduced during water treatment

Modern drinking water treatment relies on a variety of chemicals. There is little evidence that any of these chemicals pose a significant health risk with the singular exception of chlorine. The introduction of chlorination for the treatment of drinking water in the early 1900s dramatically reduced mortality from waterborne pathogens. Ironically, it may now account for a substantial portion of the residual health risks associated with drinking water. Since it was first recognized that chlorinated drinking water contained chlorinated organic compounds, particularly chloroform, a known carcinogen,[14,15] more than 30 epidemiological studies have examined the association between cancer and chlorination by-products. These studies provide evidence of an association between chlorination by-products and bladder cancer and suggest a risk of colorectal cancer,[16-18] among others. There is also emerging evidence to suggest that chlorination by-products may be associated with adverse reproductive and developmental outcomes such as low birthweight, congenital anomalies, and spontaneous abortion. In sum, the available studies generally support the notion that chlorination by-products pose risks to human health. The precise characterization of these risks is somewhat less clear. The broad category of chlorination by-products includes many different compounds and the specific compounds associated with the apparent health risks have not been clearly identified.

Utilities routinely monitor for total trihalomethanes as an indicator of chlorination by-products and they will soon be required to monitor for the trichloracetic acids as well. Also, the amount of chlorine added is a useful indicator of both the quality of the treated water and the potential for formation of by-products.

Indirect effects of drinking water contamination

Reductions in drinking water quality may have consequences beyond the direct health effects of the contaminants. Many industries require extremely high quality water, particularly in the high technology sector. Contamination of the water supply may require introduction of filtration equipment, may cause operational problems for filters already in use, and, in extreme cases, may cause some industries to relocate or decide not to locate in such ecosystems as the Great Lakes Basin. The associated economic effects could have ramifications for public health in the affected areas. Contamination of the water supply may also erode public confidence in the water supply and lead to the increased use of bottled water and water filters. Both alternatives have implications for health and the environment including increased pollution from bottle manufacturing, increased pollution from transport of bottles, increased exposure to chemicals leaching from bottles, increased solid waste, and, for water from outside the region, the loss of money from the local economy. Possible indicators for drinking water and health are included in Appendix 1.

RECREATIONAL WATER

Bathing in recreational water poses a well-documented risk of disease, primarily due to microbial contamination. Chemical contamination can pose a risk at locations that are close to toxic chemical sources, but public swimming facilities are not generally placed in such locations. At present, most of the testing of bathing beaches is limited to tests for fecal coliform during the swimming season.

In 1986, the US EPA recommended that criteria for recreational use of freshwater be based on testing for E. coli or enterococci rather than fecal coliform. This was based on data indicating that fecal coliform was not a good surrogate for the combined health risk from pathogens in ambient water. Despite this recommendation, many jurisdictions continue to use fecal coliform for monitoring of recreational water.

The accessibility of freshwater swimming beaches may also have indirect effects on human health. Increased accessibility can have benefits related to the physical as well as psychological benefits of swimming in the Lakes. The number and accessibility of beaches can also have effects relating to the desirability of these beaches for summer recreation. The population density of the Great Lakes Region and the limitations on availability of beaches near population centres can create a variety of pressures with implications for health including development of vacation homes and resorts, increased traffic with its associated air pollution and automobile injuries, and the increase in boat activity in the vicinity of beaches. Possible indicators for recreational water are presented in Appendix 1.

FRESHWATER FOOD SOURCES

Contaminant risks

Considerable work has been carried out in the Great Lakes and St. Lawrence River basins to document human exposure to chemical contaminants and estimate its impact on human health. Several indicators related to such exposure are included in the SOLEC documentation.

Most directly related to the environment are measures of contaminants in various media. SOLEC indicator #118 describes concentrations in offshore waters of the IJC priority toxic chemicals. Most are persistent and bioaccumulative as well as toxic (PBT). Important at an ecosystem level, most of these PBTs are removed by water treatment facilities and the amount of water humans directly consume from freshwater systems is sufficiently small to place a lower priority on them as indicators of potential human health impact.

Second are measures of contaminants in freshwater food sources that bioaccumulate toxins and that humans consume. This includes a wide array of fish caught and eaten in the Great Lakes (i.e., pressure indicator # 4083 of SOLEC). Additionally, some measures of other species (e.g., SOLEC pressure indicator #115 on contaminants in colonial nesting birds) may be relevant given the consumption of bird eggs in some areas, e.g., North shore of the St. Lawrence. PCBs and mercury have been the most common consumption-limiting contaminants, followed by dioxins, toxaphene, and mirex/photomirex in different Great Lakes. Such levels have been used in exposure estimation for epidemiological studies of neurodevelopmental and reproductive impacts among humans which have contributed (along with animal research) some of the most important findings to our state of knowledge on these issues.

Third are estimates of total intakes of contaminants from all sources (including water and freshwater food sources) by people with different activity profiles. Included as part of SOLEC pressure indicator #4088, such estimates have a long history in risk assessment activities.

Fourth are the most direct indicators of human body burden or accumulated dose of persistent contaminants, to which freshwater food sources may contribute. SOLEC #4177 subsumes a number of such measures. DDE and PCB levels in breastmilk, dioxin levels in plasma/serum and mercury in hair/whole blood are among the most frequently cited measures. The latter two have the greatest human health relevance given the relatively less disputed nature of their human health impacts and the fact that human levels are of the same order of magnitude as subtle effects in other species. Ways of more easily monitoring such levels in human populations on an ongoing basis need to be developed.

Finally, geographic patterns and trends in disease incidence are also included in the suite of SOLEC human health indicators (#4179). However, such attribution depends on better estimates of population exposure and dose than are usually available on a geographical basis. At present, risk assessment-based estimates are likely a better guide to human health impacts attributable to chemical contaminant exposures from freshwater sources than geographically based disease burden measures. Appendix 1 presents possible indicators for contaminant risks posed by freshwater food sources.

Health benefits

Anglers, hunters and clients of commercial operations can eat fresh food procured from freshwater lakes, rivers and streams, subject to local regulations. The Canada Health Monitoring survey estimated that almost half of Ontario residents sampled had eaten sport fish from Ontario at least once per year, while 5% reported at least weekly consumption. Similar estimates were made (42% and 7% respectively) during shoreline surveys of fishers in five Ontario Areas of Concern (AOCs) during the summers of 1995-1997.[19] Consumption of aquatic waterfowl[19] and other freshwater species (e.g., turtles, frogs, muskrat) were also reported, though much less frequently.

Fishers reported the value of fresh fish based on its perceived superior quality, its contribution to their ability to provide for themselves, and the economic advantages of being able to procure food from the environment.[19] Each of these benefits are important within broader social notions of 'health', however are difficult to measure with direct questionnaire measures, making their conversion into indicators difficult.

Quantification of potential nutritional benefits through dietary record measures has been carried out among frequent consumers in the Montreal area and Ontario AOCs.[19] Both studies indicated that sport fish consumption was associated with lower percentages of energy intake as fat, higher protein and iron intakes and higher plasma concentrations of omega-3 essential fatty acids (FA). Each of these associations can be regarded as health benefits. Although the epidemiological debate around fish consumption and heart disease continues, increased omega-3 FA intakes are important for both reproductive-developmental benefits and cardiovascular risk reduction (Toxicology Excellence for Risk Assessment, personal communication with expert panel member, Judy Sheeshka). Yet such nutritional assessment work is relatively labour-intensive if more precise intake or biological measures are required for benefits assessment. Alternatively, work on nutrient composition could be carried out for common species/location mixes. However, omega-3 fatty acid composition data, for example, are available only on some Great Lakes species, and various environmental and food availability factors affect such composition. Indicators for the health benefits associated with freshwater food sources are presented in Appendix 1.

AVAILABILITY OF FRESHWATER FOR ECONOMIC ACTIVITIES

Water resources and their utilization for navigation, hydroelectric power generation, fisheries and agriculture have historically been important policy concerns. In extreme cases, environmental and economic disasters with subsequent health impacts have occurred elsewhere in the world because of massive withdrawals of water primarily for irrigation, e.g., the Aral Sea in Uzbekistan.[20,21] Although the water resource situation is not as dramatic in the Great Lakes Basin, concern about the continuing availability of water has stimulated estimates of use and consumption.[22] Such work considers draws by industry and agriculture, among the former being massive quantities that cycle through nuclear generating stations.

Given the historic importance of water resources, the current suite of SOLEC indicators cover a variety of concerns. Water level fluctuations (SOLEC #4861) are included in both coastal wetland and nearshore terrestrial sections. The role of nearshore waters and coastal wetlands as essential areas for maintenance of the diversity and production of fish, and hence both the recreational and commercial fisheries on the Great Lakes, are reflected in a number of indicators (e.g., SOLEC #8). Related are indicators that measure aspects of fish that would detract from economic human uses (e.g., deformities/eroded fins/lesions/tumors in coastal wetland fish - SOLEC #4503).

As the IJC[22,p.26] has stated, "Water quantity and water quality are inextricably linked...In many areas, poor water quality continues to impair the potential uses of the Great Lakes." The extent to which such poor freshwater quality impacts on economic prosperity (SOLEC #7403) may be hard to estimate, yet for sustainable livelihoods such impacts must be addressed.

Whether to include this group of indicators as estimates of health impacts, is an open question. On one hand, their inclusion would reflect the broad 'ecosystem and social system sustainability for health' perspective. Yet doing so would rapidly expand the nature of indicators well beyond the traditional areas of expertise of most environmental health personnel and potentially duplicate work being done by other groups. We have not included such indicators in our short list, based primarily on the latter consideration and the need for focus on those indicators in an environmental surveillance system where health professionals can most push an agenda forward. Indicators of economic activities related to freshwater are presented in Appendix 1.

REFERENCES

1. Chen CJ, Kuo TL, Wu MM. Arsenic and cancers (letter). *Lancet* 1988;(i):414-15.
2. Wu MM, Kuo TL, Hwang YH, Chen CJ. Dose-response relation between arsenic well water and mortality from cancer. *Am J Epidemiol* 1989;130:1123-32.
3. Smith AH, Hopenhayn-Rich C, Bates MN, Goeden HM, Hertz-Picciotto I, Duggan HM, et al. Cancer risks from arsenic in drinking water. *Environ Health Perspect* 1992;97:259-67.
4. Neuberger JS. Residential radon exposure and lung cancer: An overview of published studies. *Cancer Detection and Prevention* 1991;15:435-43.
5. Brown DJ, Cothern CR. A Bayesian analysis of scientific judgment of uncertainties in estimating risk due to 222 Rn in US public drinking water supplies. *Health Physics* 1987;53:11-21.
6. Tao XG, Zhu HG, Yu SZ, Zhao QY, Wang JR, Wu GD, et al. Effects of drinking water from the lower reaches of the Huangpu River on the risk of male stomach and liver cancer death. *Public Health Reviews* 1991-1992;19:229-36.
7. Xu G, Song P, Reed PI. The relationship between gastric mucosal changes and nitrate intake via drinking water in a high-risk population for gastric cancer in Moping county, China. *Eur J Cancer Prev* 1992;1(6):437-43.
8. Tao XG, Zhu HG, Yu SZ, Zhao QY, Wang JR, Wu GD, et al. Pilot study on the relationship between male stomach and liver cancer death and the mutagenicity of drinking water in the Huangpu River area. *Public Health Reviews* 1991-1992;19:219-27.
9. Leclerc H, Vincent P, Vandevenne P. Nitrates de l'eau de boisson et cancer. *Annales de gastro-entérologie et d'hépatologie* 1991;27:326-32.
10. National Research Council. Environmental Epidemiology: Volume 1: Public Health and Hazardous Wastes. Washington, DC: National Academy Press, 1991.
11. Fagliano JM, Berry M, Bove F, Burke T. Drinking water contamination and the incidence of leukemia: An ecologic study. *Am J Public Health* 1990;80:1209-12.
12. Griffith J, Duncan RC, Riggan WB, Pellom AC. Cancer mortality in US counties with hazardous waste sites and ground water pollution. *Arch Environ Health* 1989;44:69-74.
13. Lagakos SW, Wessen BJ, Zelen M. An analysis of contaminated well water and health effects in Woburn, Massachusetts. *JASA* 1986;81:583-96.
14. Rook JJ. Formation of haloforms during chlorination of natural waters. *J Soc Water Treatment and Examination* 1974;23:234-43.

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Appendix 1

Proposed Indicators

INDICATORS FOR DRINKING WATER

Possible Indicators

SOLEC indicator #4175

* (for all SOLEC indicators see http://www.on.ec.gc.ca/solec/indicators2000-e.html)

Indicators of Exposure

Microbial

- Treated water fecal coliform
- Raw water fecal coliform levels
- Treated water turbidity

Gaps – Specific pathogens are not routinely measured. Include measures of *Cryptosporidium* and viruses as they become more available.

Chemical

- Treated water THMs
- Treated water HAAs
- Amount of chlorine used
- Recorded violations of federal drinking water regulations for other chemicals

All measurements should include max. and average levels / location. Treated water indicators should include the number of non-zero days or days in violation of existing standards. Combined indicators can be generated by calculating a weighted average with weighting based on the population served.

Gaps – Data on specific byproducts, particularly brominated by-products. Measurements of specific regulated chemicals vary in frequency and exact measurements are not routinely available unless a violation occurs.

Outcomes

- Incidence of cancer for common sites
- Rates of birth defects
- Counts of physician visits for gastroenteritis
- Population antibody levels to specific pathogens such as *Cryptosporidium*

Indirect Effects

- Total bottled water consumption in the region
- Proportion of bottled water from outside the region
- Number of bottles produced
- Sales of household water filters

Gaps – It is not clear that sales data for bottled water or water filters are routinely available.

Pressure

- Total volume of sewage discharged into the basin by treatment category
- Total volume of combined sewer overflows
- Use of agricultural chemicals in the basin by type
- Livestock density in the basin
- Total water use throughout the basin / Total flow from streams in the basin
- Aquifer use/Recharge rate
- Public vs. Private ownership of riverbanks and other key watershed land

Gaps – Combined sewer overflows are difficult to quantify and such data may not be routinely available.

INDICATORS FOR RECREATIONAL WATER

Possible Indicators

SOLEC indicator # 4081

Exposure

Until measures of coliform become more standardized, an indicator should integrate the three measures and should take into account the frequency of testing and the population served by the beach. Measurements for other pathogens should also be integrated into this indicator.

- Fecal Coliform levels
- E. Coli levels
- Enterococci levels
- Other pathogen data should be tracked (e.g., *Cryptosporidium,* Giardia, caliciviruses and rotavirus)
- Beach closings

Gaps – E. Coli and Enterococci are not routinely measured.

Outcomes

- Administrative records of medical care for gastroenteritis (as discussed for drinking water)
- Reports of swimming-related outbreaks

Gaps – Better data on the relationship between contamination of freshwater and infectious disease in swimmers needed.

Indirect Effects

- Miles of swimmable beach
- Population-weighted average of miles to nearest beach for major cities in the basin

Pressure

Indicators of pressure for drinking water as described above would also serve as indicators for recreational water.

INDICATORS FOR FRESHWATER FOOD SOURCES

RISKS

Possible Indicators: Available (A) & Gaps (G)

Pressure

- Multiple SOLEC indicators, e.g., waste water pollutant loading #7059 (mostly A)
- Estimated contaminant loadings to water (A for each Great Lake, e.g., SOLEC #117)
- Contaminant levels in water (SOLEC #118) and sediments (A for most PBT substances, e.g., mercury, DDE)

Exposure

- Population frequency and amount of freshwater sport fish and other wild food consumption, with species/location/size data (Sparse/partial A for fish, G for other wild foods, e.g., duck, muskrat)
- Contaminant levels in most frequently consumed species/locations of fish and wildfowl (Partial A; G – need for concentration on species-locations of most relevance based on human consumption data and standardization of methods, uneven coverage for other wild foods)
- Estimated contaminant intakes for different population groups (Partial A, often at broad federal or specific local risk assessment level)
- Contaminant levels in fat, serum/ plasma/blood, breastmilk, hair or other tissues (Partial A, G – not as location specific or as regular as desirable in most jurisdictions)

Outcome

- Risk assessment-based calculations of impact (Partial A. G – provincial/state or local health agency capacity to do such estimates on more local basis)

Response

- Clean-up programs to reduce contaminant loads in freshwater food sources (A though currently not adequate – G)
- Involvement of fishers in restoring and maintaining freshwater food resources (G)
- Presence of advisory programs with regard to relative levels of contamination in sport fish (A. Risk dialogue with fishers to improve fish consumption choices, e.g., Fish and Wildlife Nutrition Project, 2000,[19] chapter G) currently inadequate – G)

HEALTH BENEFITS

Possible Indicators: Available (A) & Gaps (G)

Pressure

- Multiple SOLEC indicators of pressures on fish or wild food populations (A, e.g., SOLEC #72)

Availability/Exposure

- Multiple SOLEC indicators on viability of sport fish and waterfowl populations (A, e.g., # SOLEC 8)
- Population frequency and amount of freshwater sport fish and other wild food consumption (Partial A for fish, G - not for other wild foods)
- Nutrient composition of wild foods with regard to human needs. (Partial A. G – re a number of species/locations of considerable human consumption)

Outcome

- 'Benefit' modeling incorporating data on consumption and nutrient composition to estimate positive impacts

Response

- Several responses (both currently A and G) identified for each indicator above
- Involvement of fishers in restoring and maintaining freshwater food resources (G)
- Dialogue with fishers to improve fish consumption choices (e.g., Fish and Wildlife Nutrition Project, 2000,[19] chapter G) currently inadequate – G)

INDICATORS FOR AVAILABILITY OF FRESHWATER FOR ECONOMIC ACTIVITIES

Possible Indicators: Available (A) & Gaps (G)

Pressure

- Multiple SOLEC indicators, e.g., waste water pollutant loading #7059

State

- Multiple SOLEC indicators, e.g., economic prosperity indicator #7403 could be disaggregated for sectors of interest such as the recreational fishery

Response

- Multiple SOLEC indicators, e.g., integration of sustainability principles across landscapes' #35

15. Symons JM. National Organics Reconnaissance Survey for Halogenated Organics. *J Amer Water Assoc* November 1975.
16. Morris RD, Audet AM, Angelillo IF, Chalmers TC, Mosteller F. Chlorination, chlorination by-products, and cancer: A meta-analysis. *Am J Public Health* 1992;82:955-63.
17. McGeehin MA, Reif JS, Becher JC, Mangione EJ. Case-control study of bladder cancer and water disinfection methods in Colorado. *Am J Epidemiol* 1993;138:492-501.
18. Koivusalo M, Jaakkola JJ, Varitiainen T, Jakulinen T, Karjalainen S, Pukkala E, Tuomisto J. Drinking water mutagenicity and gastrointestinal and urinary tract cancers: An ecological study in Finland. *Am J Public Health* 1994;84:1223-28.
19. Dawson J, Eyles J, Keating L, Khan H, Kraft D, Murkin E, et al. Final Report of the Great Lakes Fish Eaters Project: Dietary Survey & Assessment of Potential Risks and Benefits. Volumes 1 & 2. Sheeshka J, Cole D (Eds.). Submitted to Health Canada.
20. Tsukatani T. The Aral Sea and socio-economic development. In: Kobori I, Glantz MH (Eds.), *Central Eurasian Water Crisis: Caspian, Aral and Dead Seas.* Tokyo: United Nations University Press, 1998;53-74.
21. Upshur REG. Report of environmental health consultation regarding the health impacts of the Aral Sea disaster. Hamilton, ON: Environmental Health Program, McMaster University, 1998.
22. International Joint Commission. Protection of the Water of the Great Lakes. Interim report to the governments of Canada and the United States. Washington & Ottawa: IJC, 1999. Available on-line at www.ijc.org.