RECOMMENDED HUMAN HEALTH INDICATORS FOR ASSESSMENT OF PROGRESS ON THE GREAT LAKES WATER QUALITY AGREEMENT

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List of Acronyms

AGI	Acute gastro-intestinal illness
CFU	Colony-forming units
EDC	Endocrine disrupting compounds
EEQ	Estradiol equivalents
GLWQA	Great Lakes Water Quality Agreement
HPAB	Health Professionals Advisory Board
IJC	International Joint Commission
MPN	Most probable number
OMOE	Ontario Ministry of the Environment
SOLEC	State of the Lakes Ecosystem Conference
US EPA	United States Environmental Protection Agency

Executive Summary

The Great Lakes Water Quality Agreement of 2012 directs the governments of the United States and Canada to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes. The Agreement also specifies that the governments and International Joint Commission shall report to the public on the extent to which the Agreement's objectives have been achieved. In order to report on progress, measures or indicators are needed. In response to a request by the IJC, the Health Professionals Advisory Board (HPAB) has engaged in a process to identify a small set of indicators that clearly link to the human health objectives of the GLWQA. While other reports will cover environmental indicators, the focus of this report is identifying and defining potential human health indicators that may reflect progress towards protecting and restoring the waters of the Great Lakes. It also presents the reasoning behind selecting and defining the indicators that could potentially be used by the Commission and the Parties to report on progress towards achieving the human health objectives of the Agreement.

In order to identify these human health indicators reflective of the Great Lakes environment, the HPAB convened an expert workshop. A select group of 48 Canadian and United States experts from non-profit organizations, tribes, Metis, academia and national and local governments who were known to have expertise in human health and the Great Lakes were identified and invited as workshop participants. The workshop was convened at the US EPA Region V Chicago headquarters on January 31, 2013 and ended February 1, 2013. A pre-meeting assignment was sent to participants to stimulate their thinking and direct their focus on the task of identifying and selecting indicators. The workshop started with a description of the charge and several overview presentations. The results of the pre-workshop survey were revealed at the start of the workshop and breakout groups were organized and assigned to work on one of four topics: drinking water, recreational water use, fish consumption, and human health outcomes.

The results of the workshop were presented to the Commission in April 2013, and the human health outcomes indicators were set aside for later work. The Board members and IJC staff then consolidated the remaining 18 potential hazard indicators and drafted definitions for five. The five indicators were chosen based on the results of the workshop where each breakout group identified its priority or top indicators. Document drafts were circulated to outside experts, workshop participants, and national, provincial and state agencies. Comments were reviewed and documents were modified where appropriate. The five indicators relate to three of the General Objectives of the Great Lakes Water Quality Agreement (GLWQA): (i) be a source of safe, high-quality drinking water; (ii) allow for swimming and other recreational use, unrestricted by environmental quality concerns; and (iii) allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants. These objectives are referred to in an abbreviated manner in this document as “Drinking Water”, “Recreational Water” and “Fish Consumption” respectively. One or two indicators were selected for each objective.

The five recommended indicators by objective are:

Drinking Water	Chemical Integrity of Source Water
	Biological Hazards of Source Water
Recreational Water	Illness Risk at Great Lakes Beaches
	Identified Risks at Great Lakes Beaches
Fish Consumption	Contaminant Levels in Great Lakes Edible Fish Species

This report proposes definitions for each indicator, a statement of the purpose and importance of the indicator, a discussion of the indicator’s relevance to the GLWQA, proposed measures, and their utility and limitations. Table 2 in the Results section summarizes the delineated aspects of each indicator.

Two Drinking Water indicators were identified to respectively address the links between both chemical and biological integrity of the Great Lakes and human health. Though treated drinking water is typically measured for regulatory purposes, these indicators focus on source water to be consistent with the stated objective of the GLWQA, which is to provide a source of safe drinking water. Furthermore, with cleaner source water, treatment is more dependable and less costly. Measures identified for the Chemical Integrity of Source Water indicator include: atrazine (a widely used herbicide and marker for agricultural pesticide exposure), estrogenic compounds, and cyanotoxins as key indicators for assessing the integrity of the water regarding chemical content. This report concludes that source water concentration of atrazine could be routinely followed and compared to reference levels. This takes advantage of the fact that two assigned acceptable concentration values exist; a Maximum Contaminant Level by the US EPA for drinking water, and an Interim Maximum Acceptable Concentration by the Ontario Drinking Water Quality Standards regulation. These data are already being collected at least on a limited basis. Cumulative estrogenicity of Great Lakes water can be expressed in estradiol equivalents and followed thusly. While a Maximum Acceptable Concentration for drinking water exists for microcystin-LR in Ontario, cyanotoxicity of water is not presently an established measure and no environmental reference levels are set in regulation in the United States. However, levels of certain cyanotoxins are ascertainable and the US EPA has recently listed several cyanotoxins on its Third Candidate Contaminant List, and the state of Minnesota has developed guidance on microcystin-LR. This report goes on to recommend a schedule of testing frequency for atrazine, estrogenic compounds and cyanotoxins.

This report recommends that the biological integrity of the Great Lakes Water be assessed using an indicator composed of three measures of biological hazards: key pathogens, nitrates, and turbidity. The candidate pathogens are *E. coli*, *Cryptosporidium parvum* and *Giardia lamblia*. These three common microbes are responsible for a myriad of human illness outbreaks. Additionally, *E. coli* serves as a surrogate for the presence of other harmful bacteria originating from animal or human fecal contamination. Nitrates, resulting from agricultural and waste water contamination, are a key nutrient contributing to the eutrophication of fresh water bodies; its human toxicity is understood and its presence is regulated by both the US EPA and the Ontario Ministry of the environment. Turbidity can be a useful measure that is associated with risk of human gastrointestinal illness. It is inexpensive to monitor and has been reported historically. This report makes further recommendations for monitoring approaches and emphasizes the importance of adopting a “source to tap” program for future monitoring.

There are two indicators recommended for Recreational Water Contact. The first is Risk of Illness from Great Lakes Beaches, which recommends the use of *E. coli* levels in Great Lakes water as an indicator relevant to the objectives of the GLWQA. This measurement is well understood, has abundant historical reference information and is clearly linked to human health. The second indicator, Identified Risks at Great Lakes Beaches, is intended to assess the main pollution sources identified at beaches that employ a Beach Sanitary Survey or Environmental Health and Safety Survey. This indicator will provide an assessment of the sources of contamination for Great Lakes beaches and show how many beaches are adhering to best practices by using a beach survey tool.

The indicator explored in the category of Fish Consumption focuses on the challenges of monitoring fish contaminants as a human health exposure indicator for Great Lakes water quality. Consumable fish contamination is clearly important in terms of the human health impact with both direct and indirect effects of the consumption or lack of consumption of Great Lakes fish on human health. Fish contamination also directly links to objectives of the GLWQA and has the advantage of extensive extant historical data. However, the jurisdictional variability in monitoring practices makes using contaminant information for human health impacts a challenging task. This report points out the various problems with using information on fish contamination as it is presently collected for use as State of the Lakes Ecosystem Conference (SOLEC) indicators. For instance, the location of sampling sites and use of whole fish, rather than the consumable portion of the fish, are both problematic when extrapolating to human health. The indicator that would be established should be based on concentrations of chemicals in the edible portions of five Great Lakes fish, specifically: Lake Trout (*Salvelinus namayacush*), Walleye (*Sander vitreus*), Yellow Perch (*Perca flavescens*), Whitefish (*Coregonus clupeaformus*), and Smallmouth Bass (*Micropterus dolomieu*).

These five indicators, when combined with those proposed by the Science Advisory Board, should form the basis of the IJC Commissioners report to the Parties on progress made to meeting the objectives of the amended Great Lakes Water Quality Agreement.

Chapter 1: Looking at the Recommended Health Indicators as a Group – The Common Context, Methods and Issues

Introduction

The waters of the Great Lakes are a source of drinking water, recreation, and provide fish for human consumption to millions of people in the United States and Canada. However, human activities and natural phenomena can adversely affect human health through their impacts on the waters of the Great Lakes. This report is intended to help these governments improve their capacity to succinctly assess progress, or a lack of thereof, towards achieving the objectives of the Great Lakes Water Quality Agreement (GLWQA) (Great Lakes Water Quality Agreement, 2012).

The GLWQA of 2012 directs the governments of the United States and Canada to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes. In addition, the Agreement specifies that the governments shall report to the public on the extent to which the Agreement's objectives have been achieved.

A focused group of measures or indicators would provide a means to monitor changes in the Great Lakes ecosystem over time and form the foundation of an assessment of progress (IJC, 2013a). Consequently, the International Joint Commission (IJC) is undertaking an effort to develop a small set of indicators that clearly link to the objectives of the GLWQA and can be used by the governments and the IJC to report on progress made towards achieving Agreement objectives. The IJC is required to provide independent reports on progress made by the governments once every three years. With the cycle that starts in 2013, IJC's first assessment of progress is due in 2016. To help achieve this goal, the IJC asked the Health Professionals Advisory Board (HPAB) to provide a small set of indicators that clearly link to the human health objectives of the GLWQA.

This report describes the identification and definition of proposed indicators that would be used by the governments and the IJC to assess and report on progress towards achieving the human health objectives of the Agreement. A separate effort by the IJC and its Great Lakes advisory boards has yielded recommendations for ecosystem indicators used to measure progress towards environmental objectives (IJC, SAB, 2013b). Using both human and ecosystem indicators can yield a better understanding of conditions and trends, improve the interpretation of data provided by the governments, and foster development of more informed strategies to reduce adverse impacts from Great Lakes waters.

Methods and Development of Indicators

From January 31-February 01, 2013, the Health Professionals Advisory Board (HPAB) convened a workshop on Human Health Indicators to identify and prioritize a small number of high level human health indicators used to characterize exposure risks resulting from recreational water activities, consuming fish, and drinking water sourced within the Great Lakes basin. Participants with expertise and interests in human health and environmental monitoring were invited from tribal communities, academic and non-governmental organizations, and national and state/provincial agencies (Table 1). A participant list is provided in Appendix 1.

Participants were asked to complete a pre-workshop assignment in which they identified likely candidates for indicators in the Great Lakes in four subject areas based on criteria included in the survey: Drinking Water, Recreational Water Contact, Fish Consumption, and Human Health Outcomes. The intention of the assignment was to identify the discussion topics for the workshop, invite community feedback in advance, and provide a framework for evaluation of potential indicators during facilitated discussion.

This workshop was convened at the Environmental Protection Agency (EPA) Region V Headquarters in Chicago, IL with the assistance of EPA staff that recorded, facilitated and participated in the workshop breakout groups. Participants were divided into breakout groups under the four subject areas and reported out each day of the workshop on the scope of their discussions.

The reports from these breakout groups identified eighteen potential human health hazard indicators and three human health outcome indicators (Appendix 2). Groups prioritized two indicators for each area of Drinking Water, Recreational Water Contact and Fish Consumption considered most useful for development as human health exposure indicators. The HPAB considered Human Health Outcomes indicators identified during the workshop for future development as part of a second phase of human health indicator activities. The results of the workshop were presented to the Commission during the April 2013 Biannual Meeting in Washington, D.C.

Indicator teams comprised of HPAB members and IJC staff were then tasked with further consolidating and drafting definitions for the human health hazard indicators, and ultimately five human health exposure indicators were identified. Workshop participants, outside experts and national, provincial and state agencies were invited to review drafts of these five indicator definitions, and their comments were carefully considered by the indicator teams and HPAB during the indicator development process. Multiple rounds of participant review were requested for the “Contaminant levels in Great Lakes Fish Species” indicator after comments from the first round resulted in significant changes to the scope of the indicator.

Table 1: Affiliation and expertise of workshop participants

Affiliation	Canada	First Nations/ Tribes/Metis	United States	IJC Commissioners and Staff	Total
Academia	5		11		16
Government	4	1	18		23
Hospital/Consultant	1		1		2
NGO			2		2
IJC Commissioners and Staff				5	5
Total	**10**	**1**	**32**	**5**	**48**

Area of Expertise	Canada	First Nations/ Tribes/Metis	United States	IJC Commissioners and Staff	Total
Beach and Recreational Water Exposure	2		9		11
Fish Consumption	2	1	6		9
Human Health Outcomes	2		7		9
Quality of Source Water Used for Drinking Water	4		10		14
IJC Commissioners and Staff				5	5
Total	**10**	**1**	**32**	**5**	**48**

Results

Recommendations

The HPAB recommends that the following five indicators be used to assess progress in the Great Lakes:

Drinking Water	Chemical Integrity of Source Water
	Biological Hazards of Source Water
Recreational Water	Illness Risk at Great Lakes Beaches
	Identified Risks at Great Lakes Beaches
Fish Consumption	Contaminant Levels in Great Lakes Edible Fish Species

The indicators are described briefly below in Table 2, with complete and detailed indicator descriptions provided in Chapter 2.

Indicator Alignment with The Great Lakes Water Quality Agreement

Linkages between the five indicators and the general and specific objectives of the 2012 were assessed. Table 3 lists the General Objectives and Annexes in the Agreement and aligns them with the human health indicator that relate to each particular objective. The selected indicators align well with the relevant sections of the Agreement.

Table 2: Brief Description of Recommended Human Health Indicators

GLWQA Objective	Indicator Name	Hazard Measured	Purpose
Drinking Water			
	Chemical Integrity of Source Water	Atrazine, estrogenicity and cyanotoxins in samples taken from intakes of drinking water treatment systems	Monitoring three representative classes of compounds provides a means to assess the chemical integrity of source waters over time for pesticides (atrazine), endocrine disrupting compounds (estrogenicity) and harmful algal blooms (cyantoxins).
	Biological Hazards of Source Water	*E. coli*, *Cryptosporidium parvum* and *Giardia lamblia*, nitrates and turbidity in samples taken from intakes of drinking water treatment systems	To assess the extent of biological hazards for the Great Lakes source water from the impacts of human and agricultural activities.
Recreational Water Contact			
	Illness Risk at Great Lakes Beaches	The 95th percentile of numbers of *E. coli* measured as most probable number (MPN)/colony-forming units (CFU) *E. coli* per 100 ml at Great Lakes beaches	To infer potential harm to human health at routinely monitored beaches through use of fecal indicator organisms.
	Identified Risks at Great Lakes Beaches	Main pollution sources identified at beaches that employ a Beach Sanitary Survey or Environmental Health and Safety Survey	To characterize pollution sources impacting Great Lakes beaches.
Fish Consumption			
	Contaminant Levels in Great Lakes Edible Fish Species	A common set of fish species*, chemicals and methods for assessment across the different areas in the Great Lakes	To describe temporal and spatial trends of bioavailable chemicals of concern in representative species of commonly consumed fish in Great Lakes.

**These fish species are Lake Trout (Salvelinus namayacush), Walleye (Sander vitreus), Yellow Perch (Perca flavescens), Whitefish (Coregonus clupeaformus), and Smallmouth Bass (Micropterus dolomieu)*

Table 3: Comparison of Agreement Objectives with Proposed Human Health Indicators

GENERAL OBJECTIVES The Parties adopt the following General Objectives. The Waters of the Great Lakes should:	**ALIGNMENT CHECK** **Related Indicator and (Annex)**
(i) be a source of safe, high-quality drinking water;	Biological Hazards & Chemical Integrity of Source Water (Chemicals of Mutual Concern; Nutrients)
(ii) allow for swimming and other recreational use, unrestricted by environmental quality concerns;	Risk of Illness from Great Lakes Beaches, & Sources of Risk at Great Lakes Beaches (Chemicals of Mutual Concern; Nutrients)
(iii) allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants;	Fish Consumption (Chemicals of Mutual Concern; Nutrients)
(iv) be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain;	Biological Hazards & Chemical Integrity of Source Water; & Fish Consumption (Chemicals of Mutual Concern; Nutrients)
v) support healthy and productive wetlands and other habitats to sustain resilient populations of native species;	See Environmental Indicator Report
(vi) be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health, or human use of the ecosystem;	Biological Hazards of Source Water (Nutrients)
(vii) be free from the introduction and spread of aquatic invasive species and free from the introduction and spread of terrestrial invasive species that adversely impact the quality of the Waters of the Great Lakes;	See Environmental Indicator Report (Invasive Species)
(viii) be free from the harmful impact of contaminated groundwater; and	(Groundwater)
(ix) be free from other <u>substances, materials or conditions</u> that may negatively impact the chemical, physical or biological integrity of the Waters of the Great Lakes;	See Environmental Indicator Report
ANNEXES	
1. Areas of Concern	Biological Hazards &Chemical Integrity of Source Water; Fish Consumption; Risk of Illness from Great Lakes Beaches, & Sources of Risk at Great Lakes Beaches
2. Lakewide Management	Biological Hazards &Chemical Integrity of Source Water; Fish Consumption; Risk of Illness from Great Lakes Beaches, & Sources of Risk at Great Lakes Beaches
3. Chemicals of Mutual Concern	Chemical Integrity of Source Water & Fish Consumption
4. Nutrients	Biological Hazards of Source Water.
5. Discharges from Vessels	See Environmental Indicator Report
6. Aquatic Invasive Species	See Environmental Indicator Report
7. Habitat and Species	See Environmental Indicator Report
8. Groundwater	See Environmental Indicator Report
9. Climate Change Impacts	See Environmental Indicator Report
10. Science	Biological Hazards &Chemical Integrity of Source Water; Fish Consumption; Risk of Illness from Great Lakes Beaches, & Sources of Risk at Great Lakes Beaches

Discussion

The HPAB acknowledges that reporting on human health indicators has been hindered by the absence of a set of core indicators that are consistently collected, recorded or monitored, over time. The identification of indicators that reflect the impact on human health provides a critical extension to reporting on the environmental status of the Lakes. Such a list of indicators facilitates assessment of human health, illness, well -being, and related progress toward achieving the objectives of the Agreement.

Any attempt to correlate human health outcomes with the integrity of the Great Lakes faces formidable challenges. Foremost, is the fact that the cause and effect relationship between the integrity of the Great Lakes and specific human health indicators is confounded by many variables which cannot be controlled for and are often poorly characterized. Humans, even those living in close proximity to or in frequent contact with the Great Lakes, live in complex and extremely varied environments and their health patterns are strongly affected by their own behaviors and influences unrelated to the Great Lakes. For example, gastrointestinal illness in the Great Lakes may arise from many sources, be it food consumption, drinking water, recreational water, or person-to-person contact. Any study of Great Lakes human health indicators must attempt to account for other causal factors that might affect the results. Considering these varied causes, only the strongest correlations will be evident for a health outcomes analysis in the Great Lakes. Hence, many of the indicators proposed focus on known health hazards, rather than health outcomes.

Other obstacles exist specifically for measuring human health effects of Great Lakes conditions. The governments have developed indicators through a program known as the State of the Lakes Ecosystem Conference (SOLEC). SOLEC uses existing resources from multiple government agencies and other organizations to assess the state of the Great Lakes ecosystem. However, although the SOLEC indicators do focus on hazards which may have a human health impact, they are generally not directly quantified in terms of human health risk and presently do not directly measure any human health outcomes. Also, currently available data sources are not systematically maintained are generally not centrally coordinated and, when recorded, may be documented in non-standardized forms. They also may be challenging to access due to privacy and security concerns.

Due to the challenges in determining direct human health effects of changes in Great Lakes waters, the HPAB decided to focus initially on hazards indicators that have the potential to result in human health effects. The health impact of any particular hazard depends on how much, over what period of time and by what route (via ingestion, skin contact or breathing) individuals come into contact with that hazard. For example, the health effects from recreational water at given beaches are non-existent for people who do not visit a Great Lakes beach, are at a certain level for someone who simply wades in the water up to their knees and higher for someone who swims while holding their head below the water. The HPAB aims to pursue additional work over the next three years to advance beyond indicators of hazards and develop a candidate list of human health conditions that more directly quantify the human health impacts of Great Lakes water change. Human health indicators may include measures of reproductive, sociological, neurologic or gastrointestinal impacts.

Chapter 1 Summary

The Health Professionals Advisory Board is recommending five indicators to assess Drinking Water, Recreational Water and Fish Consumption (see Table 2). They are described in detail in the next chapter. Introduction, discussion and references are provided as part of each detailed indicator description These indicators, when combined with those proposed by the Science Advisory Board, should form the basis of the IJC Commissioners report to the Parties on progress made to meeting the objectives of the 2012 Great Lakes Water Quality Agreement.

References

Great Lakes Water Quality Agreement, 2012. Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed on October 16, 1983 and on November 18, 1987. U. S.-Can., art 2.4.i, Feb. 12, 2013. http://www.ijc.org/en_/Great_Lakes_Quality

International Joint Commission, 2013a. Assessment of Progress Made Towards Restoring and Maintaining Great Lakes Water Since 1987. 16th Biennial Report on Great Lakes Water Quality. http://www.ijc.org/files/publications/16thBE_internet%2020130509.pdf

International Joint Commission, 2013b. Technical Report on Ecosystem Indicators: Assessment of Progress Towards Restoring the Great Lakes. A workgroup Report to the International Joint Commission. http://ijc.org/files/publications/Technical%20Report_Eco%20Indicators_2013.pdf

Chapter 2: Detailed Indicator Descriptions

HPAB members, with assistance from IJC staff, drafted indicator descriptions based on the break-out group discussions at the workshop and additional literature review and insight. The authors then sought review comment on each of the indicator drafts from workgroup members and other selected reviewers. The following sections of this report present detailed descriptions of the five recommended human health indicators that can be used to assess progress towards meeting GLWQA objectives. Each indicator includes a brief description, followed by a discussion of the relevance of the indictor to the objectives, and an overview of how it represents a causal or associated effect of the lakes' condition. This is followed by a description, which provides of the metric by which the indictor is measured. Each indicator description is written as an independent section to facilitate ease of use.

Chemical Integrity of Source Water – Atrazine, Estrogenicity, and Cyanotoxins

Contributors: Tim Takaro, International Joint Commission Health Professionals Advisory Board and Simon Fraser University; Jennifer Boehme, International Joint Commission.

Introduction

The Workshop on Human Health Indicators evaluated potential indicators for drinking water as part of its overall assessment of potential human health indicators for the Great Lakes. Experts participating in the Drinking Water Breakout Group concluded that existing work by SOLEC on drinking water quality (EC and US EPA, 2014) supported the conclusion that drinking water in the basin was very likely to be safe given present treatment measures for presently identified biological, chemical and physical contaminants. This consensus prompted the group to examine the recently signed GLWQA as an opportunity to adopt a precautionary approach (Great Lakes Water Quality Agreement, 2012) as part of its consideration of potential indicators. The resulting recommendations focus broader attention on the Great Lakes as source water when developing drinking water related human health indicators, rather than exclusively monitoring of treated drinking water. The working group also emphasized the likelihood that the challenges and complexity of managing drinking water safety infrastructure (potable and waste water) was likely to increase with changes in biological, chemical and climate-related factors due to changing water levels, variations in temperature, and frequency and intensity of storms. Increased flooding and runoff was observed in the Midwest from 1958 to 2007 (latest data), where the heaviest 1% of rain events increased by 31% (U.S. Global Change Research Program, 2009). More than forty million people rely on the Great Lakes as a drinking water source and for other services, and increases in extreme precipitation have the potential to overcome existing infrastructure, especially combined sewer systems. The subsequent effects of overflow threaten both human health and recreation in the region (Patz et. al., 2008).

In its 2009 report on the State of the Great Lakes (EC and US EPA, 2009), SOLEC noted “an increase in the quantity of contaminants found in raw source water in the Great Lakes basin.” Such pressures to the Great Lakes basin can arise from watershed proximity to industrial population-induced sprawl, agriculture or industrial activities, as well as point source contamination from wastewater treatment facilities or uncontained landfills. Chemical contaminants that have been newly detected and/or recognized as potential health hazards can also pose a risk during the lag between identification and development of water treatment methodologies.

A focus on source water allows a more direct connection to be drawn between the biological, chemical and physical integrity of the Great Lakes basin and risks to human health, and increases recognition that ecological and human health are tightly linked. The origin of contaminants treated by a particular drinking water treatment system can be more directly assessed, which is particularly important for water treatment plants that rely on several sources for water. The source water indicators would be most relevant for drinking water treatment systems with intakes of from lake and surface waters and groundwater under the direct influence of surface water, also known as GUDI. In the following subsections, definitions for recommended source water indicators are presented for the Chemical Integrity of Source Water, followed by the Biological Hazard Index for Source Water.

Definition

Chemical exposure via Great Lakes drinking water sources presents a risk to human health for those residing in the Great Lakes basin. While measuring a larger number of compounds has appeal, monitoring three representative and important classes of compounds provides a means to assess the chemical integrity of source waters sustainably over time for pesticides (with atrazine as a marker compound for agricultural pesticides), endocrine disrupting compounds (estrogenicity assay) and harmful algal blooms (cyanotoxin levels).

Purpose and Importance

The monitoring of representative compounds for pesticides, endocrine disrupting chemicals, and cyanotoxins to assess the chemical integrity of the Great Lakes will allow the governments and the IJC:

- To examine trends in seasonal and geographic variability of targeted chemical contaminants in waters used as sources for the regional drinking water supply.
- To assess the level of hazard and infer the impact of chemical contaminants in drinking water sources on the health of the human populations in the Great Lakes.
- To infer the effectiveness of management actions taken to reduces the overall levels of pesticides, nutrients and endocrine disrupting chemicals in the Great Lakes source water for drinking.
- To examine indications for possible improvements to potable and waste water treatment.

Indicator Relevance

The presence of chemical contaminants in the Great Lakes basin has long been cause for concern for residents of the region who are dependent on the Lakes as a source of drinking water. This suite of measures for this indicator provides a cross section of compounds that are widely dispersed and potentially hazardous to human health (atrazine as a frequently measured marker for agricultural pesticides), as well as those where emerging science indicates cause for concern though the level of regulation in drinking water varies (estrogenicity and cyanotoxins).

Atrazine is a commonly measured pesticide in surface water, and exposure to atrazine has been linked to reproductive effects in humans (US EPA, 2012). Atrazine is commonly applied to fields used in corn and other large-scale farming production, and thereby serves as a marker for pesticide contamination associated with large-scale agriculture. Like other agriculturally based watershed contaminants, observed seasonal variability can be expected for the Great Lakes basin, especially for those lakes most heavily influenced by agricultural production.

Endocrine disrupting compounds (EDCs) can enter the Great Lakes due to the use of pharmaceuticals and chemicals by consumers, industry and agriculture. In general, pollution from human and animal pharmaceuticals and consumer products has been increasing, even as industrial exposures are controlled. Unlike industrial chemicals, pharmaceuticals are specifically designed to interact with biological systems and may represent a greater hazard. Human exposure to these compounds can cause functional changes in the endocrine and reproductive systems, in addition to other adverse effects. EDCs have been detected in source water (Snyder et. al., 2008a; Wu et. al., 2009) and finished drinking waters (Benotti et. al., 2009; Snyder et. al., 2008b). While there are many possible EDCs that can be detected in source waters, the presence and variability of estrogen-mimicking EDCs in drinking water sources can be assessed by monitoring the estrogenicity of these waters (Falconer et. al., 2006; Hecker and Hollert, 2009).

Another consequence of agricultural activity in the basin is eutrophication and excessive nutrient loading in the Great Lakes ecosystems and the production of algal blooms with massive concentrations of cyanobacteria in surface and subsurface waters of the lakes. Cyanobacteria blooms are termed harmful algal blooms (HABs) in part because of their detrimental effects on lake habitats and fish populations, and also because many cyanobacteria produce toxic substances, known as cyanotoxins, as part of their metabolism. HABs have been detected in all of the Great Lakes, and the blooms have been increasing in frequency and duration in recent years. The extent of bloom events can affect both surface waters and deeper in the water column, which presents challenges for water intake management strategies available to water treatment facilities.

To date, cyanotoxins detected in the Great Lakes are the liver toxins, microcystins and cylindrospermospin, and the neurotoxins anatoxin-a and saxitoxins (Paralytic Shellfish Toxins) (Brittain et. al., 2000; Boyer, 2008; Watson and Boyer, 2009). Exposures to cyanotoxins have led to acute animal and human toxicity and acute lethal poisonings in animals and wildlife in many states and provinces in the Great Lakes basin (IJC HPAB, 2014). In the Great Lakes, the presence of HABs and the cyanotoxins they produce have led to increasing costs for the treatment of potable water supplies (Codd et. al., 2005; Fristachi et. al., 2008).

Finally, this indicator relates to general objectives of the revised GLWQA, as amended by the Great Lakes Water Quality Protocol of 2012. The 2012 Protocol states that the waters of the Great Lakes should:

(i) be a source of safe, high-quality drinking water; and

(iv) be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain.

Such an indicator should also be relevant to the following Appendices of the Agreement: #1 Areas of Concern, #2 Lakewide Management Plans, #3 Chemicals of Mutual Concern and #10 Science.

Measurement

Atrazine is listed as a drinking water contaminant regulated by the US EPA via the Safe Drinking Water Act Chemical Phase II Rule (National Primary Drinking Water Regulations: Synthetic Organic Chemicals and Inorganic Chemicals, Monitoring for Unregulated Contaminants, National Primary Drinking Water Regulations Implementation, National Secondary Drinking Water Regulations (Phase II Rule), 1991) with a **Maximum Contaminant Level (MCL)** = 0. 003 mg/L, and via the Ontario Drinking-Water Quality Standards Regulation (Ontario Drinking-Water Quality Standards (Ontario Regulation 169/03), 2008) with an Interim Maximum Acceptable Concentration (IMAC) = 0. 005 mg/L. The IMAC is established either when faced with insufficient toxicological data to establish a Maximum Acceptable Concentration with reasonable certainty, or when it is not feasible to establish a MAC at the desired level.

Current regulation in the United States or Canada does not specify levels and reporting of estrogenicity, though research studies report estradiol equivalents (EEQ) as a measure of estrogenicity in drinking water (Stanford et. al., 2008). The use of EEQ was recommended by Human Health Indicator Workshop participants as a mechanism to monitor multiple biologically active estrogenic compounds in ‘real world’ conditions.

Ontario has set a maximum acceptable concentration (MAC) for the cyanobacterial toxin microcystin-LR in drinking water is 0. 0015 mg/L (Ontario Drinking-Water Quality Standards (Ontario Regulation 169/03), 2008). Within states bordering the Great Lakes, the Minnesota Department of Health has posted drinking water guidelines for microcystin-LR of 0.04 μg/L (Minnesota Department of Health, 2012), though presently no regulations enforcing cyanotoxin levels in drinking water exist in the United States. More information is needed about the annual variability of the cyanotoxin hazard in drinking water sources to understand the associated risk to human health in the Great Lakes.

Cyanotoxins can be measured in surface water intakes, though methodologies vary in their sensitivity and ability to provide detailed identification of toxin levels in water sources. Microcystin-LR is routinely measured for surface drinking water intakes in Ontario, and microcystin-LR, anatoxin-a, and cylindrospermopsin have been most recently listed on the US EPA Third Candidate Contaminant List (US EPA Office of Ground Water and Drinking Water, 2009), which identifies unregulated contaminants that are known or expected to occur in public water systems. It is recommended that monitored cyanotoxins should include microcystin-LR, anatoxin-a, and cylindrospermospin, recognizing that current data availability will favor microcystin-LR.

Taking these points into consideration, the following approach is recommended for an IJC indicator of Chemical Integrity of Source Waters in the Great Lakes:

1) Monitoring for levels of atrazine, estrogenicity (measured as EEQ), and initially microcystin-LR (expanding to also include anatoxin-a, and cylindrospermospin) at intakes to drinking water treatment plants with weekly frequency and standardized methodologies.

   A recommendation of weekly measurements would be appropriate for this indicator, especially given both atrazine and cyanotoxins are likely to be seasonal in variation with greatest interest in peak rather than average concentrations. Sampling would be located at the drinking water treatment plant intake. Measures involving surface water and ground water sources could be flagged for comparison and separate evaluation. Identifying the methods for cyanotoxin and estrogenicity monitoring in source water to support this indicator will be a critical next step for the IJC.

2) Establishing provisional baselines for these measures in source water.

   Provisional baselines for the presence/absence of cyanotoxins in source water would provide a link between biological-chemical integrity of the Great Lakes and human health risk posed by harmful algal blooms.

In addition, the potential impacts of these compounds extend beyond source and drinking water considerations. Potential health impacts for cyanotoxins would potentially affect swimmers and fishers as well as drinkers, and EDCs may impact fisheries health as well. For future consideration, this indicator might be a candidate for more upstream monitoring in addition to the currently recommended drinking water intakes.

References

Benotti, M.J., Trenholm, R.A., Vanderford B.J., Holady J.C., Stanford B.D., Snyder, S.A., 2009. Pharmaceuticals and endocrine disrupting compounds in U.S. drinking water. Environ. Sci. Technol. 43(3), 597-603.

Boyer, G.L., 2008. Cyanobacterial toxins in New York and the Lower Great Lakes ecosystems, in: Hudnell, H.K. (Ed.), Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs, Advances in Experimental Medicine and Biology, Volume 619. Springer, New York, pp. 141-153.

Brittain, S.M., Wang, J., Babcock, J.L. , Carmichael, W.W., Rinehart, K.L., Culver, D.A., 2000. Isolation and characterization of microcystins, cyclic heptapeptide hepatotoxins from a Lake Erie strain of Microcystis aeruginosa. J.Great Lakes Res. 26, 241-249.

Codd, G.A.,Azevedo, S.M.F.O., Bagchi, S.N., Burch, M.D., Carmichael, W.W., Harding, W.R., Kay, K., Utkilen, H.C., 2005. CYANONET A Global Network for Cyanobacterial Bloom and Toxin Risk Management, Initial Situation Assessment and Recommendations. International Hydrological Programme-VI, Technical Documents in Hydrology No. 76, UNESCO, Paris.

Environment Canada and the United States Environmental Protection Agency, 2009. State of the Great Lakes, 2009. Cat No. En161-3/1-2009E-PDF and EPA 905-R-09-031 . 443 pp. http://binational.net/solec/sogl2009/SOGL_2009_en.pdf

Environment Canada and the U.S. Environmental Protection Agency. 2014. State of the Great Lakes 2011. Cat No. En161-3/1-2011E-PDF. EPA 950-R-13-002. http://binational.netUS EPA Office of Ground Water and Drinking Water, 2009. Contaminant Candidate List 3 (CCL3). http://water. epa. gov/scitech/drinkingwater/dws/ccl/ccl3. cfm.

Falconer, I. R., Chapman, H.F., Moore, M.R., Ranmuthugal, G., 2006. Endocrine-disrupting compounds: a review of their challenge to sustainable and safe water supply and water reuse. Environ. Toxicol. 21, 181–191.

Fristachi, A., Sinclair, J.L., Hall, S., Hambrook Berkman, J.A., Boyer, G., Burkholder, J., Burns, J., Carmichael, W., DuFour, A., Frazier, W., Morton, S.L., O'Brien, E., Walker, S., 2008. Occurrence of Cyanobacterial Harmful Algal Blooms Workgroup Report, in: Hudnell, H.K. (Ed.), Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs, Advances in Experimental Medicine and Biology, Volume 619. Springer, New York, pp 45-103.

Great Lakes Water Quality Agreement, 2012. Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed on October 16, 1983 and on November 18, 1987. U. S-Can., art 2.4.i, Feb. 12, 2013, http://www.ijc.org/en_/Great_Lakes_Quality.

Hecker, M., Hollert, H., 2009. Effect-directed analysis (EDA) in aquatic ecotoxicology: state of the art and future challenges. Environ. Sci. Pollut. Res. 16, 607-613.

International Joint Commission's Health Professional Advisory Board (IJC HPAB), 2014. Human Health Effects from Harmful Algal Blooms: a Synthesis. IJC. Windsor, ON, Canada.

Minnesota Department of Health, 2012. Microcystin-LR in Drinking Water. http://www.health.state.mn.us/divs/eh/risk/guidance/gw/mclrinfo.pdf

National Primary Drinking Water Regulations: Synthetic Organic Chemicals and Inorganic Chemicals, Monitoring for Unregulated Contaminants, National Primary Drinking Water Regulations Implementation, National Secondary Drinking Water Regulations (Phase II Rule), 56 Federal Register (30 January 1991), pp. 3526-97. http://water.epa.gov/lawsregs/rulesregs/sdwa/chemicalcontaminantrules/upload/FR1-30-91.pdf.

Ontario Drinking-Water Quality Standards (Ontario Regulation 169/03), Under the Safe Drinking Water Act. Ontario Ministry of the Environment (December 2008) http://www.canlii.org/en/on/laws/regu/o-reg-169-03/latest/o-reg-169-03.html

Patz, J.A., Vavrus, S.J., Uejio, C.K., McLellan, S.L., 2008. Climate change and waterborne disease risk in the Great Lakes region of the U.S. Am. J. Prev. Med. 35(5), 451-458.

Snyder, S. A., Trenholm, R.A., Snyder, E.M., Bruce, G.M., Pleus, R.C., Hemming, J.D.C., 2008a. Toxicological Relevance of EDCs and Pharmaceuticals in Drinking Water. Awwa Research Foundation. Denver, CO, United States.

Snyder, S. A., Vanderford, B.J., Drewes, J., Dickenson, E., Snyder, E.M., Bruce, G.M., Pleus, R.C., 2008b. State of Knowledge of Endocrine Disruptors and Pharmaceuticals in Drinking Water. Awwa Research Foundation. Denver, CO, Unites States.

Stanford, B. D., Snyder, S.A., Trenholm, R.A., Holady, J.C., Vanderford, B.J., 2008. Estrogenic activity of US drinking waters: a relative exposure comparison. J. Am. Water Works Assoc. 102(11), 1-11.

US EPA, 2012. Pesticides: Topical & Chemical Fact Sheets, US EPA. http://www.epa.gov/pesticides/factsheets/atrazine_background.htm.

US Global Change Research Program, 2009. Global Climate Change Impacts in the United States. In: Karl, T.R., Melillo, J.M., Peterson, T.C. (eds.). United States Global Research Program. New York, NY, United States. http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf and http://nca2009.globalchange.gov/increases-amounts-very-heavy-precipitation-1958-2007 Updated from Groisman, P.Y., Knight, R., Karl, T., Easterling, D., Sun, B., Lawrimore, J. 2004.

Contemporary Changes of the hydrological cycle over the contiguous United States: Trends derived from in situ observations. J. Hydrometeorol. 5:64-85.

Watson, S.B., Boyer, G., 2009. Harmful Algal Blooms (HABs) in the Great Lakes: Current Status and Concerns, in: State of the Lakes Ecosystem Conference (SOLEC), 2008. Nearshore Areas of the Great Lakes September 2009. pp. 78-91.

Wu, M., Atchley, D., Greer, L., Janssen, S., Rosenberg, D., Sass, J., 2009. NRDC White Paper: Dosed Without Prescription: Preventing Pharmaceutical Contamination of Our Nation’s Drinking Water. National Resources Defense Council. New York, NY, United States.

Biological Hazard Index for Source Water - *E. coli*, nitrate and turbidity

Recommend additions to index of *Cryptosporidium parvum* and *Giardia lamblia* when data are available. These additions would support future additions to health outcomes of GI illness from these organisms.

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Definition

The extent of biological hazard for the Great Lakes source water can be assessed for the impacts of human and agricultural activities by monitoring the presence of key pathogens: *E. coli*, *Cryptosporidium parvum* and *Giardia lamblia*, as well as physical and chemical markers for human health hazards such as nitrates from septic systems and agriculture and turbidity. Trends in the clarity of Great Lakes source waters used for the production of drinking water would be monitored by measuring turbidity. Increased turbidity in source waters is associated with increased risk of acute gastrointestinal illness (AGI) from viral, bacterial and parasitic pathogens. Nitrate would be monitored as a marker for nutrient inputs that cause risk to human health. These hazards could be linked to future monitoring of reportable sporadic gastrointestinal illnesses, in addition to standard outbreak reporting, from these same pathogens to provide the link between the hazards (our proposed indicators) and health risk.

Purpose and Importance

Monitoring biological hazards in source waters for drinking water systems, particularly if augmented by measurements in treated water and tap water, will enable the governments and the IJC:

- To examine trends in the endemic, seasonal and episodic presence of sewage and agricultural effluent and other contaminated runoff in the Great Lakes.
- To examine seasonal and geographic distribution of selected human pathogens.
- To infer the effectiveness of management actions taken to reduce the impact of pathogens and nitrate in source waters.

Indicator Relevance

Human exposure to surface or drinking waters contaminated with pathogens contributes to constant sporadic AGI in populations and can lead to wide outbreaks of gastrointestinal and more severe illnesses. Thus, the presence of pathogens in the Great Lakes presents a human health risk unless adequately addressed by drinking water treatment. There are many standard methods in use for routine monitoring of biological hazards in source waters. Of those suggested here, turbidity measurements are generally straightforward and less expensive to implement. Nitrate and E. coli measures are more complex to implement than turbidity, yet provide complimentary information that is measured regularly by water treatment plants. Methods for determining the presence of *C. parvum* and *G. lamblia* are the most complex of the measures recommended here, are and expensive, and hence less often utilized, especially for drinking water treatment plants that serve small and under-resourced communities. *C. parvum* and *G. lamblia* are protozoa that are known to cause AGI in humans and are relatively resistant to treatment, while *E. coli* is commonly found in the digestive tracts of humans and animals and is used as a proxy for the presence of other pathogenic bacteria in surface waters from agriculture, sewage effluent or other contaminated runoff. *E. coli* or a more general coliform count also serves as a commensal indicator organism to predict the presence or absence of pathogens in wastewater treatment facilities.

Nitrate can be found in aquatic systems in elevated levels due to its presence as a significant component of fertilizer runoff from agricultural activities as well as sewage and from septic systems. Increases in nitrate have contributed to the overall eutrophication of the Great Lakes basin. Its presence in drinking water is regulated by the US EPA and Ontario Ministry of the Environment due to health risks, especially to children due to interference with oxygen transport in the blood. The fetuses in pregnant women are also likely to be at risk, though data in humans is limited.

Turbidity measures water clarity based on the amount of light passing through suspended materials in the sample. While turbidity is not considered a substitute for other pathogen indicators monitored in drinking water treatment facilities, as it lacks the ability to identify specific organisms, it is a relatively inexpensive surrogate measure for indicating the presence of pathogens. It has been widely monitored and reported over many decades. Turbidity is not without its drawbacks as an indicator for human health in source water due to low specificity, however it is no more confounded than many other drinking water indicators, is relatively sensitive and has good data availability, even from drinking water treatment plants that are otherwise resource-challenged. While invasive mussels have caused shifts in the measured clarity of the Great Lakes leading to shifts in the natural ecosystem (MacIsaac, H.J. 1996, Barbiero, et al., 2006; Binding, et al., 2007.), this has not affected the recommendations for turbidity measurements at the intakes of drinking water treatment plants in the United States and Canada. Drinking water systems that obtain raw water intake from surface waters, in addition to ground water under the direct influence of surface waters in the Great Lakes basin, are recommended to routinely measure turbidity of the source water intake prior to treatment (Water Supply Committee of the Great Lakes—Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 2012; Health Canada, 2013).

High turbidity in source water is associated with waterborne pathogen contamination (Aramini, 2000; Atherholt et. al., 1998; Jagai et. al., 2012). Turbidity is prone to rapid change due to storms, landslides, increased runoff, agricultural practices and other episodic events. Suspended materials include a variety of abiotic and biotic particulates present in source waters due to natural and human processes such as erosion, waste discharge, runoff from storm events, combined sewer overflows, and growth of plankton, algal blooms, and other microorganisms. The particulates that cause increases in turbidity can provide food and shelter for pathogens (Medema et. al., 2009), increase loads on water treatment systems (e.g., clogging filtration), and contribute to regrowth of pathogens within a drinking water distribution system (Title XIV of The Public Health Service Act: Safety of Public Water Systems (Safe Drinking Water Act) Amendments of 1996, 1996).

Microbiological contamination of surface waters in the Great Lakes can be attributed to raw sewage or sewage effluent from primarily human origin (e.g., combined sewage overflow events) as well as from runoff from agriculture, and wild or domesticated animal feces in the watershed. All three microorganisms proposed in this indicator, along with nitrate and turbidity, are monitored in finished drinking water as contaminants with reporting requirements outlined by standards in United States (National Primary Drinking Water Regulations: Filtration, Disinfection, Turbidity, Giardia lamblia, Viruses, Legionella, and Heterotrophic Bacteria (Surface Water Treatment Rule),1989; National Primary Drinking Water Regulations: Total Coliforms (Including Fecal Coliforms and E. coli), Final Rule, 1989; National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment, 1998; National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule, 2002; National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule, 2006)) and Ontario (Ontario Drinking-Water Quality Standards (Ontario Regulation 169/03), 2008). The existence of source water monitoring and reporting to support this indicator, especially microorganisms, are less readily available. Recently, source-to-tap approaches to monitor pathogens in the drinking water production and consumption chain have been promoted, and source monitoring can be effective for inferring human health risk from pathogens in drinking water (Medema et. al., 2009). These finished drinking water alerts could certainly contribute valuable information to complement the source water monitoring proposed here.

This indicator relates to the following general objectives of the revised Great Lakes Water Quality Agreement, as amended by the Great Lakes Water Quality Protocol of 2012. The Protocol states the waters of the Great Lakes should:

(i) be a source of safe, high-quality drinking water;

(iv) be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain; and,

(vi) be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health, or human use of the ecosystem.

Biological Integrity of Source Water and its measures also relate to the following Appendices of the Agreement: #1 Areas of Concern, #2 Lakewide Management Plans, #4 Nutrients and #10 Science.

Measure

Existing reporting and monitoring of source water is currently performed by utilities, and differences exist between requirements for utilities in the United States and Canada. While measuring turbidity in nephlometer units is fairly standard, various methods for measuring and reporting nitrate, *E. coli*, *C. parvum* and *G. lamblia* in source and drinking waters the United States and Canada have been developed. One aim for the next phase of indicator development will be to examine the status of current data sets and recommend standardization of measurements and reporting.

When considering existing reporting for this source water indicator, Ontario's Provincial Water Quality Network provides source water monitoring for source waters in the region, with *E. coli* as a bacteriological indicator, though not *C. parvum* and *G. lamblia*. There is no continuous national program for monitoring these three microorganisms in source waters in the United States, though recent baseline monitoring of *C. parvum* in source waters was enacted by the US EPA as part of implementing its Long Term 2 Enhanced Surface Water Treatment Rule (National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule, 2006). This monitoring was not established as a continuous long term program, and measurement of *E. coli* was an acceptable cost-effective substitute for smaller treatment facilities. Similar data does not exist for *G. lamblia* under this program.

Measurement of nitrate and turbidity the Great Lakes basin is subject to strict definitions for both measurement and reporting within the United States and Canada based on regulations for drinking water treatment and distribution (Ontario Drinking-Water Quality Standards (Ontario Regulation 169/03), 2008; National Primary Drinking Water Regulations: Filtration, Disinfection, Turbidity, Giardia lamblia, Viruses, Legionella, and Heterotrophic Bacteria (Surface Water Treatment Rule), 1989; National Primary Drinking Water Regulations: Synthetic Organic Chemicals and Inorganic Chemicals, Monitoring for Unregulated Contaminants, National Primary Drinking Water Regulations Implementation, National Secondary Drinking Water Regulations , 1991;National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment, 1998; National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule, 2002). Both countries require turbidity reported as nephelometric turbidity units (NTU). Drinking water turbidity should be <5 NTU, and nitrate levels in drinking water cannot exceed 10 mg/L as Maximum Allowable Concentration in Canada (Ontario Drinking-Water Quality Standards (Ontario Regulation 169/03), 2008) and Maximum Contaminant Level in the United States (National Primary Drinking Water Regulations: Filtration, Disinfection, Turbidity, Giardia lamblia, Viruses, Legionella, and Heterotrophic Bacteria; Final Rule, 1989; National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment, 1998; National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule, 2002).

Since the frequency of source water nitrate and turbidity measurements in the Great Lakes varies, recent state and provincial recommendations for new Great Lakes drinking water treatment facilities consider daily raw water turbidity measurements (every 4 hours) as part of minimum data monitoring requirements for new treatment plant construction (Water Supply Committee of the Great Lakes—Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 2012).

Source water turbidity varies between regions and seasons (10-1000s of NTUs), and anticipated increases in weather extremes associated with climate change are anticipated for the Great Lakes region, bringing with it increasing variation in precipitation (and hence turbidity) as well as waterborne disease risk (Patz et. al. 2008). Categorizing existing data relative to regional high, normal and low turbidity for source water within the Great Lakes basin would provide a scheme for public reporting on the link between physical integrity and human health risk.

Recommendations for this implementing this indicator include:

1) Monitor for *E. coli* (expanding to also include *C. parvum* and *G. lamblia*), nitrate and turbidity at intakes to drinking water treatment plants with standardized methodologies with daily frequency.

   When identifying location and frequency of measurement provisions for the indicator and providing frameworks for reporting to the IJC, it is important to note that health hazard, or at least the impact on water treatment requirements, likely varies daily. We recommend that monitoring intakes of drinking water treatment plants would provide a practical, reliable measure and relevant location for the protection of health. Governments should consider standardized daily collection and reporting for these components of this indicator. Measures involving surface water and ground water sources could be flagged for comparison and separate evaluation.

2) Trend analysis should focus on extremes or exceedences of measurement beyond the provisional baselines (establishment recommended below) rather than averages.

3) Consider steps to incorporate data from smaller municipalities and regions with lower population densities.

The number and geographic diversity of the collection sites within the basin will be important for the optimization of this indicator. Current reporting requirements may lead to greater representation in a data set of large municipalities over areas with smaller populations, and this consideration should be weighed when developing the indicator framework particularly considering that agriculture is an important source for many of the contaminants of concern.

4) Establish provisional baselines for these measures in source water.

Formulation of a biological hazard index could move ahead using the already existing datasets for turbidity, nitrates and *E. coli*. The use of *E. coli* as surrogate marker for the other organisms listed above could proceed if indeed that is the only source water data available for particular geographic areas of interest.

For future efforts, it is recommended that the IJC would advocate for the permanent inclusion of standardized measurements of *G. lamblia* and *C. parvum* in a source water monitoring scheme supported by federal agencies in the US and Canada to augment this indicator. For example, Canada currently has no equivalent requirement to the US EPA’s Long Term 2 Enhanced Surface Water Treatment Rule requirement for surface water systems to monitor for *C. parvum*. To tie this indicator to human health outcomes in the future, illness rates for reportable gastrointestinal illnesses due to pathogenic *E. coli, C. parvum* and *G. lamblia* could be incorporated through annual reporting by census tract (Michigan Department of Community Health, 2008; Vrbova et. al., 2012).

Finally, while it is important to incorporate source water monitoring as means of assessing human health risks in the Great Lakes, infectious threats in drinking water may arise not only from source contamination, but also from inadequate drinking water treatment and contamination of treated water in aging distribution systems, including cross-contamination from waste- and storm-water collection systems. Aging treatment and distribution infrastructure also threatens water quality, especially as treatment systems are called upon to address more complex source water issues (e.g., parasites, viruses, chemical contaminants, and climate extremes).

Consequently, an exclusive focus on source water is inadequate to protect human health, and the adoption of a ‘source-to-tap’ monitoring program (Medema et. al., 2009) would be useful in the Great Lakes basin. It is suggested that source water monitoring, as recommended by this report, should be augmented by future monitoring post-treatment and post-distribution in the Great Lakes basin.

References

Aramini, J., McLean, M., Wilson, J., Holt, J., Copes, R., Allen, B., Sears, W., 2000. Drinking water quality and health care utilization for gastrointestinal illness in Greater Vancouver. Can. Commun. Dis. Rep. 26(24), 211-214.

Atherholt, T.B., LeChevallier, M.W., Norton, W.D., Rosen, J.S., 1998. Effect of rainfall on *Giardia* and *Cryptosporidium*. J. Am. Water Works Assoc. 90(9), 66-88.

Barbiero, R., Tuchman, M., Millard, E.S. 2006 Post-dreissenid Increases in Transparency During Summer Stratification in the Offshore Waters of Lake Ontario: Is a Reduction in Whiting Events the Cause? Journal of Great Lakes Research 32(1), 131-141.

Binding, C, Jerome, J.H , Bukata, R. , Booty, W. 2007. Trends in Water Clarity of the Lower Great Lakes from Remotely Sensed Aquatic Color. . Journal of Great Lakes Research 33(4),828-841.

Health Canada (2013). Guidance on Providing Safe Drinking Water in Areas of Federal Jurisdiction. Version 2, Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada. Ottawa, Ontario, Canada (Catalogue No. H128-1/05-440-1E-PDF).

Jagai, J. S., Griffiths, J.K., Kirshen, P.K., Webb, P., Naumova, E.N., 2012. Seasonal patterns of gastrointestinal illness and streamflow along the Ohio River. Int. J. Env. Res. Pub. Health 9(5), 1771-1790. doi:10.3390/ijerph9051771.

MacIsaac, H.J. 1996. Potential abiotic and biotic impacts of zebra mussels on the inland waters of North America. American Zoologist 36:287-299.

Medema, G., Teunis, P., Blokker, M., Deere, D., Davison, A., Charles, P., Loret, J-F., 2009. Risk assessment of *Cryptosporidium* in drinking water. World Health Organization, pp.134.

Michigan Department of Community Health, 2008. Reportable Infectious Diseases in Michigan, 2003-2007 Summary. http://www.michigan.gov/documents/mdch/Final_Reportable_ID_2003_to_2007_Summary_251984_7.pdf

National Primary Drinking Water Regulations: Filtration, Disinfection, Turbidity, Giardia lamblia, Viruses, Legionella, and Heterotrophic Bacteria (Surface Water Treatment Rule), Final Rule, 54 Federal Register (29 June 1989), pp. 27486-27541. http://water.epa.gov/lawsregs/rulesregs/sdwa/swtr/upload/SWTR.pdf

National Primary Drinking Water Regulations: Total Coliforms (Including Fecal Coliforms and E. coli), Final Rule, 54 Federal Register, (29 June 1989), pp. 27544-27568. http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/upload/tcr1989.pdf

National Primary Drinking Water Regulations: Synthetic Organic Chemicals and Inorganic Chemicals, Monitoring for Unregulated Contaminants, National Primary Drinking Water Regulations Implementation, National Secondary Drinking Water Regulations, 56 Federal Register (30 January 1991), pp. 3526-97. http://water.epa.gov/lawsregs/rulesregs/sdwa/chemicalcontaminantrules/upload/FR1-30-91.pdf.

National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment, 63 Federal Register (16 December 1998), pp. 69477-69521. http://www.gpo.gov/fdsys/pkg/FR-1998-12-16/html/98-32888.htm

National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule, 67 Federal Register (14 January 2002), pp. 1811-1844. https://federalregister.gov/a/02-409.

National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule, 71 Federal Register (05 January 2006), pp. 654-786. https://federalregister.gov/a/06-4.

Ontario Drinking-Water Quality Standards (Ontario Regulation 169/03), Under the Safe Drinking Water Act. Ontario Ministry of the Environment (December 2008) http://www.canlii.org/en/on/laws/regu/o-reg-169-03/latest/o-reg-169-03.html

Title XIV of The Public Health Service Act: Safety of Public Water Systems (Safe Drinking Water Act) Amendments of 1996., Pub.L. 104–182, 110 Stat. 1613 (August 06, 1996), http://www.gpo.gov/fdsys/pkg/PLAW-104publ182/html/PLAW-104publ182.htm

Vrbova, L., Johnson, K., Whitfield, Y., Middleton, D., 2012. A descriptive study of reportable gastrointestinal illnesses in Ontario, Canada, from 2007 to 2009. BMC Public Health 12, 970-981. doi:10.1186/1471-2458-12-970

Water Supply Committee of the Great Lakes—Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 2012. Recommended Standards For Water Works - Policies for the Review and Approval of Plans and Specifications for Public Water Supplies. Health Research Inc., Health Education Services Division. Albany, New York, United States. 130 pp.

Risk of Illness from Great Lakes Beaches

Contributors: Howard Shapiro, International Joint Commission Health Professionals Advisory Board and Toronto Public Health.

Definition

Recreational surface waters and beach sands may harbor microorganisms capable of causing illness in beach visitors, primarily due to contamination with fecal material from people and animals. This indicator uses *E. coli* levels, which are taken routinely as part of beach monitoring programs, to assess the risk of illness to people using Great Lakes beaches.

Purpose and Importance

- To infer potential harm to human health at routinely monitored beaches through use of fecal indicator organisms, as surrogates for pathogens.
- To describe temporal and spatial trends in recreational water quality throughout the Great Lakes.
- To be able to compare recreational water quality across jurisdictions using a common methodology.

Use of Great Lakes coastal beaches is an important recreational activity for the over 30 million people who live in the Great Lakes basin. Although exact figures are not available, there are estimates that millions of people each year use beaches on the Great Lakes (Great Lakes Information Network, 2012). Targeted epidemiological studies have shown a number of adverse health outcomes (including gastrointestinal and respiratory infections) to be associated with fecally polluted recreational water. This can result in a significant burden of disease and economic loss (World Health Organization, 2003).

Indicator Relevance to the Great Lakes Water Quality Agreement

This indicator is relevant to the following general objectives of the GLWQA as amended by the Great Lakes Water Quality Protocol of 2012:

(ii) allow for swimming and other recreational use, unrestricted by environmental quality concerns;

The indicator is also relevant to the following GLWQA 2012 Protocol Annexes: #1 Areas of Concern, #2 Lakewide Management Plans and #10 Science.

Measures

The indicator consists of:

The 95th percentile of numbers of *E. coli* measured as the most probable number (MPN)/ colony-forming units (CFU) of *E. coli* per 100 ml at Great Lakes beaches (traditional approach) to determine change over time.

Sampling of recreational water should be done according the relevant state or provincial protocol with *E. coli* enumerated by a method recommended by Health Canada (Health Canada, 2012) or the US EPA (US EPA, 2012). The 95th percentile should be calculated using the Hazen method (World Health Organization, 2003). Raw counts of *E. coli* would be submitted to the IJC, who would then calculate the 95th percentile. This approach was considered superior to the previous indicator of beach closures, which uses different criteria in different jurisdictions and is affected by factors such as testing frequency. Obtaining raw data would also allow for additional calculation of central tendency and other summary statistics as required.

By collecting raw counts of *E. coli* for each beach, different metrics can be calculated (single sample maximum exceedences, 30-day geometric mean, 75th percentile, historical averages, etc.). *E. coli* was chosen for this indicator given its use at many Great Lakes beaches in Canada and the United states as the national standard for measurement with the most extensive set of historical data. A number of different methods are being considered by beach managers for broader implementation (fecal streptococci, modeling using weather data, etc.), which may eventually change the national measurement standard for both countries. If a national standard changes, then the raw data can be reanalyzed using the new standard, allowing the root indicator to remain relevant over time and across wide geographic areas. The high values of *E. coli* at the top end of the statistical distribution are of greatest public health concern and are well reflected by the 95th percentile, as opposed to a measure such as the median or mean (World Health Organization, 2003). The 95th percentile value is a widely accepted method, is used internationally and allows cross jurisdictional comparisons more readily than compliance with a numerical standard. Recreational water quality guidelines vary within and across provinces, states, and countries such as Canada and the United States have differing water quality standards. (Health Canada, 2012; US EPA, 2012).

Gathering sources of pollution at Great Lakes beaches will provide valuable new information about root causes of this hazard, and would prove helpful in providing priorities for action. Having both a measure of microbiologic quality of the recreational water such as *E. coli* and sources of nearby pollution for each beach provides the potential to one day combine them into a single indicator of overall beach quality which is being done in some other jurisdictions (World Health Organization, 2003).

References

Great Lakes Information Network, 2012. Beach Health and Water Quality. http://www.great-lakes.net/beachcast/health_quality.html

Health Canada, 2012. Guidelines for Canadian Recreational Water Quality Third Edition. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada. Ottawa, ON, Canada.

US EPA, 2012. Recreational Water Quality Criteria. United States Environmental Protection Agency, Office of Water. Washington, DC, United States.

World Health Organization, 2003. Guidelines for safe recreational water environments: volume 1 coastal and fresh waters. World Health Organization. Geneva, Switzerland.

Sources of Risk at Great Lakes Beaches

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Definition

Recreational surface waters and beach sands may harbor microorganisms capable of causing illness in beach visitors, primarily due to contamination with fecal material from people and animals. Identification of fecal contamination sources is important in order to provide effective exposure interventions, prioritize clean-up and target remediation efforts (US EPA, 2012) as part of a multi-barrier approach to minimize health risk at beaches (Health Canada, 2012). Guided data collection tools, called Beach Sanitary Surveys (US) or Environmental Health and Safety Surveys (Canada) have been developed for this purpose. In addition to expanded monitoring for fecal indicator bacteria and assessments of environmental parameters, additional methods may be employed to further characterize the potential hazard. For example, microbial source tracking (MST) can be used to identify the host source(s) of fecal pollution impacting a particular beach, (e.g., human vs. non-human, or ruminant vs. avian) (Whitman et al., 2007). This indicator describes the main sources and relative contributions of locally derived pollution impacting recreational surface water (e.g., waste water treatment plants, agricultural run-off, combined sewer overflows, etc.).

Purpose and Importance

- To characterize the pollution sources impacting Great Lakes beaches.

Use of Great Lakes coastal beaches is an important recreational activity for the over 30 million people who live in the Great Lakes basin. Although exact figures are not available, there are estimates that millions of people each year use beaches on the Great Lakes (Great Lakes Information Network, 2012). Targeted epidemiological studies have shown a number of adverse health outcomes (including gastrointestinal and respiratory infections) to be associated with fecally polluted recreational water. This can result in a significant burden of disease and economic loss (World Health Organization, 2003).

Indicator Relevance to the Great Lakes Water Quality Agreement

This indicator is relevant to the following general objectives of the GLWQA as amended by the Great Lakes Water Quality Protocol of 2012:

(ii) allow for swimming and other recreational use, unrestricted by environmental quality concerns;

The indicator is also relevant to the following GLWQA 2012 Protocol Annexes: #1 Areas of Concern, #2 Lakewide Management Plans, and #10 Science.

Measures

The indicator consists of:

i. Main pollution sources identified at beaches that employ a Beach Sanitary Survey or Environmental Health and Safety Survey.

ii. Percentage of beaches that employ a Beach Sanitary Survey or Environmental Health and Safety Survey in a given year (this will provide context as to how many beaches are providing data for this indicator).

The Beach Sanitary Survey or Environmental Health and Safety Survey should be done using the respective tools and methods as described by the US EPA (US EPA, 2008) and Health Canada (Health Canada, 2012). The survey should be conducted on an annual basis at a minimum.

Sanitary surveys are recommended best practices for beaches by both the US EPA and Health Canada. Many beaches on the Great Lakes already use this tool. This indicator will provide an assessment of the sources of contamination for Great Lakes beaches and show how many beaches are adhering to best practices.

References

Great Lakes Information Network, 2012. Beach Health and Water Quality. http://www.great-lakes.net/beachcast/health_quality.html.

Health Canada, 2012. Guidelines for Canadian Recreational Water Quality Third Edition. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada. Ottawa, ON, Canada.

US EPA, 2008. Great Lakes Beaches Sanitary Survey User Manual. EPA-823-B-06-001. http:// http://water.epa.gov/type/oceb/beaches/upload/2008_05_29_beaches_sanitarysurvey_user-manual.pdf.

US EPA, 2012. Recreational Water Quality Criteria. United States Environmental Protection Agency, Office of Water. Washington, DC, United States.

Whitman , R. L.,Przybyla-Kelly, K. , Shively D., and Byappanahalli, M., 2007 Incidence of the Enterococcal Surface Protein (esp) Gene in Human and Animal Fecal Sources. Environ. Sci. Technol.41 (17), 6090–6095.

World Health Organization, 2003. Guidelines for safe recreational water environments: volume 1 coastal and fresh waters. World Health Organization. Geneva, Switzerland.

Contaminant Levels in Great Lakes Edible Fish Species

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Introduction

Through collaboration and consultation between the IJC and the relevant partners to develop a fish consumption indicator for the Great Lakes, it has become evident that jurisdictional differences in methods for collection, analysis, and issuing advice pose challenges in developing a Great Lakes basinwide indicator for fish consumption. However, it is important to address this important human health issue and to continue to work with partners in the development of an indicator. This section discusses the available data, the challenges of using those data for basin-wide reporting, and proposes a path forward to improving upon an indicator for Great Lakes fish consumption.

Definition

Fish consumption represents an important nutritional component for many Great Lakes residents. While consumption of fish from Laurentian Great Lakes provides established health benefits, toxic chemicals found in those fish may mitigate the beneficial effect. Sport fishing is enjoyed by millions of Great Lakes anglers, and consumption of sport and commercial fish from the lakes is a primary pathway for human exposure to some contaminants, such as mercury and PCBs (Turyk et. al., 2012). There are also indirect effects that may occur from the inability to eat fish. Health risks can occur from a diminished intake of omega fatty acids and protein. In addition, the inability to consume fish, or sell fish to other consumers, may be stressful mentally or economically, and may indirectly have an adverse impact on morbidity or mortality.

Indigenous populations (e.g., Native Americans, First Nations and Metis) may be particularly affected nutritionally, economically, culturally, and spiritually as they continue to maintain commercial and subsistence fish production, particularly in Lake Superior (Dellinger et. al., 2012).

A useful surrogate measure for the potential impact of fish consumption on human health is the actual contaminant level in the fish themselves. These data can also be used to assess trends in edible fish. The measure is most accurate when data are available on contaminants in edible portions of particular species consumed by regional inhabitants (Dellinger et. al., 2014). Such a measure would be useful to assess progress towards achieving several of the objectives of the Great Lakes Water Quality Agreement as amended by the Great Lakes Water Quality Protocol of 2012 (Agreement), in particular the objective of allowing for human consumption of fish and wildlife, unrestricted by concerns due to harmful pollutants.

Purpose and Importance

- To describe temporal and spatial trends of bioavailable contaminants of chemicals of concern in representative species of commonly consumed fish throughout the Great Lakes.
- To estimate the impact of these measured contaminants on the health of humans.
- To evaluate the effectiveness of remedial actions to reduce critical pollutant burdens in the lakes.

Concerns about levels of persistent bioaccumulative toxic contaminants in Great Lakes fish in the 1960s and the possible human health consequences of eating the fish led to the banning of several of the chemicals of greatest concern, including DDT, PCBs, chlordane and toxaphene (EPA, 2011). These concerns also prompted public health advice on consumption of Great Lakes fish from federal, state/provincial and local health agencies, based on state and provincial monitoring (Anderson et. al., 1993, McCann et.al., 2007). The concerns also spurred the initiation of long-term monitoring of contaminant levels in sport fish (Gewurtz et. al., 2011) and edible portions of tribal commercial fish by the Chippewa-Ottawa Resource Authority (CORA) and by the Great Lakes Indian Fish and Wildlife Commission (Dellinger et. al., 2012).

Most contaminant levels have decreased considerably since that time (Bhavsar et. al., 2007; Bhavsar et. al., 2008; Bhavsar et. al., 2010; Carlson et. al., 2010; Chang et. al., 2012; US EPA, 2013; Dellinger et. al., 2014), yet fish consumption continues to be a health concern (Bhavsar et. al., 2011; OMOE, 2013; US EPA, 2013a). All states and provinces have issued fish consumption advisories (Table 1), and many tribal, First Nations and Metis officials have provided consumption guidelines and harvesting advice (Dellinger et. al., 2012). Fish consumption advisories are management actions that are usually issued by public health or environmental agencies. Advisories specify the frequency of a particular species of fish that can be consumed safely (e.g., on a monthly basis). Advisories frequently include more stringent restrictions on sensitive populations such as women of child bearing age and children (OMOE, 2013; US EPA, 2013a).

Indicator Relevance to the Great Lakes Water Quality Agreement

It is important to choose an indicator relevant to the following general objectives of the revised 2012 Agreement, the waters of the Great Lakes should:

(iii) allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants;

(iv) be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain;

Such an indicator should also be relevant to these Appendices of the Agreement: #1 Areas of Concern, #2 Lakewide Management Plans, #3 Chemicals of Mutual Concern, and #10 Science.

Challenges with Selecting Measures for this Indicator

The State of the Lakes Ecosystem Conference (SOLEC) reports two indicators related to contaminants in fish: (1) Contaminants in Whole Fish and (2) Fish Consumption Restrictions (SOLEC, 2011). IJC (2013) included both of these indicators, among the 16 indicators used to assess progress made in protecting and restoring the Great Lakes since 1987, illustrating the value of both of them.

Contaminants in Whole Fish SOLEC indicator

The fish contaminants indicator assesses the temporal and geographic trends in the chemical contaminant levels in Lake Trout (*Salvelinus namayacush*) from Lakes Ontario, Huron, Michigan and Superior, and Walleye (*Sander vitreus*) from Lake Erie. The purpose of this indicator is to help report on the ecological health of the Great Lakes, and by design is not intended to be a human health indicator. Environment Canada and the US EPA both contribute data to this indicator (EC, 2013; US EPA, 2010; US EPA, 2013b) although different methodologies limit the statistical analyses that can be performed (Gewurtz et. al., 2011). Samples of Lake Trout or Walleye are collected and analyzed at least every two years at 10 established sites (2 in each of the 5 Great Lakes) for the US EPA program and annually at the 12 sites established by Environment Canada in Superior, Huron, Erie and Ontario (Carlson et. al., 2010; Gewurtz et. al., 2011). Similarly, CORA contracts with commercial fishermen to collect samples from Lake Trout and Whitefish on a three year rotational basis from specific treaty areas of Lakes Superior, Huron and Michigan; however, because these data are edible portions as opposed to the whole fish samples collected for SOLEC, the data are not included in the SOLEC dataset (Dellinger et. al., 2014).

Through US EPA and Environment Canada monitoring, contaminant analyses in whole fish have included legacy pollutants such as PCBs, organochlorine pesticides, mercury and other trace metals, and also have included some contaminants of emerging concern such as polybrominated diethyl ethers (PBDEs), fluorinated chemicals and synthetic musks (US EPA, 2013b; US EPA, 2013c). Trends through time are assessed using first-order log-linear regression models of annual median concentrations to estimate percent annual declines. Concentrations are also compared to applicable benchmarks for concentrations in whole fish.

Utility and Limitations

This indicator is very useful for measuring status and trends of contaminant concentrations in these fish to determine ecological health and for assessing the progress made by remedial actions. However, the sampling design and methods employed to use fish to help evaluate the ecological health of the Great Lakes may not be not optimal for evaluating risks from consuming Great Lakes fish.   For instance, while the number and location of sampling sites are appropriate for assessment of ecological health, the number and location of sites are not appropriate for determining human health because they are not representative of the populations consuming fish or the fact that the majority of non-commercial anglers are catching nearshore, not offshore fish, and concentrations may vary widely between the two. The potential for valuable human health data in the current whole fish indicator is recognized. However, an indicator focused on fish portions would be more representative of human diet and more suited to capturing human health risk. Another limitation is that data are only collected for two fish species. Further, the SOLEC indicator reports the contaminant levels in whole fish (including bones and organs). Bones and organs are not typically consumed (Awad, 2006), nor is use of this indicator consistent with food preparation guidelines that advocate removal of skin and fat, the areas containing the highest levels of some contaminants (Zhang, et. al., 2013).   As a result, there are many limitations when using the Whole Fish indicator for assessing the risks of human fish consumption.

Fish Consumption Restrictions SOLEC Indicator

This SOLEC indicator is based on the frequency and severity of restrictive fish consumption advisories. Various tribal, state/provincial and federal agencies have monitored contaminant levels in Great Lakes for sport fish fillets, at varying frequencies. For the Canadian side, the OMOE has been monitoring fish contaminant levels for four decades and issuing advisories based on tolerable daily intakes from Health Canada (Bhavsar et. al., 2011; OMOE, 2013). Similarly, on the US side, the Great Lakes states use state-specific data to issue fish consumption advisories (Anderson et. al., 1993; McCann et. al., 2007).

In an attempt to use fish consumption advisories in the Great Lakes for summary reporting, a new Fish Consumption Advisory Rating Indicator was created jointly by US EPA and OMOE in 2011. In this new rating method, scores on a scale of 1 to 5 were assigned to each advisory based on the severity of the restriction. The scores were based on the advisories issued by the Great Lakes states and OMOE for lake trout and walleye —according to size class and the common contaminant PCBs. Lake trout and walleye were chosen because they are top predator fatty fish and they represent a reasonable “worst case scenario” for fish consumption advisories that are largely driven by bioconcentrations of organic chemicals such as PCBs. Average scores for each lake were derived by taking the mean of the applicable states' and Ontario's scores for each lake. Because this is a recent method, trends are not readily available. Using available historical data, a trend analysis could be developed, but this may require additional resources.

Utility and Limitations

Over time, the Fish Consumption Restriction SOLEC indicator will be useful in delineating the status and trends related to the GLWQA objective that fish consumption not be restricted by contaminant levels. While the SOLEC indicator is certainly practical and beneficial, there are some limitations. One limitation is that only two fish species are used in the scoring and rating system. Another limitation is that each US state and Ontario have different methods and standards for issuing an advisory, and the same fish may have a different consumption advisory as it swims across a state or international border. The different methods used by various jurisdictions make it difficult to analyze basin wide data, and have not allowed a direct correlation to be established between the presence of contaminants in blood or breast milk and fish consumption.

In summary, the SOLEC indicators provide important information regarding human health risks, however, the range of uncertainty poses many limitations to their use as indicators of health risk from fish consumption.

Data Sources

Edible fish are collected by the states, provinces and tribes/First Nations and Metis, however, they use different methods and standards for collecting samples, analyzing samples, and issuing fish consumption advisories making it difficult to identify unified basin wide status and trends. The data gathered by the OMOE long-term monitoring program are appropriate to use for long-term trend analysis but do not address Lake Michigan. CORA collects contaminant data in the edible portions of fish from Lakes Superior, Michigan, and Huron (Dellinger et. al., 2014). In the United States, all of the eight Great Lake states collect, analyze and issue fish consumption advice. Some states, such as Minnesota and Wisconsin, issue joint advice for shared water bodies. Additionally, the Great Lakes Consortium for Fish Consumption Advisories has developed protocols for issuing consistent advice for select contaminants. However, despite the collaboration of the eight Great Lakes States, uniform advice for the shared waters of the Great Lakes has not been achieved.

Recommendations: A Basin-Wide Edible Fish Indicator

The Health Professionals Advisory Board (HPAB) and the authors recognize that from the standpoint of Great Lakes assessment and resource management it would be ideal if Great Lakes governments and tribes/First Nations and Metis reach agreement on a standardized sampling approach, analytical methods, data interpretation and the issuing of advice. This standardization would allow for the development of a basin-wide human health indicator to characterize risks and benefits from fish consumption. The IJC recognizes that achieving such standardization is a tremendous challenge and not practical because each jurisdiction uses their own techniques to make decisions that go beyond the Great Lakes. The IJC is uniquely positioned as an organization that can facilitate the development of an effective basin-wide indicator, despite these challenges. The IJC should set up the necessary conference calls and workshops to bring together basin-wide representatives from government, tribes, Metis, First Nations, and the Great Lakes Fishery Advisory Consortium to discuss differences and develop the optimal indicator that would work best with the various jurisdictional needs. It would be essential to include management officials in this process to ensure success through the allocation of funds and manpower.

Indicator Development

An assessment encompassing a common set of fish species and chemicals needs to be developed for future indicators. Based on data availability and commonly consumed fish species, such an indicator should be reflect concentrations of chemicals in the edible portions of Great Lakes fish, specifically Lake Trout (*Salvelinus namayacush*), Walleye (*Sander vitreus*), Yellow Perch (*Perca flavescens*), Whitefish (*Coregonus clupeaformus*), and Smallmouth Bass (*Micropterus dolomieu*).

These species are recommended because they are some of the most commonly consumed fish species in the Great Lakes region and because many states and Ontario already collect contaminant data on the concentrations in the edible portions of these fish species. The use of five species would provide more robust data than the existing SOLEC indicators, which are based on only two species.

Contaminants that should be measured include legacy persistent bioaccumulative toxicants, such as PCBs (with limited congeners), total DDT/DDE, mercury, total chlordanes, toxaphene and mirex. Fish consumption advisories and trend data have been used to select chemicals for monitoring. Not all chemicals would be measured in all five lakes and the chemicals may change over time (e.g., mirex levels have decreased and at some point this chemical may come off the list).

When making decisions about consuming fish or issuing fish consumption advisories, the risks and benefits of eating fish need to be considered. Fish are an excellent source of protein and healthy unsaturated fatty acids but may contain contaminants at high enough levels to impact human health. Decisions should also consider the common alternative food sources that would be consumed in place of fish. Alternate foods may have health promoting nutritional value, but may contain harmful contaminants along with saturated fats or sugars.

Beyond this Indicator

To prioritize public health educational or regulatory interventions, HPAB and other authors recommend that an effects indicator be developed that would allow estimation of the human health impact of changing toxic levels within Great Lakes Fish. The effects indicator would expand upon the results of the chemicals in fish indicator by using biomonitoring and health effects data. Additional data sets that should be considered and analyzed include: the size, age, and vulnerability of the population eating fish; the amount consumed; the expected body burden; and the expected human health outcomes. The effects indicator should be validated by human biomonitoring and health/disease data. This indicator should be applicable to both geographic and ethnic communities around each lake and allow for trend analysis, comparisons between communities, and comparisons with alternate food sources.

Summary of Recommendations:

IJC and the governments should provide the resources needed to analyze time trends.

IJC should provide the necessary coordination via workshops and teleconferences to refine the edible fish indicator while recognizing the many differences between jurisdictions.

Further investigation of exposure pathways is merited, not just for fish, including spatial and temporal analysis of biomonitoring data as well as morbidity outcomes specifically due to Great Lakes fish consumption.

References

Anderson, H. A., Amrhein, J.F., Shubat, P., Hesse, J., 1993. Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory. Great Lakes Sport Fish Advisory Task Force.

Awad, E., 2006. The results of the 2003 Guide to Eating Ontario Sport Fish questionnaire. Ontario Ministry of the Environment. Toronto, ON, Canada.

Bhavsar, S.P., Jackson, D.A., Hayton, A., Reiner, E.J., Chen, T., Bodnar, J., 2007. Are PCB levels in fish from the Canadian Great Lakes still declining? J. Great Lakes Res. 33, 592-605.

Bhavsar, S.P., Awad, E., Fletcher, R., Hayton, A., Somers, K.M., Kolic, T., MacPherson, K., Reiner, E.J., 2008. Temporal trends and spatial distribution of dioxins and furans in lake trout or lake whitefish from the Canadian Great Lakes. Chemosphere 73, S158-S165.

Bhavsar, S.P., Gewurtz, S.B., McGoldrick, D.J., Keir, M.J., Backus, S.M., 2010. Changes in mercury levels in Great Lakes fish between 1970s and 2007. Environ. Sci. Technol . 44, 3273-3279.

Bhavsar, S.P., Awad, E., Mahon, C.G., Petro, S., 2011. Great Lakes fish consumption advisories: is mercury a concern? Ecotoxicol. 20, 1588-1598.

Carlson, D.L., De Vault, D., Swackhamer, D., 2010. On the rate of decline of persistent organic contaminants in lake trout (Salvelinusnamaycush) from the Great Lakes, 1970-2003. Envion. Sci. Technol. 44(6), 2004-2010.

Chang, F., Pagano, J.J., Crimmins, B.S., Milligan, M.S., Xia, X.,Hopke, P.K., Holsen, T.M., 2012.Temporal trends of polychlorinated biphenyls and organochlorine pesticides in Great Lakes fish, 1999-2009. Sci. Total Environ. 439, 284-90.

Dellinger, J.A., Dellinger, M., Yauck, J., 2012. Mercury exposure in vulnerable populations: guidelines for fish consumption, in: Bank, M.S. (Ed.), Mercury in the environment: pattern and process. University of California Press, Berkeley, CA, United States, pp. 289-300.

Dellinger, J.A., Moths, M.D., Dellinger, M.J., Ripley, M.P., 2014. Contaminant trends in freshwater fish from the Laurentian Great Lakes: a 20-year analysis. Hum. Ecol. Risk Assess.: An Int. J. 20(2), 461-478. doi: 10.1080/10807039.2012.759475.

Environment Canada (EC), 2013. Fish Contaminants Monitoring and Surveillance Program. http://www.ec.gc.ca/scitech/default.asp?lang=en&n=828EB4D2-1#bank

Gewurtz, S.B., Backus, S.M., Bhavsar, S.P., McGoldrick, D.J., de Solla, S.R., Murphy, E.W., 2011. Contaminant biomonitoring programs in the Great Lakes region: review of approaches and critical factors. Environ. Rev. 19, 162-184.

International Joint Commission (IJC), 2013. Assessment of Progress Made Towards Protecting and Restoring Water Quality Since 1987: 16th Biennial Report on Great Lakes Water Quality. http://www.ijc.org/files/tinymce/uploaded/Publications/16thBE_internet%2020130509.pdf

McCann, P. J., Anderson, H.A., Great Lakes Sport Fish Consortium, 2007. A Protocol for Mercury-Based Fish Consumption Advice: An Addendum to the 1993 Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory. Great Lakes Sport Fish Advisory Task Force.

OMOE, 2013. 2013-2014 Guide to Eating Ontario Sport Fish. Ontario Ministry of the Environment. Toronto, Ontario, Canada. http://www.dhs.wisconsin.gov/eh/fish/fishfs/2007hg_add_final_05_07.pdf

Schaeffer, D.J., Dellinger, J.A., Needham, L.L., Hansen, L.G., 2006. Serum PCB profiles in Native Americans from Wisconsin based on region, diet, age, and gender: implications for epidemiology studies. Sci. Total Environ. 357, 74-87.

SOLEC, 2011. SOLEC Draft Indicator Reports. http://www.solecregistration.ca/en/indicator_reports.asp

Turyk, M.E., Bhavsar, S.P., Bowerman, W., Boysen, E., Clark, M., Diamond, M., Mergler, D., Pantazopoulos, P., Schantz, S., Carpenter, D.O., 2012. Risks and benefits of consumption of Great Lakes fish. Environ. Health Perspect. 120, 11-18.

US EPA, 2010. Great Lakes Fish Monitoring and Surveillance Program. www.epa.gov/glnpo/monitoring/fish/index.html

US EPA, 2011. Persistent Organic Pollutants: A Global Problem, A Global Response. http://www.epa.gov/oia/toxics/pop.html

US EPA, 2013a. Fish Consumption Advisories. http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/index.cfm

US EPA, 2013b. Open Lakes Trend Monitoring Program. http://www.epa.gov/glnpo/monitoring/fish/contaminant_concentrations.html

US EPA, 2013c. Emerging Chemical Surveillance Program. http://www.epa.gov/glnpo/monitoring/fish/health.html

Zhang, X., Gandhi, N., Bhavsar, S.P., Ho, L.S.W., 2013. Effects of skin removal on contaminant levels in salmon and trout filets. Sci. Total Environ. 443, 218-225.

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Appendix 2 - Potential Human Health Indicators as identified during expert consultation

Indicators selected as priority indicators by breakout groups for their topic are shown in bold.

Human Exposure Pathway	#	Indicator Description
Beach and Recreational Water Exposure	1	*E. coli* burden at Great Lakes beaches
	2	Concentration and frequency of human sewage detected at Great Lakes beaches
	3	**Number of Great Lakes beaches that have employed the US or Canadian standardized sanitary survey tool to identify sources of contamination**
	4	**Threshold of E. coli (95th percentile) estimated by qPCR and/or CFU in sand at Great Lakes beaches**
	5	Concentration and frequency of human sewage detected in sand at Great Lakes beaches (using hydrodynamics and a suite of chemical and microbial markers)
Quality of Source Water used for Drinking Water	6	Physical Integrity
		Turbidity
	7	**Biological Integrity - Pathogens**
		Cryptosporidium
		Giardia
		E. coli
	8	**Chemical Integrity**
		Estrogenicity
		Atrazine
		HMF
		Nitrate
	9	System compliance indicator
		Compliance for drinking water treatment
		Total volume of Combined Sewer Overflows
	10	Chemical and Biological Integrity
		Cyanotoxins
Fish Consumption	**15**	**Utilize SOLEC Contaminants in Whole Fish indicator**
	16	**Calculation of fraction of health burden from consumption of fish consumption**
	17	**Calculate economic impact of health burden**
	18	**Advisory effectiveness and potential human exposure**
Human Health Outcomes	19	Breast Milk for Chemicals of Mutual Concern, Basin-Wide and for Vulnerable Populations
	20	Blood orHair analysis for Mercury
	21	Acute Gastrointestinal Illness Related to Recreational Water and Beach Exposure