Indicators of Persistent Toxic Substances in the Great Lakes Basin

A White Paper for the PTS Reduction Strategy Team of the Great Lakes Regional Collaborative

Discussion Draft Version 2 - February 11th, 2005

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Developing strategies for reducing the impacts of persistent toxic substances in the Great Lakes basin requires the ability to define goals and assess progress toward meeting them. Such goals and assessments must be based on indicators that are 1) quantifiable; 2) able to be measured consistently across time and geography; and 3) adequately reflect the state of the environment with regard to the impacts in question.

Defining goals and indicators

A first step in defining indicators is to define the types of goals toward which progress must be indicated. With regard to persistent toxic substances, the Great Lakes Water Quality Agreement has set a goal of "virtual elimination." In addition, Annex 2 to the Agreement defines 14 "impairments of beneficial use" which are to be avoided. Among these 14, many are or may be caused by PTSs, including restrictions on fish and wildlife consumption, degradation of fish and wildlife populations, fish tumors and other deformities, bird or animal deformities or reproduction problems, restrictions on dredging activities, restrictions on drinking water consumption, added costs to agriculture or industry, and degradation of phytoplankton and zooplankton populations. Whereas "virtual elimination" is a long-term goal, these beneficial uses point toward a more proximate goal of reducing emissions and environmental concentrations of PTSs to levels at which they do not pose observable risks to human or wildlife populations.

Tracking progress toward PTS reduction goals requires a thorough knowledge of current and past PTS concentrations throughout the basin. The Great Lakes basin is a large area with diverse environmental characteristics. Lake depths, water and air temperatures, chemical characteristics, ecosystem structure and many other factors vary widely both within and among the five Great Lakes and their connecting waterways. PTSs possess a similarly broad diversity with regard to their physio-chemical properties which determine their behavior in the environment and in biota. Because of these differences in environmental and chemical characteristics, it is problematic to extrapolate observations made for an individual chemical and geographic area to another chemical or geographic area.

Indicators must therefore be evaluated separately for each PTS of concern and with high spatial resolution. At a minimum, indicators should be assessed individually for the five lake basins. Many indicators will require a finer spatial scale of assessment. Indicators to be monitored can be grouped into three categories: 1) concentrations in environmental compartments and biota; 2) releases, emissions and out-of-basin transport; and 3) human and wildlife health impacts and biological markers. Each of these indicators must be assessed at a temporal resolution adequate to determine trends and patterns. Although reporting might be done on an annual or biennial basis, assessments will need to be based on data that adequately resolves seasonal patterns.

Concentrations in environmental compartments and biota

The most direct indicators of progress toward reducing or eliminating PTSs are the amounts of these compounds found in the Great Lakes environment, biota and humans. Environmental compartments for which PTS concentrations should be should be tracked include water, soil, air and

Potential PTS Indicators
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Concentrations in environmental compartments and biota
- Concentration in Great Lakes water
- Concentration in inland waters
- Concentration in sediment
- Concentration in soil
- Concentration in air
- Concentration in phytoplankton, algae and microorganisms
- Concentration in invertebrates
- Concentration in forage fish
- Concentration in piscivorous fish
- Concentration in piscivorous birds
- Concentration in piscivorous mammals
- Concentration in terrestrial plants and animals
- Concentrations in humans

Emissions, loading and out-of-basin transport
- Emissions to water
- Emissions to air
- Emissions to soil
- Atmospheric deposition (dry, wet and gaseous)
- Tributary inputs
- Recovery trajectory
- Contribution of long-range transport

Human and wildlife health impacts and biological markers
- Predicted impacts on microorganisms
- Predicted impacts on invertebrates
- Predicted impacts on forage fish
- Predicted impacts on piscivorous fish
- Predicted impacts on piscivorous birds
- Predicted impacts on piscivorous mammals
- Predicted cancer impacts on human
- Predicted non-cancer impacts on humans
- Sediment toxicity by laboratory test
- Estrogenic / Androgenic activity of sediments
- Additional biological markers

Each of the above indicators would require data collection and assessment that adequately covers: 1) all PTSs of concern; 2) the full geographic scope and diversity of the Great Lakes basin; and 3) a temporal scale and resolution adequate to monitor trends and observe patterns.

sediments, many of which can be divided into multiple sub-components. Although these compartments contain the majority of chemical mass, it is the biota and human concentrations that are ultimately of concern.

Biota concentrations are directly impacted by environmental concentrations. However, significant variations and uncertainties are present in this relationship do to the diverse and complex ecosystem structures and exposure routes involved. It is therefore desirable to have an indicator of PTS concentrations at each of many representative portions of the Great Lakes ecosystem and aquatic foodchain, including—but not limited to—phytoplankton, algae, and microorganisms; invertebrates; forage fish; piscivorous fish, birds, and mammals; and humans.

Emissions, loadings and out-of-basin transport
Tracking concentrations in the ambient environment and biota will provide information on current and past levels. However, to gain information on how these levels are likely to change in the near and somewhat distant future, it is important to have information on PTS emissions to the water, air and soil of the Great Lakes region; the PTS loadings to the lakes form all relevant routes; and the atmospheric transport of PTSs to the Great Lakes region from further abroad. Tracking of these characteristics for each PTS will enable mass balances to be established and recovery trajectories to be determined under various future loading scenarios. These indicators are important for informing management decisions.

Human and wildlife health impacts and biological markers
Additional indicators include observations and predictions of the actual impacts of PTSs on human and wildlife receptors and markers that illustrate the biological response to individual chemicals or mixtures. Indicators of impacts can be divided into two categories: prediction of impacts and observation of impacts. The former category involves the collection of environmental or biota concentrations and an estimation of impacts based on known dose-response models. In this way, the impacts of chemical concentrations can be determined and compared both between chemicals and over time. The second category involves the collection of environmental or biota

concentrations along with indicators of ecosystem, wildlife or human health and assessing the correlation of the two categories.

In addition to indicators of health impacts, indicators of biological or physiological response to PTSs are desirable in a number of cases. Whole sediment toxicity testing is an example of such an experimental indicator. In addition to whole organism toxicity tests, recent advances in cellular biotechnology have made available a wide variety of tests for biological response. Using such tests, sampled environmental media, such as water or sediments, can be tested for their ability to cause adverse cellular responses, such as estrogenic and androgenic gene expression or induction of liver cytochromes. These types of tests have an advantage in that they can account for the toxicological interactions of the complex mixtures of chemicals present in the actual environment.

Monitoring, modeling and information management

Each of the indicator types described above require information to be gathered to support their assessment. In many cases, this will require monitoring of contaminants in the ambient environment and biota. In some cases, modeling can supplant a portion of this monitoring by using known chemical and ecosystem parameters—such as partition coefficients, bioaccumulation factors and foodchain structure—to fill gaps in monitored data. However, monitoring efforts must be sufficiently intensive to help formulate, validate and inform these models. In addition to monitoring and modeling data, many other information types are required for various indicators, including emissions information and toxicity data. To allow assessment of comparable indicators across time and space, consistent data collections and management protocols are an important consideration.

Current Indicators - SOLEC

The major mechanism for reporting on environmental conditions in the Great Lakes is the State of the Lakes Ecosystem Conference (SOLEC) and associated reports. Under this collaborative effort of the U.S. EPA and Environment Canada, a conference is held and a report issued on a biennial basis, each reporting on nearly 100 indicators of ecosystem status in the Great Lakes basin. The indicators included on the 2004 revised list which are most directly related to PTSs are listed in the following table. There are many additional indicators that impact or are impacted by PTSs, but less directly.

ID	SOLEC Indicator Title	2000 Status	2001 Status	2002 Status	2003 Status
114	Contaminants in Young-of-the-Year Spottail Shiners	NR	NR	Mixed, improving	Mixed, improving
115	Contaminants in Colonial Nesting Waterbirds	Good	Good	Mixed, improving	Mixed, improving
117	Atmospheric Deposition of Toxic Chemicals	Mixed, improving	Mixed, improving	Mixed	Mixed
118	Toxic Chemical Concentrations in Offshore Waters	Mixed	Mixed	Mixed, improving	Mixed, improving
119	Concentrations of Contaminants in Sediment Cores	NR	NR	Mixed, improving	Mixed, improving
121	Contaminants in Whole Fish	New indicator†			
3515	Cosmetic Pesticide Controls	New indicator†			
4177	Chemical Contaminants in Human Tissue	NR	NR	NR	NR

4201	Contaminants in Sport and Commercial Fish (*Contaminants in Edible Fish Tissues 4083)	Mixed, improving	Mixed, improving	Mixed, improving	Mixed, improving
4506	Contaminants in Snapping Turtle Eggs	Mixed	Mixed	Mixed	Mixed
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, improving	Mixed, improving	Mixed, improving	Mixed, improving
8142	Sediment Available for Coastal Nourishment	NR	NR	NR	NR
8147	Contaminants Affecting the American Otter	NR	Insufficient data	Mixed	Mixed
TBD	Contaminant Accumulation in Coastal Wetlands	New indicator†			
3514	Commercial/Industrial Eco-Efficiency	New indicator†			
7057	Energy Consumption	NR	NR	Mixed, deteriorating**	Mixed, deteriorating**
7064	Vehicle Use (*Mass Transportation 7012)	NR	Insufficient data	Mixed	Mixed

* Replaced by new indicator in 2004
**Assessment is for Lake Superior only
† Indicator Added in 2004

The current list of SOLEC indicators includes many, but certainly not all, indicators identified above as desirable for tracking progress toward reducing and eliminating PTSs in the Great Lakes basin. Some notable omissions are the bottom portions of the food-chain (phytoplankton, microorganisms and invertebrates), terrestrial ecosystems, emission levels, tributary loadings, long range transport and biological markers (estrogen activity, etc.). Expansion of the SOLEC PTS indicator list to fill such gaps will in many cases require significant additional monitoring, modeling and data collection. In addition to expanding the list, the current indicator suite should be evaluated to determine the adequacy of their coverage of temporal and spatial scales and chemicals of concern.

Current Indicators - Other

In addition to SOLEC process, there are other efforts in the region to assess and report on indicators of PTS contamination in the Great Lakes. One additional effort is the Great Lakes Environmental Indicators (GLEI) program being conducted by the Natural Resources Research Institute at University of Minnesota Duluth, in cooperation with numerous partners around the region. Among the numerous indicators currently being developed by this program, two are directly related to PTSs. One of these indicators assesses the risk of larval fish to PAH contamination, particularly with regard to increased risk due to photo-activation of these compounds in areas with high UV penetration. The second indicator associates elevated levels of specific chemicals with increased expression of an estrogen-induced protein in male fish.