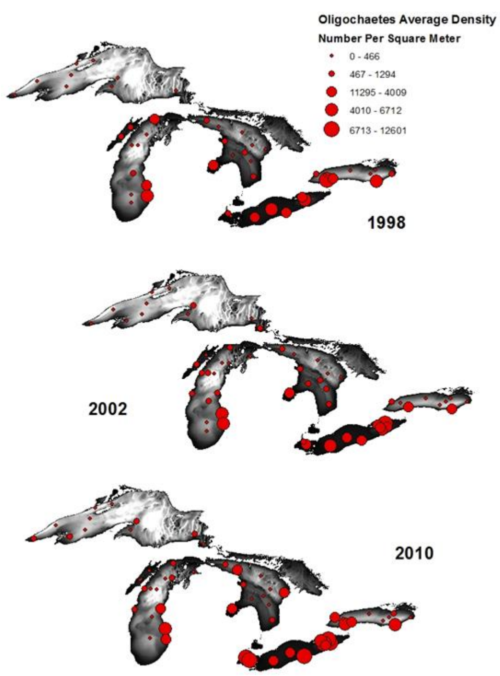
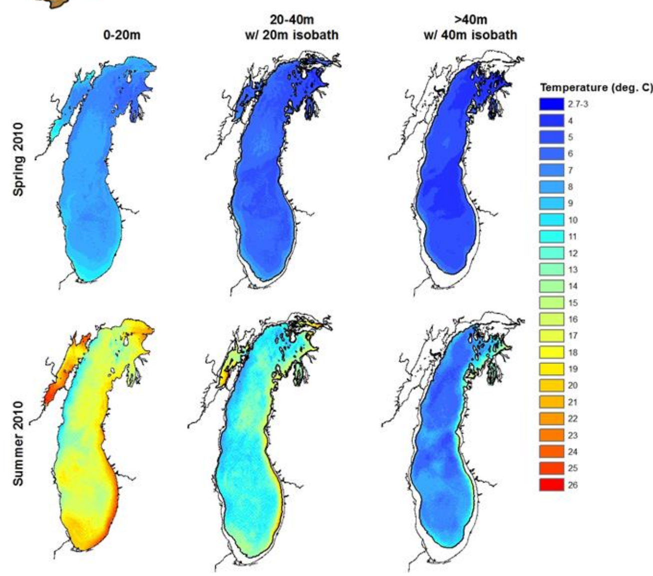
Data Availability Assessment: IJC Apex Ecological Indicators for Evaluation of Progress toward Restoring the Great Lakes





Images courtesy of
Great Lakes Aquatic Habitat Framework (GLAHF)

Report prepared for the International Joint Commission (IJC)

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4/30/2013

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Executive Summary

Contract work description: The International Joint Commission (IJC) contracted with Catherine Riseng and Beth Sparks-Jackson to research and prepare a summary report on what data are available, what data gaps exist, and what data collection programs are needed for 16 apex environmental indicators that will be used by the IJC to evaluate progress toward restoring the Great Lakes.

Data assessment reports: Data availability, status, and recommendations for each indicator have been summarized and described following a standard format: indicator summary, indicator details, data evaluation, references, a list of relevant State of the Lake Ecosystem Conference (SOLEC) indicators, and a table detailing data applicable to the indicator. The indicator summary section provides a brief description of the indicator, indicator spatial and temporal coverage, and data processing needs. Indicator details provides a detailed assessment of the indicator components/subcomponents, calculations, spatial and temporal units for analyses, the combination of components/subcomponents, and how progress will be measured by the indicator. The data evaluation portion addresses the sufficiency of available data, additional data needs, and the anticipated effort required for data calculation and processing with respect to the draft indicator. The list of relevant SOLEC indicators identifies 2009 reports and provides links to draft 2012 SOLEC indicators. The table at the end of each data assessment report includes information about data holders and contact information, data format, general and specific information about the data, an assessment of the accessibility of the data, and spatial and temporal coverage of each data source.

Challenges and solutions: We encountered some common challenges during development of the data assessment reports. Some draft indicators lacked a sufficiently detailed description of what the indicator is intended to measure. To solve this challenge, if possible, we contacted the draft indicator's author for clarification. If the author was unavailable, we have suggested specific indicator components based on the data available or simply identified the data that are available. Another challenge was the availability of raw versus summarized data. When summarized data was applicable to the draft indicator we noted the sources for the raw data but targeted our data assessment on summarized data. Lastly, we found some data were available from numerous independent sources and these data varied greatly in spatial and temporal coverage. We targeted efforts at data sources that could provide standardized data across the Great Lakes Basin and noted additional data sources that could supplement the larger data sets.

Because of our comprehensive attention to all 16 apex indicators, we were in a unique position to identify issues both within and between indicators. We identified one ill-fitting component and two instances of the same components included in more than one draft indicator. In the water level indicator, the final component is specified as "a measure of the effects of water level on Great Lakes ecosystems". This component is fundamentally different from and fits poorly with the other four components in this indicator. Council of Great Lakes Research Managers (CGLRM) members questioned whether this component might fit better in the coastal wetlands indicator; however, the type and organization of data for the coastal wetland indicator precludes including the effect of water level component in the coastal wetlands indicator. The importance of this component and whether it can be modified to better fit with the other water level components requires further discussion. The original drafts of the indicators Persistent Bioaccumulative Toxic (PBTs) Chemicals in Biota and Abundance & Distribution of Fish-Eating and Colonial Nesting Birds both include components built on contaminant concentration data for Herring Gulls and Bald Eagles. We feel this component fits best in the bird indicator and the indicator titles should be changed to PBTs in Fish and Biological Integrity of Fish-Eating and Colonial Nesting Birds accordingly. Both the Harmful and Nuisance Algae and Lower Trophic Food Web Productivity/Health indicators suggest including a Plankton Index of Biotic Integrity. As both of these draft indicators need refinement, we suggest using this component in only one of the indicators, but we do not suggest which one.

<u>Common data needs and concerns:</u> We identified three frequent data needs or concerns. First, we found numerous differences between US and Canadian data collection/processing programs. The data available for calculation of the Land Cover and Conversion Rate indicator illustrates this problem. The US has two types of presettlement land covers and a program in place to produce consistent, modern national land cover maps every five years. In Canada presettlement mapping is limited to a small portion of Ontario and land cover maps with highly variable spatial extents are produced by disparate organizations; these maps are rarely updated. For other indicators, differences in sampling and processing methodology present challenges for combining US and Canadian collected data. Second, ongoing monitoring of the environmental health of the Great Lakes requires regular production of standardized data. Although many existing programs through Environment Canada, the Land Cover Institute, the Great Lakes National Program Office, and the Great Lakes Coastal Wetland Consortium (GLCWC) satisfy this need, other efforts, such as mapping of shoreline habitat, do not. Third, there is a general bias toward data collection in offshore areas of the Great Lakes. This is especially true for water quality, phytoplankton and zooplankton, and benthic monitoring programs. An exception to this offshore bias is the GLCWC, a large, binational coastal wetland monitoring program.

<u>Caveats</u>: Due to contract time constraints, we were not able to exhaustively explore and assess the data availability and quality of every possible source of data. We focused our effort on spatially and temporally comprehensive programs with documented quality control programs. We acknowledge there are likely data sources we have omitted in the data assessment reports.

Summary: Indicator calculation and definition

Indicator:	Can indicator be calculated with existing data?	Does the indicator definition need to be modified?
Land Cover and Conversion Rate	Yes for USA, No for Canada (data are insufficient in Canada but could be developed)	Yes: Indicator is sufficiently detailed but may require changes due to lack of data
Tributary Physical Integrity	Yes	No
Groundwater Contamination	Yes	Yes: More detailed definition of indicator and choice of spatial scale of analyses required
Shoreline Alteration Index (SAI)	Yes: for physical component only and if maps of shoreline structure continue to be developed	Depends: Biological component needs to be developed, but physical component can be calculated now
Extent, Composition, and Quality of Coastal Wetlands	Mostly: Summary and two subcomponents currently in development	No
Water Temperature	Yes	Yes: More detailed definition of indicator required
Water Level	Mostly: Can be calculated for all but one component	Yes: More detailed definition of indicator required
Atmospheric Deposition of Toxic Chemicals	Yes	Yes: Use of raw versus summarized data and analytical techniques need to be chosen
Chemicals of Mutual Concern in Water	Somewhat: few data for Lake MI, data mostly offshore, current monitoring program under review	Yes: Specific chemicals and analytical techniques need to be chosen
Phosphorus Loads and In-Lake Concentrations	Somewhat: Requires development of DRP loads/model and additional nearshore monitoring	Minor changes: How components will be combined needs to be addressed
Invasive Species	Yes: For all but two subcomponents; recommendations for improved monitoring included	Yes: components “impact of select AIS” requires specificity and biomass of AIS requires refinement
Harmful and Nuisance Algae	No: Largely limited to Lakes Erie and Ontario; data are only available for some components	Possibly: Indicator should be reviewed after a full analysis of available data is completed and the indicator is fully developed
Lower Food Web Productivity/Health	Yes: For some components, especially measures of health	Yes: Goal of indicator may need to be reassessed and individual metrics need to be chosen

Indicator:	Can indicator be calculated with existing data?	Does the indicator definition need to be modified?
Fish Species of Interest	Yes	Minor changes: Inclusion of additional metrics may improve indicator
PBTs in Fish	Yes for top predators, mostly for forage fish	Potentially minor to moderate changes: If desired, an effects based indicator needs to be developed
Fish Eating and Colonial Nesting Birds	Yes, although it is unclear if effects models already exist or need to be developed	Minor changes: A more detailed definition of the effects model is required

Individual Indicator Data Assessment Reports

Land Cover and Conversion Rate

Summary:

The Land Cover Indicator consists of the Land Cover Conversion Index and Fragmentation Index computed from spatially-explicit comparisons of historic baseline natural land cover and current land cover over time using a geographic information system (GIS).

Spatial coverage: Includes the five Great Lakes Basins. Analyses will calculated within selected river watersheds (i.e. scale is HUC 8/Tertiary) and summarized by Lake Basin.

Temporal coverage: Two possible pre-settlement covers are available for the United States of America (USA), but Canadian presettlement data is limited to four areas within Ontario. Modern land cover for the USA is available from 1992-2013 on a five-year rotation. Modern land cover in Canada (CAN) is limited to early 2000s. Crosswalked USA and CAN maps are available for 2000/2001.

Data processing needs: This indicator cannot be computed as drafted because of the lack of comprehensive presettlement maps for Canada. If watersheds in Southern Ontario are included in analysis, there needs to be an expansion of the crosswalk of land cover types to include Southern Ontario Land Resource Information System (SOLRIS). An automated GIS process is needed to calculate land-use conversion and land cover fragmentation metrics in each watershed.

Indicator Details:

The Land Cover Indicator consists of the Land Cover Conversion Index and Fragmentation Index computed from spatially-explicit comparisons of historic baseline natural land cover and current land cover over time using GIS. The capital letters, such as A, A', B, C1-C4, D-F, and G, in the last column of the table below represent the letters in the first column of the Indicator Data table on pages 11-16. Subsequent data assessment reports also use this reference system.

Components:	Component specifications:	Data source: (see data table)
Land Cover Conversion Index	*Metrics: in %* 1. Natural land cover type unchanged 2. Minor change in natural land cover type (still natural land cover) 3. Major change in natural land cover type (still natural land cover) 4. Major change to anthropogenic non-urban or industrial land use (restorable) 5. Major change to urban or industrial land use ("unrestorable")	Historic/Natural Land Cover: *CAN*: A and possibly A' *USA*: B or C1-C4 Modern Land Cover: *CAN*:D-F (depends on choice of watersheds) *USA*: G

Components:	Component specifications:	Data source: (see data table)
	6. Changed to water	
Fragmentation Index	*Metrics: in %* 1. Average number of patches for each natural land cover class 2. Average patch size for each natural land cover class	Modern Land Cover: same as above

Calculations: Requires spatially explicit analysis of historic/natural land-use/cover maps and current land cover maps. Percentages for each of these metrics are calculated within a, yet to be determined, nested set of watershed and/or ecoregional assessment units that provide a local to basin-wide perspective on spatial and temporal changes in natural land cover. We suggest using the Great Lakes Aquatic Habitat Framework (GLAHF) derived watersheds (similar to CAN tertiary watersheds and USA HUC 8). Because a standardized process delineates both the USA and CAN watersheds, these are the most consistent watersheds developed for the Great Lakes Basin.

Combination of components: Each of these metrics provides information that is of interest to managers, yet there is a need for a robust and meaningful approach to aggregating these metrics into an overall index. Aggregation into overall index is yet to be determined. For the Land Conversion Index we suggest an approach that assigns increasing scores to levels of change, (i.e. 0 to metric 1, 1 to metric 2,…, 4 to metric 5, 0 to metric 6), multiplying each score by the percent in each metric, and summing the score and dividing by 100.

Spatial and temporal coverage: We suggest calculating the index for all major USA and CAN watersheds for each lake (USA for Lake MI only). Spatial coverage largely depends on data availability. Land cover in the USA is updated every five-years by the National Land Cover Institute.

Measurement of progress: Either decreases in land cover conversion index scores or declines in the rate of conversion would signify progress. Decreased fragmentation of natural land cover is desirable (evidenced by fewer, larger patches).

Data Evaluation:

Sufficiency and accessibility: Both the land conversion and fragmentation portions of this indicator lack sufficient data to calculate the indicator.

Presettlement land cover: Presettlement or natural land cover data exists for four locations in Ontario. These mapped areas span only two complete tertiary watersheds that include Toronto and Hamilton. Two of the areas are extremes on a development spectrum, the extremely developed Greater Toronto Area and the largely preserved Algonquin Park. To calculate the indicator, targeted development of presettlement maps would need to be generated (i.e. for selected watersheds). As a surrogate for presettlement maps, it was suggested that an early land-use map may suffice. The earliest available land cover for Canada we were able to find is from 1966 and does not include all of Ontario.

In contrast, two types of presettlement data exist for the USA: LANDFIRE biophysical settings and presettlement maps based on historical land surveys. LANDFIRE biophysical setting have the advantage of being developed following a standard protocol for the contiguous USA, i.e. no crosswalking between different maps required. However, biophysical setting maps are modeled data. They are based on both the current biophysical environment and an approximation of the historical disturbance regime. Map units are based on NatureServe's Ecological Systems classification and represent the natural plant communities that may have been present during the reference period. In contrast, most state presettlement maps are based on actual land survey records. However, these maps also present difficulties. Available state maps (i.e. MI, WI, MN, and OH) cover only a portion of the U.S. Great Lakes basin and contain different land classes for each state. Some simplification of the classes and a crosswalk to standardize classes between states would need to be developed.

"Modern" land cover: Sufficient, comparable data exist in the USA, however, land cover data in Ontario is limited to the early 1990s. Land cover maps in the USA are on a 5 year rotation; Ontario does not appear to have any plans to update land cover maps. It is worth exploring whether Canadian Conservation Authorities have developed more recent land cover maps targeted to specific areas.

Additional needs: Described in detail above. Need presettlement and current land-use maps for Canadian side of the Great Lakes Basin.

Required data processing and calculation effort: Many steps are required to calculate the Land cover and conversion index. Major watersheds for analysis should be identified. We suggest use of GLAHF developed watershed boundaries (excluding interfluves) as these watersheds are consistently defined across the entire Great Lakes Basin. Secondly, maps to be compared need to have identical grids so that change within each pixel can be quantified. This will require polygon shapefiles to be converted into grids. Third, each of the land cover conversion metrics classes need to be defined by specific transitions in land cover, e.g. assign a class for each specific transition. Finally, changes in the status of individual pixels need to be aggregated to the watershed and Lake Basin, or other desired spatial unit.

Relevant 2009 SOLEC Indicators:

#7002 Land Cover/Land Conversion

Indicator Data:

Suggested watersheds:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	GLAHF watersheds	Danielle Forsyth, 734-663-3554 ext. 11755, dforsyth@umich.edu or Catherine Riseng, Assistant Research Scientist, 734-763-9422, criseng@umich.edu	No constraints	Watersheds developed using the same process for CAN and USA tributaries to the great lakes. Interfluves will likely need to be excluded (simply specify a size threshold).	Similar in scale to CAN National Hydrography Network Tertiary watersheds and USA NHD HUC 8. Can be scaled up into larger watersheds.

Presettlement/natural land cover:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Ontario Ministry of Natural Resources: Science and Information branch, including Southern Science and Information Section	To access existing presettlement maps: Danijela Puric-Mladenovic, Senior Analyst, Settled Landscapes (705) 755-3262, danijela.puricmladenovic@ontario.ca To discuss expanding to other areas: Silvia Strobl, Coordinator, (705) 755-3208, silvia.strobl@ontario.ca	Will share with IJC; Seeking funding to continue development of presettlement maps across southern Ontario.	Limited area mapped: Greater Toronto area (including York, Peel, Hamilton, and Halton regions and the Credit Valley Watershed), Temagami, and Algonquin Park. Vegetation classes used differ between areas mapped.	Presettlement maps based on statistically derived models that map tree species distributions and landscape characteristics as they were prior to European Settlement; relies heavily on historical surveyors’ records.
A’	1966 Canadian Land cover map	Not applicable	No access or use constraints	Only a small selection of the country was produced.	North American Datum of 1927

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	available from GeoGratis		Five shapefiles for portions of Ontario available for free at http://geogratis.cgdi.gc.ca/geogratis/en/option/select.do?id=96461240-ECEE-38D9-9318-7638F9D0A9D1	The coverage is divided by NTS 1:50,000. Metadata lacks details about how the maps were created and digitized.	Fourteen classes of land use represent the land use capability map at a scale of 1:250,000.
B	LANDFIRE biophysical settings (developed by Forest Service, USGS, TNC, and Dept. Interior 30m Raster digital data	http://www.landfire.gov/NationalProductDescriptions20.php	Freely downloadable at http://landfire.cr.usgs.gov/viewer/ Metadata: http://landfire.cr.usgs.gov/distmeta/servlet/gov.usgs.edc.MetaBuilder?TYPE=HTML&DATASET=f4q	The Biophysical Settings (BpS) layer represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on both the current biophysical environment and an approximation of the historical disturbance regime. The actual time period for this data set is a composite of both the historical context provided by the fire regime and vegetation dynamics models and the more recent field and geospatial data used to create it.	Suggested versions: LF 2008 "Refresh"/LF_1.1.0: Updated LF_1.0.5 products to reflect vegetation changes and disturbances 1999 – 2008. (Sometime in 2013 version LF 2010/LF_1.2.0 may be available and will reflect vegetation change and disturbance 1999 -2010.) 2008 refresh contains 356 vegetation classes in the continental USA. Map Projection: Albers Conical Equal Area Datum: North American Datum of 1983
C1	MI Natural Features Inventory: MI 1800s vegetation cover	Rebecca Rogers, 517-241-4249, rlr@msu.edu or Edward Schools, 517-373-0798, schools@msu.edu	Free by request from MNFI Polygon shapefile	Vegetation map of MI circa 1800s interpreted from General Land Surveys; Biologists from MNFI developed a methodology to translate the notes of the	Spatial Coverage: MI 27 vegetation classes

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				GLO surveys into a digital map.	
C2	MN DNR: 1895 MN vegetation cover	Tim Loesch, GIS Manager DNR-MIS 500 Lafayette Road, Box 11 St. Paul, MN 55155-4011, 651-259-5475	Polygon shapefile Metadata and download information at http://deli.dnr.state.mn.us/metadata/pveg_mrschpy1.html Data are unrestricted with regards to access and use of the data is constrained only by the DNR GIS Data License Agreement.	Presettlement vegetation of Minnesota based on Marschner's original analysis of Public Land Survey notes and landscape patterns. Marschner compiled his results in map format, which was subsequently captured in digital format. Caveats: This shapefile has significant omissions. Many small polygons have not been captured. Some one by one-half degree blocks in the central portion of the state have large numbers of missing polygons. The data also exhibits significant positional off-sets, of up to one thousand feet in places. Use with caution.	17 vegetation classes Map projection: Transverse Mercator Datum: NAD83
C3	University of Wisconsin at Madison: Original Vegetation Cover of Wisconsin	Wisconsin Dept. of Natural Resources (DNR)	Polygon shapefile Available for free from DNR FTP site: ftp://dnrftp01.wi.gov/geodata/orig_veg_cover/ Metadata available at: http://dnr.wi.gov/maps/	This is a polygon shapefile derived from a 1:500,000-scale map showing the original, pre-settlement vegetation cover in Wisconsin. The original vegetation cover data was digitized from a 1976 map created from land survey	16 vegetation classes Map projection: Transverse Mercator Datum: D_North_American_1983_HARN

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			gis/documents/orig_vegetation_cover.pdf	notes written in the mid-1800s when Wisconsin was first surveyed.	
C4	Natural Vegetation of Ohio, at the Time of the Earliest Surveys Ohio Department of Natural Resources	Steve Lewis, Coastal Lands GIS Specialist, 419-609-4101, steve.lewis@dnr.state.oh.us	Polygon shapefile Available for free download at http://www.dnr.state.oh.us/website/ocm_gis/mapviewer_app/	Mapped in 1966 by Robert B. Gordon and digitized in 2003 by the ODNR Office of Coastal Management	Spatial coverage: Statewide data were clipped with the Lake Erie watershed boundary Digitization of 1:500,000 scale map 13 land cover/vegetation classes

"Modern" Land covers:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
D	Ontario Provincial Land Cover: 2002	Through GLAHF: Danielle Forsyth, 734-663-3554 ext. 11755 dforsyth@umich.edu or Catherine Riseng, Assistant Research Scientist 734-763-9422, criseng@umich.edu)	Available from GLAHF GLAHF accessed the data through the Ontario Geographic Data Exchange (OGDE) program as a part of the Land Information Ontario (LIO) data warehouse. TIFF format with .shp layer index correlating to documentation for vintage of data.	The Ontario Ministry of Natural Resources Provincial Land Cover Raster includes 28 land cover classes and spans the entire landmass of Ontario. The Ontario Land Cover data was derived from digital, multispectral LANDSAT Thematic Mapper data. The inventory represents the landscape from 1999 to 2002. It is important to note that the Provincial Land Cover Data Base is generalized land	USE SOLRIS LANDCOVER 2002 FOR SOUTHERN ONTARIO. 28 land cover classes (has been crosswalked by GLAHF to NLCD 2001) The data is based on UTM, North American Datum 1983, Zone 15, 16, 17 and 18.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				cover. It is NOT appropriate for detailed site-specific large scale studies.	
E	Southern Ontario Land Resource Information System (SOLRIS): 2000-2002	Ian Smyth, Remote Sensing Specialist, Ontario Ministry of Natural Resources Science and Information Branch, ian.smyth@ontario.ca	The final version of SOLRIS (v1.2) is made available through the Ontario Geographic Data Exchange (OGDE) as part of the Land Information Ontario (LIO) data warehouse. (http://www.mnr.gov.on.ca/en/Business/LIO/index.html) Should be available free of charge but must have LIO access to download. Available in shapefile and ESRI grid formats.	SOLRIS was created by integrating geospatial databases of forests and wetlands with topographic maps, aerial photos and satellite imagery for seamless coverage of Ecoregions 6E and 7E. Note: Although released in 2008, and often associated with that year, the land cover is from 2000-2002.	23 land cover classes The shape file coordinate system is in MNR Lambert Conformal Conic. ESRI grid coordinate system is in UTM zone 17, NAD 83 and UTM zone 18, NAD83.
F	Ontario Conservation Authorities	Bill Taylor (wdtaylor@uwaterloo.ca) suggested that his graduate students may know which conservation authorities have updated data	Some conservation authorities websites include displays of available data, however a login might be required to access A full assessment of the availability and accessibility of Conservation Authority land-use maps was not	Considerable GIS processing is required to integrate/crosswalk data from individual conservation authorities into a basin-wide land-use database.	Each potential data source has not been specifically assessed.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			completed; Bill Taylor's graduate students may be able to help identify potential data sources		
G	USGS: National Land Cover Datasets: http://www.mrlc.gov/finddata.php	None (For crosswalked Ontario Provincial Land Cover 2000 and NLCD 2001 contact Danielle Forsyth, 734-663-3554, ext. 11755, dforsyth@umich.edu or Catherine Riseng, Assistant Research Scientist, 734-763-9422, criseng@umich.edu)	In zipped files that can be downloaded for free from: 1992: http://www.mrlc.gov/nlcd92_data.php 2001: http://www.mrlc.gov/nlcd01_data.php 2006: http://www.mrlc.gov/nlcd06_data.php	All are 30m resolution grids Contain land cover, %impervious, and tree canopy density (except 2006). NLCD92 is based primarily on the unsupervised classification of Landsat Thematic Mapper (TM) circa 1990's satellite data. NLCD2001 is based primarily on the unsupervised classification of Landsat Enhanced Thematic Mapper+ (ETM+) circa 2001 satellite data. NLCD2006 is based primarily on the unsupervised classification of Landsat Enhanced Thematic Mapper+ (ETM+) circa 2006 satellite data.	All classification systems are modified from the Anderson Land Cover Classification System. 1992 has 21 land cover classes; 2001 and 2006 have 16 land cover classes. Should NOT try to compare 1992 and 2001 data. If this comparison is desired use the 1992/2001 retrofit land cover change product. NLCD2006 also quantifies land cover change between the years 2001 to 2006. Note: NLCD 2011 is currently in production and is expected to be released in Dec. 2013.

Tributary Physical Integrity

Summary:

The Tributary Physical Integrity indicator consists of two components, a measure of hydrologic alteration (requires daily discharge measurements) and a measure of connectivity to receiving waters (requires barrier locations and calculation of accessible and total main stem river lengths).

Spatial coverage: Hydrologic alteration can be calculated at gauged watersheds across the Great Lakes Basin and Connectivity can be calculated within watersheds or across watersheds within each of the 5 Great Lake Basins.

Temporal coverage: Hydrological Alteration uses rivers with gauges with a minimum 20-year history to present; Connectivity is based on current tributary barriers and should be recalculated as changes in dam/barrier status occur.

Data processing needs: IJC will need to develop an automated process to calculate hydrologic alteration for each gauged watershed for each year. Required stream lengths for connectivity based on major dams are already calculated for USA watersheds; The CAN map of dams/barriers may need updating and all main stem stream lengths need to be calculated. Both USA and CAN dam/barrier maps need to be updated with the removal/addition of dams. Data is organized and compiled for large dams, but disparate for small dams and other barriers.

Indicator Details:

The Tributary Physical Integrity indicator consists of two components, a measure of hydrologic alteration and a measure of connectivity to receiving waters.

Components:	**Component specifications:**	**Data source: (see data table)**
Hydrologic Alteration (within a watershed):	R-B Index = $\frac{\sum_{n=1}^{365} \lvert q_n - q_{n-1} \rvert}{\sum_{n=1}^{365} q_n}$ Where q is average daily discharge and n is the day of the year	A & B

Components:	Component specifications:	Data source: (see data table)
Connectivity to receiving waters (*within* a watershed):	$C_{rw}= (L_{rw}/L_m) \times 100$ Where C_{rw} is the percent of the naturally accessible mainstem channel length within a watershed that is connected to the receiving water body, L_{rw} is the length of mainstem accessible from receiving water body, and L_m is the total length of the river mainstem that is naturally accessible.	"Current" barriers: C-F Updates to barriers: G & H
Connectivity to receiving waters (*across* watersheds within Lake Basin):	Watershed Connectivity$_{rw}$ = $\frac{\sum_{n=1}^{ntot} L_{rw_n}}{\sum_{n=1}^{ntot} L_{m_n}} \times 100$ Variables same as above and n denotes each watershed included in analysis and n_{tot} is the total number of watershed included in analysis within a lake basin.	"Current" barriers: C-F Updates to barriers: G & H

Calculations:

<u>*Hydrologic Alteration*</u>: The Richards-Baker Flashiness Index (R-B Index) is a quantitative measure of the hydrologic response of a stream or river to changing precipitation/runoff events. The R-B Index is calculated using sum of consecutive daily flow differences on an annual basis (i.e., the sum of the absolute values of day-to-day changes in mean daily flow) divided by total discharge over that time interval (Baker *et al.* 2004).

<u>*Connectivity*</u>: This indicator quantifies the percent of the naturally accessible mainstem channel length that is connected to the Great Lakes. The indicator can be calculated for a single tributary (or watershed) or multiple watersheds. The indicator can be applied to watersheds of any size and is dimensionless. Within a watershed C_{rw} is the percent of the naturally accessible mainstem channel length that is connected to the Great Lakes. Within a lake basin, Watershed Connectivity$_{rw}$ is a multi-river summary of river lengths connected to the Great Lakes as a percentage of naturally accessible mainstem channel lengths.

Combination of components: Although these components could be combined into a single measure for each watershed, we recommend analyzing the two components separately. Large dam removals and new construction are generally rare, thus the tributary connectivity component may not substantively change over short time periods, especially if scaled at the Lake Basin. However this assumption will need to be revisited, as more dams are targeted for removal. In Michigan alone, recent State funding will support the second phase of the Boardman River dam removal project, the Kalamazoo River and Otsego Township dam repair project, the Ionia Conservation District's Lyons dam removal project, the

Shiawassee Town Dam removal, the Vassar dam removal project, and the Sunday Lake Dam spillway gate replacement.

Spatial and temporal coverage: The hydrologic alteration component, as measured by the R-B Index, is best used to track changing hydrologic responses of streams through time by calculating the relative change in the R-B Index over time on a watershed-by-watershed basis across the Great Lakes basin. An assessment of hydrologic alteration at the broader Lake Basin unit could be made through noting changes in the distribution of trend categories (see measurement of progress section) over time. Historical R-B Index values should be established for watersheds with long monitoring histories and annual calculations should be updated every three to five years (or the interval between indicator measurements). The connectivity component can be measured at the watershed scale or summed across a Lake Basin. The connectivity component will only change when changes in river accessibility occur, such as when a dam is removed or added. These are rare events so the connectivity portion of the indicator should be recalculated as necessary for affected watersheds/lake basins.

Measurement of progress:
*Hydrologic alteration***:** Trends in the R-B indicator (i.e. relative increases or decreases) would be reported on a watershed-by-watershed basis across the Great Lakes basin. Changes in the R-B Index can be displayed graphically to illustrate trend or mapped geospatially to show geographic changes in the distribution of flashiness. In almost all cases, reductions in the R-B Index (i.e. negative change values) would be considered desirable. Conversely, increases in the R-B Index (i.e. positive change values) would be considered undesirable. For example, watersheds undergoing rapid urbanization would typically show increases in flashiness due to increased channelization and imperviousness. The following trend categories are suggested for the R-B Index:

Excellent - decreasing trend in flashiness (negative values - > 20% change in Index value)
Good - decreasing trend in flashiness (negative values - < 20% change in Index value)
Neutral – no trend in flashiness (zero change values)
Poor - increasing trend in flashiness (positive change values)

Connectivity: Values range from 0 to 100. A value of 0.0 represents a main stem channel that is not connected to the receiving water body (no connectivity) and a value of 100 represents a main stem channel with unimpaired connectivity. These values are also applicable to watershed connectivity (to receiving waters). In almost all cases, increases in watershed connectivity would be considered desirable (impediments to sea lamprey infestation are the exception). Conversely, decreases in watershed connectivity would be considered undesirable. The following ranking categories are suggested for the watershed connectivity indicator:

Excellent – 90% to 100% (unimpaired connectivity)
Good – 70% to 90%
Fair – 50% to 70%
Poor – less than 50% (impaired connectivity)

Data Evaluation:

Sufficiency and accessibility:
Hydrologic Alteration: Long-term and current monitoring of daily stream discharge throughout the Great Lakes Basin provides sufficient and accessible locations and data for the calculation of this portion of the indicator. Streamflow daily discharges collected by U.S. Geological Survey in the USA portion of the basin can be accessed through the National Water Information System (NWIS) and streamflow daily discharges in the CAN portion of the basin can be accessed through Environment Canada's Water Survey of Canada. A draft of the 2012 SOLEC Indicator Tributary Flashiness includes calculations for 11 rivers, (Genesee, Maumee, Saginaw, Muskegon, St. Joseph, Fox, St. Louis, Humber, Thames, Saugeen, and Pic), although many more rivers meet the data requirements outlined below.

Connectivity: A 2012 cover of major dams has been compiled for the USA and is freely available as the National Anthropogenic Barrier Dataset (NABD). The National Dam Inventory is a program that monitors major dam removal and construction in the USA and can be used to update the NABD in the future. Additionally, Arthur Cooper and Dana Infante at Michigan State University have calculated connected and total mainstem river lengths based on the NABD for all rivers for the USA side of the Great Lakes Basin. These calculations are not included with the NABD dataset, but willingness to share with the IJC has been expressed. Smaller dams in the USA are largely monitored on a state-by-state basis. Regulation of dams in Canada is a provincial/territorial responsibility. Unlike other countries, Canada does not have a federal regulatory agency or over-arching program which guides the development of requirements for the safe management of dams. However, in 2003 the Canadian Dam Association (CDA) mapped major dams within Canada. Smaller dams in Ontario are also regulated and a dam registry is kept by OMNR conservation districts. Individual district office should be aware of dam removal/construction projects within a district. We are not aware of any measurements of inaccessible stream lengths on Canadian streams. Two additional maps (data sources E & F) indicate that some work has been done to compile barrier information for both USA and CAN basins for Lakes Superior and Lake Ontario.

Additional needs: There are no additional data needs for stream alternation index components. For the connectivity component, a critical requirement will be periodic updates and validation of the dam inventory database for additions and removals of barriers, however rare these may be. Also, the connectivity across dams with fish passages may need to be as assessed individually. For example, although the upper dams on the Boardman River in MI are slated for removal, a large lower dam will remain in place and retrofitted with new fish access controls. How connectivity of such a dam will be classified needs to be documented. To calculate the connectivity portion of the indicator, connected and mainstem lengths of rivers need to be determined for Canadian rivers and barriers.

Required data processing and calculation effort: This indicator requires substantial calculations and data processing.

Hydrologic Alteration: There are several steps to the calculation of the R-B index of hydrologic alteration:

1) Select desired stations based on these criteria: ≥20 year stream discharge record, limited or no gaps in the records, natural flow, not extraneous activity that affects flow (i.e. beavers, water withdrawal, etc.), and unique station for each gauged watershed (to avoid independence issues).
2) Download daily discharge for all desired stations.
3) Calculate R-B index, potentially using programming scripts, database macros, etc., for each station for each year with full records.
4) Examine trends in R-B index over time at each station. Summarize the results using the trend categories mentioned in "Measurement of Progress" section of this report.

Connectivity: If analysis is restricted to only large barriers, many of the calculations for the connectivity portion of the indicator are already completed for the U.S. portion of the Great Lakes Basin and should be relatively easy to complete for the Canadian portion of the Great Lakes Basin. If smaller barriers are also included, maps of these barriers need to be created, connected to spatially-explicit stream line data, and connected and total stream lengths need to be calculated. Updating of barrier maps should occur at regular intervals based on individual dam additions/removals.

References:

Baker, D.B., R.P. Richards, T.T. Loftus, and J.K. Kramer. 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. Journal of the American Water Resources Association 40: 503-522.

Relevant SOLEC Indicators:

Aquatic Habitat Connectivity: Draft 2012 SOLEC indicator available for review at http://www.solecregistration.ca/documents/Aquatic%20Habitat%20Connectivity%20DRAFT%20Oct2011.pdf

Tributary Flashiness: Draft 2012 SOLEC indicator available for review at http://www.solecregistration.ca/documents/Tributary%20Flashiness%20DRAFT%20Oct2011.pdf

Indicator Data:

Daily streamflow:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	USA stream discharge (daily values)	For general information: http://waterdata.usgs.gov/nwis/ http://waterdata.usgs.gov/nwis/dv?referred_module=sw&search_criteria=huc2_cd&search_criteria=site_tp_cd&submitted_form=introduction	Accessible online: To search for appropriate USA stations and download data for selected stations: http://waterdata.usgs.gov/nwis/dv?referred_module=sw&search_criteria=huc2_cd&search_criteria=site_tp_cd&submitted_form=introduction Daily discharge can be downloaded in compressed or uncompressed tab separated files	Several hundred locations with sufficient discharge history. Search for stations with natural flow, 20+ years of records with no gaps, and no extraneous activities affecting flow (e.g. beavers, water withdrawal, etc.).	For watersheds with multiple stations, we recommend selecting the downstream-most station.
B	CAN stream discharge (daily values)	Environment Canada, Water Survey of Canada, National Inquiry Response Team, 819-994-0736 or via web inquiry at http://www.wateroffice.ec.gc.ca/mainmenu/contact_us_e.html	Accessible online: To search for appropriate CAN stations and then select stations to download data: http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm?stype=location	100+ locations with sufficient discharge history. Search for stations with natural flow, 20+ years of records with no gaps, and no extraneous activities affecting flow (e.g. beavers, water withdrawal, etc.).	For watersheds with multiple stations, we recommend selecting the downstream-most station.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			Daily discharge can be downloaded in a variety of CSV formats.		

Barriers to connectivity:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
C	2012 National Anthropogenic Barrier Dataset (NABD) and derived connectivity metrics	Arthur Cooper, coopera6@msu.edu, and Dana Infante, Assistant Professor, Michigan State University, 517-432-7232, infanted@anr.msu.edu	NABD shapefile (dam location liked to NHD) is freely available at https://www.sciencebase.gov/catalog/catalogParty/show/Andrea%20Ostroff Contact Arthur Cooper or Dana Infante for access to calculated stream lengths; they have expressed willingness and ability to share with IJC.	For USA portion of Great Lakes Basin only. Michigan State University conducted a spatial linkage of the point dataset of the 2009 National Inventory of Dams (NID) created by the U.S. Army Corps of Engineers (USACE) to the NHDPlusV1/NHD. The pool of dam data included were modified based on 1) dam removals that occurred after development of the 2009 NID and 2) the identification of duplicate dam records along state boundaries (cases where more than one state reported the same dam).	Derived connectivity metrics include a measure of the proportion of open mainstem (accessible mainstem length divided by total mainstem length) for stream reaches in the NHDPlus V1 along with a field indicating if a reach has connectivity to the Great Lakes. Mainstem for each reach defined as the longest navigable pathway upstream of each reach.
D	Canadian Dam Association and the Atlas of Canada 1,000,000 National Framework	User Support Group Government of Canada, Natural Resources Canada, Earth Sciences Sector,	Available through GeoGratis. GeoGratis is a portal provided by the Earth Sciences Sector (ESS) of Natural	Dams: Canadian Dam Association (CDA) Register of Dams in Canada. The register for 2003 lists 933 dams (of which 849 are included in	Both files: North American Datum of 1983 Dam layer is for entire nation and is limited to “large”

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		1-800-661-2638, info@atlas.gc.ca	Resources Canada (NRCan) which provides geospatial data at no cost and without restrictions. Dams: ESRI shapefile download at http://www.geogratis.gc.ca/geogratis/en/option/select.do?id=0D4E0553-0FEC-F9F6-F207-710FECA17DC9 River network: ESRI shapefile download at http://www.geogratis.gc.ca/geogratis/en/option/select.do?id=2D20EF22-53A1-B052-EA21-FB5636413405	this data), including all those existing or under construction. The tailings dams and the dams under construction listed in the register are not included in this dataset. Other reference data was used to obtain positional data. This dataset has been integrated with other National Scale Frameworks hydrology datasets and is considered a component of the "Hydrology Theme". The Atlas of Canada Stream network: 1,000,000 National Frameworks Data are a set of integrated base map layers which form the Atlas of Canada National Frameworks Data collection. These data have been compiled at a scale of 1:1,000,000 with the primary goal being to indicate correct relative positioning with other frameworks layers rather than absolute positional accuracy.	dams. Although 2003 data, dam information reflects status as of 2000. Select Ontario during download to restrict drainage network. Then restrict to Great Lakes Basin. NOTE: There is NO national inventory of small dams; many small dams exist that are not represented by this data source. For example OMNR estimates there are 2600 dams total in Ontario, few of which are represented in this dataset.
E	Lake Superior Lakewide	Marie Wines, US EPA, 312-886-6034	Not able to contact Marie Wines; email and	A binational dataset has been created that includes stream	Spatial coverage includes both US and CAN portions of

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	Management Plan Annual Report 2011; Original sources MI DNR IFR 2004 and OMNR 2000	wines.e-marie@epa.gov	phone not working	gauge information such as location, type of data collected, dams and other barriers to fish passage, current mines and land use in the watershed.	Lake Superior basin and designates stream segments as accessible or not accessible.
F	Lake Ontario Biodiversity Conservation Strategy Working Group, In cooperation with the U.S. – Canada Lake Ontario Lakewide Management Plan Map accessible at: http://conserveonline.org/workspaces/lakeontario.conservation/feb2007maps/tribconnectivity/view.html	Ontario Ministry of Natural Resources in the Aquatic Landscape Information System (ALIS) and comparable data on migration barriers in for Lake Ontario tributary streams and rivers in New York were part of a stream habitat fragmentation model developed by Cornell University (Meixler *et al.* 2003).	Contact TNC or Marci Meixler for access The Nature Conservancy's New York State Office and Great Lakes Program, Kamayo Smith, 518-690-7850, kamayo_smith@tnc.org Marci Meixler, Assistant Professor, Rutgers University, 848-932-1081, meixler@aesop.rutgers.edu	Ontario Ministry of Natural Resources in the Aquatic Landscape Information System (ALIS). Comparable data on migration barriers for Lake Ontario tributary streams and rivers in New York were part of a stream habitat fragmentation model developed by Cornell University (Meixler et. al. 2003). Data were not available for the St. Lawrence River tributaries in Ontario or New York. In addition, discrepancies were noted for three tributaries in the Niagara region of Ontario. Future versions of this map will add new data and corrections.	Spatial coverage includes both US and CAN portions of Lake Ontario basin and designates stream segments as accessible or not accessible.

Updates (construction and removal) to barrier information:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
G	USA: National Inventory of Dams (NID)	NID Data Team at nid@usace.army.mil	To query the 2010 NID database, you must request a username and	The NID consists of dams meeting at least one of the following criteria: 1) High	

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		NID website home: http://geo.usace.army.mil/pgis/f?p=397:1:0::NO	password. Non-government users can query the database using the interactive report and map functions but cannot directly download any data from this site.	hazard classification - loss of one human life is likely if the dam fails, 2) Significant hazard classification - possible loss of human life and likely significant property or environmental destruction, 3) Equal or exceed 25 feet in height and exceed 15 acre-feet in storage, 4) Equal or exceed 50 acre-feet storage and exceed 6 feet in height.	
H	Ontario Dam Registry	Contacts to individual district offices: http://www.mnr.gov.on.ca/en/ContactUs/2ColumnSubPage/STEL02_179002.html Possibly the Canadian Dam Association, but they currently have no plans to update their 2003 list. Don Butcher, Executive Director, CDA, 416-255-7076, executive.director@cda.ca	Regulation of dams in Canada is a provincial/territorial responsibility. Unlike other countries, Canada does not have a federal regulatory agency or over-arching program which guides the development of requirements for the safe management of dams. Individual district office should be aware of dam removal or construction projects within a district.	In Ontario the Ontario Lakes & Rivers Improvement Act (LRIA) and Ontario Regulation 454/96 require that the location and plans and specifications for dam works be approved by the Ministry of Natural Resources (MNR). Under the LRIA, the MNR must approve the location and plans and specifications for dam construction, alterations, improvements and repairs.	Contains information about both small and large dams. OMNR estimates there are 2,600 dams in Ontario.

Groundwater Contamination

Summary:

The groundwater contamination indicator will focus on groundwater as a transmitter/vector of contaminants and nutrients to Great Lakes waters, primarily as it impacts the quality of water in streams flowing into the Great Lakes.

Spatial coverage: This indicator follows contaminant pathways from sources in Great Lakes Basin to Great Lakes waters. Analyses can be targeted (using five well-studied areas/watersheds) or broad (basin-wide).

Temporal coverage: Mining data includes all current and historical mines in both the USA and Canada. Land use/cover maps vary by country (early 2000s for CAN and 5 year intervals from 1992-2013 for USA) Groundwater monitoring data are available from 2000+ surface water monitoring data are available as early as the 1960s. USA groundwater and surface water quality monitoring is widely available after 1960. Baseflow and total river flow are from a 2005 report.

Data processing needs: Data is sufficient and accessible to calculate many of the components of this indicator. However, the draft indicator currently lacks sufficient detail as to exactly what will be measured and how the components will be connected. We offer some suggestions and detail what data are available.

Indicator Details:

The groundwater contamination indicator will focus on groundwater as a transmitter/vector of contaminants and nutrients to Great Lakes waters, primarily as it impacts the quality of water in streams flowing into the Great Lakes. This focus necessitates four types of data: 1) Potential sources of groundwater contamination (e.g. mining and development); 2) water quality samples of groundwater; 3) water quality samples of stream/river water; and 4) quantification of the relative contribution of groundwater to the total river flow delivered to the Great Lakes.

Components:	**Component specifications:**	**Data source: (see data table)**
1) Potential sources of groundwater contamination:	Mines: Location and type	A
	Land-use: Developed land	B, C, & D
2) Water quality samples of groundwater	Select physio/chemical parameters	E, F, & G
3) Water quality samples of streams	Select physio/chemical parameters	E, F, & H

Components:	Component specifications:	Data source: (see data table)
4) Stream discharge and groundwater delivery to Great Lakes	Proportional contribution of groundwater to total streamflow	I

Calculations: These are not specifically defined in the current draft of the indicator. This is our suggested approach.

1) Link contamination to its source: Proximity analyses of sources of contamination and groundwater water quality.

2) Identify water quality problems: Use samples of water quality in groundwater and surface water to identify areas of contamination and levels of contamination. For each water quality sample: Physical parameters of interest include location, water level and/or flow, Temperature, pH, and Specific or electrical conductance. Specific chemical parameters of interest include Sodium, Calcium, Magnesium, Potassium, Chloride, Sulfate, Alkalinity, Nitrate, Nitrite, Ammonia, Dissolved Phosphorus, Dissolved oxygen, Total dissolved solids, Oxygen reduction potential, Iron, and Manganese. Future analyses may also include selected synthetic organics, isotopes, and emerging contaminants (e.g. metals, pesticides, PCBs, etc).

3) Calculate delivered loads of chemicals of interest to the Great Lakes: Calculate yearly loads based on repeated samples at the same location. Use Neff *et al.* (2005) to determine stream flow and the relative contribution of groundwater to surface water within a watershed to partition groundwater sources contaminant loads.

Combination of components: Combination of components should follow the route of groundwater contamination from the source to delivery to Great Lakes waters. Exactly how this will be accomplished requires refinement of the indicator description.

Spatial and temporal coverage: There are two possible spatial approaches to measuring this indicator: 1) using a few well-studied areas/watersheds to represent trends in the entire Great Lakes Basin or 2) using representative locations from throughout the Great Lakes Basin. If the watershed-intensive study approach is used we recommend fiver areas for study: Grand River in the province of Ontario, watershed/s in the National Water-Quality Assessment Program (NAWQA) Lake Erie study area, watershed/s in the NAWQA Western Lake Michigan study area, the Muskegon River in the state of Michigan, and the St. Louis River in Northeastern Minnesota. Basin-wide data sources included in the components table above include locations within each of these watersheds and would need to be summarized by the watershed boundary. Data contacts/sources specific to the five watersheds are also listed in data table rows J-N.

Measurement of progress: Reductions in groundwater contamination and delivery to the Great Lakes would signify progress.

Data Evaluation:

Sufficiency and accessibility: Data is sufficiently available and accessible for all four components of the indicator at both the basin-wide and watershed-specific scale. Some watersheds have more groundwater monitoring locations than others and a few do not have any monitoring sites.

Additional needs: No additional data needs. The spatial scale for analysis needs to be chosen and how the indicator components will be linked needs to be explicitly defined.

Required data processing and calculation effort: We are not able to assess data processing and calculation effort due to the generality of the draft of the indicator. The processing and calculation effort will largely depend on exactly how the indicator will be calculated.

References:

Neff, B.P., S.M. Day, A.R. Piggott, and L.M. Fuller. 2005. Base Flow in the Great Lakes Basin: U.S. Geological Survey Scientific Investigations Report 2005-5217, 23 pp. Available at http://pubs.usgs.gov/sir/2005/5217/

Relevant 2009 SOLEC Indicators:

#7100 Natural Groundwater Quality and Human-Induced Changes

#7101 Groundwater and Land: Use and Intensity

#7102 Base Flow Due to Groundwater Discharge

Indicator Data:

Basin-wide data sources:

Contamination sources:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	USA and CAN Mines: Mineral Resources Data System (MRDS)	Distributor: Peter N Schweitzer, USGS, ER Geologist, 703-648-6533 (voice), pschweitzer@usgs.gov Data questions: Paul G Schruben, USGS, 703-648-6142, pschrube@usgs.gov	General information at: http://mrdata.usgs.gov/mrds/ Numerous formats available: Vector point shapefile, tables, Google earth, etc. Free download of mines in USA GL basin and Ontario at http://tin.er.usgs.gov/mrds/select.php (need to download USA GL basin and Ontario separately)	For USA: This database contains the records previously provided in the Mineral Resource Data System (MRDS) of USGS and the Mineral Availability System/Mineral Industry Locator System (MAS/MILS) originated in the U.S. Bureau of Mines.	6,988 records lie within USA Great Lakes basin; 433 records lie within Ontario. Includes type of commodities present: metallic, non-metallic, or both, and lists specific commodities. Also includes operation type (surface, underground, leaching, well, etc.), size, and status (i.e. legacy or active).
B	USA Land-Use USGS: National Land Cover Datasets: http://www.mrlc.gov/finddata.php	None (For crosswalked Ontario Provincial Land Cover 2000 and NLCD 2001 contact Danielle Forsyth, 734-663-3554 ext. 11755 dforsyth@umich.edu or Catherine Riseng, Assistant Research	In zipped files that can be downloaded for free from: 1992: http://www.mrlc.gov/nlcd92_data.php 2001: http://www.mrlc.gov/nlcd01_data.php	All are 30m resolution grids Contain land cover, %impervious, and tree canopy density(except 2006). NLCD92 is based primarily on the unsupervised classification of Landsat Thematic Mapper (TM) circa 1990's satellite data.	All classification systems are modified from the Anderson Land Cover Classification System. 1992 has 21 land cover classes; 2001 and 2006 have 16 land cover classes Should NOT try to compare 1992 and 2001 data. If this comparison is desires use the 1992/2001 retrofit land cover change product.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		Scientist, 734-763-9422 criseng@umich.edu)	2006: http://www.mrlc.gov/nlcd06_data.php	NLCD2001 is based primarily on the unsupervised classification of Landsat Enhanced Thematic Mapper+ (ETM+) circa 2001 satellite data. NLCD2006 is based primarily on the unsupervised classification of Landsat Enhanced Thematic Mapper+ (ETM+) circa 2006 satellite data.	NLCD2006 also quantifies land cover change between the years 2001 to 2006. Note: NLCD 2011 is currently in production and is expected to be released in Dec 2013.
C	CAN Land-Use Ontario Provincial Land Cover: 2002	Through GLAHF: Danielle Forsyth, 734-663-3554, ext. 11755 dforsyth@umich.edu or Catherine Riseng, Assistant Research Scientist, 734-763-9422 criseng@umich.edu)	Available from GLAHF GLAHF accessed the data through the Ontario Geographic Data Exchange (OGDE) program as a part of the Land Information Ontario (LIO) data warehouse.	The Ontario Ministry of Natural Resources Provincial Land Cover Raster includes 28 land cover classes and spans the entire landmass of Ontario. The Ontario Land Cover data was derived from digital, multispectral LANDSAT Thematic Mapper data. The inventory represents the landscape from 1999 to 2002. It is important to note that the Provincial Land Cover Data Base is generalized land cover. It is NOT appropriate for detailed site-specific large scale studies.	USE SOLRIS LANDCOVER 2002 GTA FOR SOUTHERN ONTARIO. 28 land cover classes (has been crosswalked by GLAHF to NLCD 2001). TIFF format with .shp layer index correlating to documentation for vintage of data. The data is based on UTM, North American Datum 1983, Zone 15, 16, 17 and 18.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
D	CAN Land-Use Southern Ontario Land Resource Information System (SOLRIS): 2000-2002		The final version of SOLRIS (v1.2) is made available through the Ontario Geographic Data Exchange (OGDE) as part of the Land Information Ontario (LIO) data warehouse. (http://www.mnr.gov.on.ca/en/Business/LIO/index.html) Should be available free of charge but must have LIO access to download. Available in shapefile and ESRI grid formats.	SOLRIS was created by integrating geospatial databases of forests and wetlands with topographic maps, aerial photos and satellite imagery for seamless coverage of Ecoregions 6E and 7E. Note: Although released in 2008, and often associated with that year, the land cover is from 2000-2002.	23 land cover classes The shape file coordinate system is in MNR Lambert Conformal Conic. ESRI grid coordinate system is in UTM zone 17, NAD 83 and UTM zone 18, NAD83.

Water quality:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
E	USA groundwater and surface water quality samples: National Water Information System (NWIS)	Stephanie Beeler, Hydrologic technician, USGS, 517-887-8934, sbeeler@usgs.gov Additional contacts: Howard Reeves (hwreeves@usgs.gov) or Chris Hoard (cjhoard@usgs.gov)	Potential sites are viewable for the Great Lakes region at http://maps.waterdata.usgs.gov/mapper/index.html	The best way to access these data are to arrange a time with Stephanie to extract desired information. Although you can access the data from the NWIS (http://www.waterqualitydata.us/), the interface is no t intuitive and these data can be more effectively and efficiently extracted by USGS staff.	Several hundred groundwater and several hundred more surface water sample locations. Physical, nutrient, and metal and nonmetal parameters available. At selected surface-water and groundwater sites, the USGS maintains instruments that continuously record

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
					physical and chemical characteristics of the water including pH, specific conductance, temperature, dissolved oxygen, and percent dissolved-oxygen saturation.
F	USA groundwater and surface water quality samples: EPA STORET	STORET@epa.gov or 1-800-424-9067	Download current and legacy STORET data at http://www.epa.gov/STORET/dbtop.html	The STORET Data Warehouse is EPA's repository of the water quality monitoring data collected by water resource management groups across the country.	Includes chemical parameter measurements made in the field or lab and physical parameter measurements such as water temperature or pH.
G	Canadian Groundwater water quality samples: Provincial Groundwater Monitoring Network (PGMN)	Dr. Rogojin Vasily, Senior Hydrogeologist, Ministry of Environment Groundwater Unit , 416-235-6172, Vasily.Rogojin@Ontario.ca	Locations available in shapefile, water levels and precipitation in CSV, and chemistry in TXT. Can be downloaded in zipped folders from http://www.ene.gov.on.ca/environment/en/resources/collection/data_downloads/index.htm#PGMN Restrictions on private wells: Information from PGMN wells that are located on privately owned land is limited to Lot, Concession, Township, County, and	The PGMN program began in 2000 and is designed to monitor ambient groundwater level and chemistry conditions across Ontario These wells are not used to supply water and are used for monitoring groundwater conditions only	There are currently 474 wells in the PGMN program that monitor groundwater levels on an hourly basis. (Note: in downloadable files only one day every couple of years is included for a site). Approximately 380 sites have been selected for long-term annual water chemistry monitoring. Precipitation is monitored at 45 sites. At most sites around 200 chemicals are measured including chemicals of interest for this indicator.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			Conservation Authority. Locations of these wells cannot be released. The associated tabular data is included, but coordinates have been removed. No other use constraints.		
H	Canadian stream water quality: Provincial (Stream) Water Quality Monitoring Network (PWQMN)	Aaron Todd, PWQMN Coordinator, Aaron.Todd@ene.gov.on.ca	Locations available in shapefile. Data for the years 2002-2011 inclusive can be downloaded as an Access database. Data for individual years can be downloaded as Excel spreadsheets. Results are shared free of charge. Can be downloaded in zipped folders from http://www.ene.gov.on.ca/environment/en/resources/collection/data_downloads/index.htm#PGMN	The PWQMN is a partnership between the Ontario Ministry of the Environment (MOE) and other conservation partners to undertake surface water quality monitoring throughout Ontario. Over 400 locations are currently monitored in partnership with Ontario's Conservation Authorities, participating municipalities, and provincial parks. Water quality results that were deemed to be unreliable were removed from the dataset. Please exercise caution when interpreting the field data (water temperature, field pH,	Although downloadable data are from 2002 about 300 sites have long-term data (e.g. 1960's to 2000s) About 30 chemical parameters sampled. Locations repeatedly sampled with varying intensity, typically summer samples (usually May-Aug).

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				stream condition, ambient conductivity and dissolved oxygen) since these observations are performed in the field and are not subject to our laboratory QA/QC protocol. Please ensure to check the remark code fields when interpreting the accuracy of the water quality results.	

Streamflow separation:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
I	Base Flow in the Great Lakes Basin, USGS Scientific Investigations Report 2005-5217	Authors: B.P. Neff, S.M. Day, A.R. Piggott, and L.M. Fuller Contacts are Brian. P. Neff, self-employed, bneff@uwaterloo.ca and Andrew. R. Piggott, Andrew.Piggott@ec.gc.ca (no longer at EC but this is the only email I could find)	Report and data appendices available at: http://pubs.usgs.gov/sir/2005/5217/ Groundwater (G-model) and Groundwater/Surface water (G-SW-model) estimates and Baseflow Index are downloadable as TXT files	Provides groundwater and total flow estimates for each HUC 8 (USA) and tertiary (CAN) Watershed in the Great Lakes basin. Consistent methods used across entire basin.	BFI is the average rate of base flow divided by the corresponding average rate of total streamflow. BFI is a number between zero and one; increasing values indicate an increasing ratio of base flow to total streamflow. Six hydrograph-separation methods were used to perform these analyses, generating six datasets describing base flow at current and historical gages.

Watershed specific data sources and contacts:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
J	Grand River: Grand River Conservation Authority	Sandra Cooke, Senior Water Quality Supervisor, 519-621-2763 x2224, scooke@grandriver.ca and Jeff Pitcher, Water Information Specialist, (519) 621-2763 x2291, jpitcher@grandriver.ca	SOLEC 2009 reports 7100 (natural groundwater quality and human-induced changes) and 7101 (Groundwater and Land: Use and Intensity) highlight work done in the Grand River http://www.epa.gov/solec/sogl2009/7100gwquality.pdf http://www.epa.gov/solec/sogl2009/7101gwlanduse.pdf	Intense study on the Grand River in Ontario Grand river is heavily developed (5% urban, 76% agriculture, 17% forest) and approx, 80% of the 875,000 residents use groundwater as their primary source of drinking water. Much of the GIS data has been compiled and processed for SOLEC reports	Significant increases in Chloride observed in well water from 1960-2000. Problems with nitrate contamination also observed.
K	USGS and NAWQA Lake Erie/Lake St. Clair study area	Mary Ann Thomas, Hydrologist, USGS, Water Resources Division, 614-430-7736, mathomas@usgs.gov Dan Button, dbutton@usgs.gov	1st Report available at: http://pubs.usgs.gov/circ/circ1203/index.html 2nd Report available at http://oh.water.usgs.gov/reports/wrir/wrir00-4146.pdf	In residential areas underlain by sand and gravel, more than 75 percent of ground water recharged since 1953 shows evidence of human activities in the form of nitrate, chloride, or volatile organic compounds (VOCs). Links significantly higher concentrations of chemical constituents to human activities and development.	Although impacts documented in the NAWQA study are from the late 1990s, this information could serve as a baseline for the basin. Development in this basin has increased since the late 1990s.
L	NAWQA Western Lake MI major	David A. Sad, Hydrologist, USGS,	Overview at: http://wi.water.usgs.gov	Three pronged approach to assessing the quality of	Long-term monitoring of this area provides an excellent

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	aquifer study	Wisconsin Water Science Center, 608-821-3865, dasaad@usgs.gov	/wmic/	recently recharged ground water associated with present and recent human activities. In the Western Lake Michigan Drainages, two major aquifer studies, two land-use studies, and two flow path studies have been conducted since 1991.	opportunity for continued, intense study.
M	Muskegon River: Grand Valley State University Annis Water resources Institute and University of Michigan, School of Natural Resources	Dr. Rick Rediske, 616-331-3047, redisker@gvsu.edu and Michael J. Wiley, 734-764-6286 mjwiley@umich.edu	Depends largely on data type, but researchers generally open to sharing data.	Muskegon was heavily studied by multiple universities in the mid to late 2000s. Much less developed than other three proposed watersheds.	Much GIS data has been compiled and processed for the Muskegon basin Bryan Pijanowski has developed land use scenarios of future development in the Muskegon watershed
N	St. Louis River: Minnesota Pollution Control Agency, Duluth Office	Stacia Grayson, 218-302-6631, groundwater load monitoring, Stacia.Greyson@state.mn.us Jenny Jasperson, 218-302-6634, Water quality monitoring, Jenny.Jasperson@state.mn.us	General information about the St. Louis River available at http://www.lakesuperiorstreams.org/general/reports_Harbor.html	St. Louis watershed includes two Areas of Concern and copper, nickel, and platinum mines and taconite mines in the headwaters. There are also several proposed new mines in the watershed.	Groundwater monitoring locations are clustered in the SW of the watershed and in the northern headwaters. St. Louis River has a long history of citizen involvement as well.

Shoreline Alteration Index (SAI)

Summary:

The Shoreline Alteration Index (SAI) is a measure of man-made protected shoreline length that is physically and biologically unfavorable.

Spatial coverage: The SAI indicator will include the entire Great Lakes shoreline summarized by Lake Basin, with targeted attention to specific locations.

Temporal coverage: Historical/baseline shoreline maps are available from pre-1990 and early 1990s; Maps reflecting "current" condition could be developed from recent imagery/LIDAR.

Data processing needs: The SAI requires GIS calculated ratios of lengths of shoreline hardening and biological incompatibility. The physical component of the SAI can be applied immediately to historical shoreline maps to establish "baseline" conditions. Maps representing current shoreline hardening can be developed from widely available imagery. There is a need to develop consensus on impacts of shoreline modifications on nearshore and coastal biological systems before the biological component of the SAI can be included.

Indicator Details:

The Shoreline Alteration Index (SAI) is a measure of man-made protected shoreline length that is physically and biologically unfavorable. The physical component is the ratio of the lineal length of armored shoreline relative to total lineal length of the shoreline. The biological component is based on the lineal length of biologically incompatible shoreline structures relative to the total lineal length of protected shoreline.

Components:	**Component specifications:**	**Data source: (see data table)**
Physical shoreline indicator:	Ratio of the lineal length of armored shoreline relative to total lineal length of the shoreline (i.e. the ratio x 100 = percent of armored shoreline).	"Historical" or baseline shoreline map: (Two options) A+B or C+D "Recent" shoreline map: Targeted areas are E & F; Broader areas are G & H
Biological shoreline indicator	Ratio of the lineal length of biologically incompatible structures relative to total lineal length of protected shoreline.	Currently in development
SAI (total):	SAI = 1 – (P ratio x B ratio)	Currently missing biological component

Calculations: Calculated as the ratios described above.

Combination of components: Shoreline Alteration Index (SAI) would be calculated by multiplying the physical and biological shoreline indicator values and subtracting the resulting value from one (1), i.e. SAI = 1 – (P ratio x B ratio).

Spatial and temporal coverage: It is recommended that the SAI indicator be calculated on a 5-year cycle. By applying the SAI at multiple spatial scales, comparisons between specific geographic areas can be made.

Measurement of progress: Physical Shoreline Indicator: A value of zero (0) would represent an unprotected natural shoreline and a value of one (1) would represent a highly modified or 100% engineered shoreline. Biological Shoreline Indicator: A value of zero (0) would represent no biological or ecological impact (high compatibility) and a value of one (1) would represent significant biological or ecological impact (low compatibility). Shoreline Alternation Indicator (SAI) is a combined measure of protected shoreline length that is physically and biologically unfavorable. The resulting SAI would range from zero (0) representing a highly altered biologically incompatible shoreline to one (1) representing a biologically compatible shoreline (even though it may still be armored).

The endpoints and categories for the physical indicator are identical to those proposed in the SOLEC draft indicator report for Coastal Habitats. The biological indicator is not categorized as it is a value used to “adjust” the physical shoreline alteration ratio by accounting for biologically compatible shore structures.

Indicator (Sub)	Poor	Fair	Good	Excellent
Physical	0.7 to 1.0	0.4 to 0.7	0.15 to 0.4	0.0 to 0.15
Biological	n/a	n/a	n/a	n/a
SAI	0.0 to 0.3	0.3 to 0.6	0.6 to 0.85	0.85 to 1.0

Data Evaluation:

Sufficiency and accessibility: With respect to implementation, the physical component of this indicator can be applied immediately to historical shoreline maps to establish “baseline” conditions. However, additional work is needed to develop consensus on consistent biological/ecological criteria to evaluate impacts of shoreline modifications on nearshore and coastal biological systems.

This physical portion of the indicator requires historical and current shoreline maps with measured line segments attributed with shoreline types/classes that can easily be reclassified into armored or not armored. Coarse-scale (i.e. km segments of shoreline) basin-wide historical data (pre 1990s) are available as well as historical finer-scale shoreline maps originally developed for oil spill response (e.g. Environmental Sensitivity Atlas (ESA) and Environmental Sensitivity Index (ESI)). Since armoring is rarely removed, either of these data sources is sufficient to establish a baseline, or “best case” scenario for the physical shoreline indicator. There are two segments of the Lake Erie and Lake Michigan shoreline that have been mapped in the ESA but have not been digitized. If these mapped areas in the ESA can be digitized, Environmental Sensitivity maps are preferred over the NOAA/USACE shoreline, because the ESA/ESI include more spatially precise locations and lengths of shoreline structures.

Because of advances in mapping and the wide spread availability of high resolution imagery, NOAA/USACE has no plans to revisit km-by-km shoreline mapping along Great Lakes shorelines. No updates to the ESA/ESI shorelines are planned either. Instead, updated shoreline maps have been developed in limited areas around the Great Lakes (e.g. portions of Lake Michigan and Southern Georgian Bay). More recent shoreline maps could be developed using new and recurring high-resolution aerial photography and/or satellite imagery. This data exists for much of the U.S. shoreline (see NOAA's Digital Coast viewer). Computers could be trained to classify imagery data into shoreline types/structures. A map of spatially referenced points for all visible man-made structures along Great Lakes shorelines (derived from direct interpretation of aerial photos), may be of great assistance during such training.

Additional needs: The calculation of the SAI indicator requires current and future Great Lakes basin-wide shoreline maps and consensus on consistent biological/ecological criteria to evaluate impacts of shoreline modifications on nearshore and coastal biological systems.

Required data processing and calculation effort: Effort is minimal once maps are developed. Reclassification of existing categories into armored and not armored is simple. Examples of hardening or armoring include: dikes, revetments, breakwalls, seawalls, jetties, piers, retaining walls, boat docks, groins, gabions, riprap, boat launches and bulkheads. Analysis in GIS program is also straight-forward.

Relevant SOLEC Indicators:

Hardened shorelines: Draft 2012 SOLEC indicator available at
http://www.solecregistration.ca/documents/Hardened%20Shorelines%20DRAFT%20Oct2011.pdf

Indicator Data:

"Historical" or presettlement maps:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	NOAA/USACE	For GIS shapefile: Lacey Mason, Data Analyst, 734-663-3554 ext. 12155, lmas@umich.edu	In the GLGIS: Line shapefile, freely accessible and sharable	Entire GL shoreline in kilometer-by-kilometer spatial units Would serve as a good baseline dataset since armoring is generally permanent. Compiled in 1992, but aerial photos are actually from 1979 for lake MI and 1987-1989 for the rest of the basin.	3-tiered shoreline classification scheme for the Great Lakes including the geomorphic shore type present, the level of shoreline protection present, and the geological composition of the nearshore zone. This original classification was applied to all of the Great Lakes shoreline, including Lake Michigan, and associated statistics on the various shoreline types were generated.
B	International Joint Commission (IJC) initiated Lake Ontario – St. Lawrence River Water Level Regulation Study (LOSLRS) shoreline and Environment Canada	Lacey Mason, Data Analyst, 734-663-3554 ext. 12155, lmas@umich.edu	In the GLGIS: Vector (Line) shapefile, freely accessible and sharable	1999 update to NOAA/USACE shoreline; Limited to kilometer-by-kilometer spatial units along Lake Ontario & St. Lawrence River. (See Stewart 2003 for details: available at http://www.cjscons.com/downloads/Stewart01.pdf)	Similar to NOAA/USACE shoreline.
C	Environment Canada: Environmental Sensitivity Atlas	Danielle Forsyth, Data Analyst, 734-663-3554 ext. 11755, dforsyth@umich.edu	In GLAHF; received from Mike Roberts; Vector (Line) shapefile (digitized version from	Derived from pre-1994 maps (exact dates not specified) Digitized spatial coverage:	Developed to aid agencies and companies prepare and respond to spills of oil and other hazardous materials.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			original maps in booklets)	Entire Canadian shoreline EXCEPT for portions of Lake Erie and portions of Eastern Lake MI; maps exist for these portions of shoreline but need to be digitized (GLAHF is currently exploring this)	Created in 1994 using data interpreted by a biologist & geomorphologist from video of the shoreline captured from a helicopter. The shoreline is classified by substrate and natural environment. 13 shoreline classes (with multiple subclasses).
D	NOAA Environmental Sensitivity Index	Danielle Forsyth, Data Analyst, 734-663-3554, ext. 11755, dforsyth@umich.edu Detailed information about ESI maps available at: http://response.restoration.noaa.gov/maps-and-spatial-data/environmental-sensitivity-index-esi-maps.html ESI contact: esi.orr@noaa.gov	In a geodatabase format for use in Esri's ArcMap product: Contains shoreline line shapefile (with an occasional polygon) and point/polygon data associated with bird nesting, fish spawning sites, mammal info, etc.	Map publish dates 1993-94; Imagery used is from 1991-93. Entire USA Great Lakes shoreline Cross walk between Environment Canada ESA and USA ESI is nearly complete. Armored classes easy to identify in both ESA and ESI and crosswalked ESA/ESI.	Developed to aid agencies and companies prepare and respond to spills of oil and other hazardous materials. 10 shoreline classes (with multiple subclasses). Shoreline may have two or three different classifications. These multiple classifications exist if multiple structures are encountered. In addition to the line features, tidal flats, marshes, and scrub-shrub wetlands are also stored as polygons.

"Recent" shoreline maps:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
E	Southern Georgian Bay (SGB) shoreline map OMNR: Science and Information Section, Science and Information Branch	Coordinator, Information Management & Spatial Analysis Unit, Southern Science & Information Section Ontario Ministry of Natural Resources, 705-755-3208	Summarized in 2010 report "Status and trends in shoreline development and alteration along the southern Georgian Bay shoreline". Call for more information.	Digitized shoreline highlighting alteration and hardening activities Digitized from SWOOP 2006 and North Simcoe Muskoka 2008 imagery campaigns at a 1:2000 scale. Spatial Coverage: 660.8 km of shoreline along SGB (Tobemory to Port Severn Ontario).	Note: added riprap installations from ES Atlas, but this is still likely an underestimate of shoreline hardening since riprap cannot be seen from aerial photos
F	USACE	Detroit Area office: 313-226-2206 General Information: http://www.lre.usace.army.mil/greatlakes/hh/greatlakestudies/lakemichiganpotentialdamagesstudy/gisanalyses/shorelineprotectioninventories/	Contact USACE for GIS files River mouth report: http://www.lre.usace.army.mil/_kd/Items/actions.cfm?action=Show&item_id=3458&destination=ShowItem	1999/2000 inventory of shore protection structures in five prototype counties and four river mouth systems along Lake Michigan River mouth and upstream river shorelines sub-divided into 1/10th km sub reaches	New level of classification developed for boating related structures
G	NOAA Digital Coast: Coastal Change Analysis Program Regional Land Cover		Data available and compiled for distribution at http://www.csc.noaa.gov/dataviewer/#	Provides access to recent digital imagery (2007-2011) and LIDAR (1998-2011) for USA coastal areas throughout the Great Lakes	High resolution imagery or LIDAR could be used to develop more recent shoreline maps
H	Great Lakes Environmental Assessment and	Sigrid Smith, Research Area Specialist Associate, University	General info about GLEAM: http://www.greatlakes	Map of spatially referenced points for all visible man-made structures along Great	Developed from visual inspection of aerial photos along GL shoreline.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	Mapping Project (GLEAM): Shoreline structures	of Michigan, 734-764-6553, sdpsmith@umich.edu	mapping.org/home Vector (point) shapefile	Lakes shorelines sub km scale	Could be used to "train" interpretation of recent imagery or LIDAR.

Extent, Composition, and Quality of Coastal Wetlands

Summary:

This indicator tracks trends in Great Lakes coastal wetland ecosystem health by measuring wetland area and extent, monitoring water quality, and calculating condition indices for vegetation, macroinvertebrates, fish, plants, amphibians, and birds.

Spatial coverage: This indicator will include all lacustrine, barrier-protected, and riverine wetlands greater than 4 hectares throughout the entire Great Lakes Basin. The scale of analysis is hierarchical from site subcomponents, site, lake subbasin, lake basin, ecoregion, to the entire Great Lakes Basin. The scale of analysis can be chosen by the user. Maps of wetland cover for the entire Great Lakes are available and are currently being updated.

Temporal coverage: Most indicator subcomponents have been monitored since the late 1990s. A comprehensive, coordinated sampling program funded under Great Lakes Restoration Initiative began in 2011 and continues through 2015. The stratified random sampling design of this study includes repeated sampling of a subset of sites, facilitates a comprehensive annual assessment of Great Lakes coastal wetlands as well as quantification of wetland by year interactions. Great Lakes National Program Office (GLNPO) is currently seeking funding to continue this monitoring indefinitely. Maps of wetland cover exist for the early 2000s and are being developed for 2008-2010.

Data processing needs: The indicator includes one summary component calculated from the combination of seven components. Five of the subcomponents are being calculated now. The two remaining subcomponents (wetland area, extent, and water quality) and the summary component are in development. For most subcomponents, historical and current conditions can be calculated. All data, from raw counts to summary conditions across the entire Great Lakes Basin will be supplied to the IJC. We suggest trend analysis of ecological condition at the lake level or subbasin level based on summary metrics at each site. These summary metrics will be supplied by a queryable database and will require a minimal amount of further analysis. Recurring development of coastal maps based on satellite imagery is required for the Wetland Area and Extent subcomponent.

Indicator Details:

This indicator tracks trends in Great Lakes coastal wetland ecosystem health by measuring wetland area and extent, monitoring water quality, and calculating condition indices for vegetation, macroinvertebrates, fish, plants, amphibians, and birds.

Components/Subcomponents:	Component specifications:	Data source: (see data table)
Summary	An overall index of wetland health combining the following individual scores:	C
Subcomponents:		
1)Wetland Area and Extent	Potential metrics may include gains and losses of wetland area, land cover/land use adjacent to each wetland, and area dominated by invasive vegetation	A & B
2) Water quality	An indicator of chemical integrity (ICI) is currently in development. The following are collected at each site: Temperature, dissolved oxygen, pH, specific conductivity, transparency tube clarity oxidation-reduction potential (redox), in situ chlorophyll fluorescence, alkalinity, turbidity, soluble reactive phosphorus (SRP), [nitrate+nitrite]-nitrogen, ammonium-nitrogen, chlorophyll-a, total nitrogen (TN), total phosphorus (TP), chloride, color, and sediment percent organic matter.	C
3) Vegetation	Wetland ecosystem health according to GLCWC (2008): 9 metrics described on pp. 81-82 of Uzarski *et al.* 2011; relies heavily on the Floristic Quality Index (FQI), the coverage and distribution of invasive plants, and the coverage and diversity of submergent and floating plants	C
4) Macroinvertebrates	GLCWC (2008) Index of Biotic Integrity (IBI): metrics depend on wetland type and are described on pp. 83-86 of Uzarski *et al.* 2011;	C
5) Fish	GLCWC (2008) IBI: Many individual metrics depending on wetland zone (*Schoenoplectus* or *Typha*) described on pp. 86-87 of Uzarski *et al.* 2011	C
6) Amphibians	IBI based on combination of three metrics: Described on p. 88 of Uzarski *et al.* 2011	C
7) Birds	IBI based on combination of three metrics: Described on p. 88 of Uzarski *et al.* 2011	C

Calculations: All calculations are detailed in Uzarski *et al.* 2011 (see pages listed in component/subcomponent sections in above table).

Combination of components: The individual measures derived for each of the subcomponents above can be used independently as a measure of Great Lakes coastal wetland ecosystem health. Attempts to develop an indicator of chemical integrity for water quality, formalize the wetland area and extent subcomponent, and to combine subcomponents into an overall measure of wetland health are currently underway. Combining individual subcomponents scores may provide the most reliable and complete measure of the extent, composition and quality of coastal wetlands in the Great Lakes basin.

Spatial and temporal coverage: This indicator will include all lacustrine, barrier-protected, and riverine wetlands greater than 4 hectares throughout the entire Great Lakes Basin. A coordinated, standardized, and comprehensive monitoring program officially began in 2011 and will continue through 2015. By 2015, every Great Lakes coastal wetland (except dune and swale complexes, forested swamps, and barrier beaches) greater than 4 hectares in size with a surface water connection to the Great Lakes will be sampled for all relevant subcomponents and a baseline will be established. It is estimated that each year of sampling will include over 200 sites and by the end of the project about 1100 sites will have been sampled. GLNPO is currently seeking funding to continue this monitoring indefinitely. Some subcomponents of the indicator have longer-term monitoring histories throughout the Great Lakes or in target areas (e.g. at least as early as 1999 for vegetation, 1997 for invertebrates, 1990 for fishes, and 1995 for birds and amphibians).

Data developed by the Great Lakes Coastal Wetland Consortium (GLCWC) can be reported/summarized at any spatial unit of interest; by subunits within a site, by site, by wetland class (e.g. lacustrine, barrier-protected, and riverine), by lake subbasin, by lake, or for the entire GL Basin. We suggest analysis at the lake or subbasin spatial scale using summary metrics at each site.

Measurement of progress: Overall, improvement in the summary wetland condition index would reflect improvements in coastal wetlands health. Scoring for the Vegetation, Macroinvertebrate, Fish, Amphibian, and Bird subcomponents are described in detail in Uzarski *et al.* 2011 and the individual measures could be used to assess progress for each subcomponent.

Data Evaluation:

Sufficiency and accessibility: Under the current GLCWC project nine Universities and three government organizations function as one large unit to coordinate and standardize coastal wetland sampling and data reporting. Data, complete metadata, and biannual reports to GLNPO will be compiled and housed at the Natural Resources Research Institute (NRRI) at the University of Minnesota-Duluth (this compilation is currently under the direction of Valerie Brady). This specialized database will be dedicated to GLCWC monitoring data and include 1) GIS polygons with sampled wetlands and sampling locations within each wetland, 2) water quality data, 3) macrophyte taxa, % cover metrics, and FQI, 4) macroinvertebrate taxa, counts, and IBI scores, 5) fish taxa, counts, and IBI scores, 6) amphibian taxa and IBI scores, and 7) bird taxa and IBI scores. IJC will have unlimited access to these data at any level, from the raw data (e.g. counts, species lists, etc.) to the combined subcomponent scores in a single summary measure, and at all spatial scales (e.g. summaries can be requested at any desired spatial scale).

Additional needs: Since this is an ongoing project, the summary metric (i.e. a single combined measure of overall wetland health based on the seven subcomponents) and assessments of chemical/physical condition and wetland area and extent will not be immediately available. It is also worth mentioning that this fine-scale sampling of wetland conditions for evaluating trends is very expensive. Although satellite derived maps of coastal wetlands are currently sufficient to compare wetland change from the early 2000s to 2008-2010, regular updating of such maps should be supported in order to continue calculations of the wetland area and extent subcomponent of this indicator.

Required data processing and calculation effort: We recommend using summary data provided though the NRRI maintained database to monitor trends in the extent, composition, and quality of coastal wetlands in the Great Lakes. Summary data from sites within a lake basin or subbasin may need to be combined but these efforts should require minimal processing and calculation effort.

References:

Albert, D.A. 2008. Great Lakes Coastal Wetlands Monitoring Plan, Chapter Three, Vegetation Community Indicators. Developed by the Great Lakes Coastal Wetlands Consortium, A project of the Great Lake Commission. Available at http://www.glc.org/wetlands/final-report.html.

Crewe, T.L. and S.T.A. Timmermans. 2005 Assessing Biological Integrity of Great Lakes Coastal Wetlands Using Marsh Bird and Amphibian Communities, Project # WETLAND3-EPA-01 Technical Report. Available at http://www.oiseauxcanada.org/download/MMP%20GLCWC%20Technical%20Report%202005.pdf;

Uzarski, D.G., T.M. Burton and J.A. Genet. 2004. Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline. Aquatic Ecosystem Health & Management 7:269-288.

Uzarski, D.G., T.M. Burton, M.J. Cooper, J.Ingram and S.T.A. Timmermans. 2005. Fish habitat use within and across wetland classes in coastal wetlands of the five Great lakes: Development of a fish-based index of biotic integrity. Journal of Great Lakes Research 31:171-187.

Uzarski, D.G., T.M. Burton, J.C. Brazner and J.J.H. Ciborowski. 2008. Great Lakes Coastal Wetlands Monitoring Plan, Chapter Five, Fish Community Indicators. Developed by the Great Lakes Coastal Wetlands Consortium, A project of the Great Lake Commission. Available at http://www.glc.org/wetlands/final-report.html.

Uzarski, D.G., V.J. Brady and M. Cooper. 2011. Quality Assurance Project Plan, GLIC: Implementing Great Lakes Coastal Wetland Monitoring. Report prepared for: U.S. EPA GLNPO, Project Identifier: EPAGLNPO-2010-H-3-984-758.

Relevant 2009 SOLEC Indicators:

#4501 Coastal Wetland Invertebrate Communities

#4502 Coastal Wetland Fish Community Health

#4504 Wetland Anurans

#4507 Coastal Wetland Bird Communities

#4510 Landscape Extent and Composition

#4862 Coastal Wetland Plant Communities

Some progress reports on these indicators available at http://www.solecregistration.ca/en/indicator_reports.asp

Indicator Data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Great Lakes Coastal Wetland Consortium Coastal (GLCWC) Wetland maps (original and modified)	For the original map: John Hummer, 734-971-9135jhummer@glc.org, or GLAHF: Lacey Mason, Data Analyst, 734-663-3554 ext. 12155, lmas@umich.edu or Catherine Riseng, Assistant Research Scientist, 734-763-9422, criseng@umich.edu) For original or modified map: GLAHF	No restrictions on access Contact GLAHF for distribution of original or modified map or download original file from http://glc.org/wetlands/inventory.html Available as GIS shapefiles	Original map: Published in 2006 all coastal wetlands in the Great Lakes basin were digitized resulting in over 7000 wetland polygons. Modified map: Wetland scientists reviewed the original GIS maps and modified them to more accurately reflect current condition (eliminating nonexistent wetlands and small wetlands, and combining many separated wetlands); Modified shapefile contains 1039 wetlands (all >4 hectares).	Includes variables for size, lake basin, hydrogeomorphic class, and various structures (jetties, dykes, marinas, etc). Original map: Due to existing data limitations, estimates of coastal wetland extent, particularly for the upper Great Lakes are acknowledged to be incomplete. The modified map serves as the base map for stratified sampling program in the 2011-2015 GLCWC project.
B	Michigan Tech Research Institute (MRTI): Coastal Wetland and Land Cover mapping	Laura Bourgeau-Chavez, 734-913-6873, Laura.chavez@mtu.edu	No restrictions once maps are developed. Note: There is some uncertainty about the future development of these maps. The satellite that produces the imagery fell out of orbit and a new satellite is expected to be launched. However, the	MTRI is charged with "recreating" Coastal Wetland and land-use maps based on recent (2008-2010) high resolution imagery and radar. New maps are based on imagery and ground-truthed with field data Status as of 3/2013 Finished with all of Lake Michigan, US	Minimum mapping unit for wetlands is ½ acre. Maps define wetlands based on vegetation type; these detailed classes can be collapsed into more general wetland classes. Also includes land cover classes of coastal areas

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			contract to receive and process the satellite data has not yet been renewed.	side of Huron, and about ½ of Lake Erie; mapping of Lake Ontario and Superior are not done; All maps expected to be done by May 2014.	
C	Central Michigan University (CMU) and various researchers affiliated with GLCWC	Don Uzarski, CMU Associate Professor and Director of CMU Institute for Great Lakes Research, 989-774-2504, uzars1dg@cmich.edu	For IJC: No restrictions on raw data or summaries of condition; lay public only has access to summarized data Contact Don for access to historical, current, and future data and summaries	Data collected prior to 2011: Don indicates he has access to or can supply contacts to provide access to much of the data collected prior to 2011; This includes work by Denny Albert (vegetation), Don Uzarski (inverts and fish), Thomas Burton (fish), and Crewe and Timmermans (birds and amphibians). 2011-2015: Don is also the contact; Data, complete metadata, and biannual reports to GLNPO will be compiled and housed at the Natural Resources Research Institute (NRRI) at the University of Minnesota-Duluth under the direction of Valerie Brady. NRRI database will be dedicated to GLCWC monitoring data and include 1) GIS polygons with sampled wetlands and sampling locations within each wetland, 2) water quality	Historical data includes the following studies: Vegetation: Albert 2008: only metrics available, no raw data; 40 wetlands across four regional areas of lakes Erie, Ontario, and Huron. Invertebrates: Uzarski *et al.* 2004: 22 wetlands in Lakes MI and HU during 1997-2001. Fish: Uzarski *et al.* 2005 and Uzarski *et al*. 2008: 61 wetlands across five lakes, nine ecoregions, four wetland types in 2002. Birds and amphibians: Crewe & Timmermans 2005: sampled 88 bird and 87 amphibian Great Lakes coastal wetlands; Based on Canadian Marsh Monitoring Program collected data from 1995-2003.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				data, 3) macrophyte ID, cover %s and FQIs, 4) macroinvertebrate IDs, counts, and IBIs, 5) fish IDs, counts, and IBIs, and 6) amphibian IDs and IBIs, and 7) bird IDs and IBIs.	

Water Temperature

Summary:

The water temperature indicator tracks trends in water temperature and ice cover metrics.

Spatial coverage: Water temperature and ice cover data are available for the five Great Lakes.

Temporal coverage: Temperature measures are available from 2006/7-2010/11 and Ice Cover data are available from 1973-2011.

Data processing needs: Desired components need to be specified (suggestions are included). The required data are available and accessible. Processing and calculation effort should be minimal as much of the processing of these data has been completed by other groups.

Indicator Details:

The Water Temperature Indicator tracks trends in water temperature and extent of winter ice cover for the open water and nearshore areas for each of the five Great Lakes.

Components:	**Component specifications:**	**Data source: (see data table)**
Water temperature:	Surface water (annual summer average temperature)	A
	Vertical water temperature summaries	B
Ice Cover:	Timing of 1st ice, last ice, and/or ice duration	C
	Mean ice cover (%)	C
	Maximum ice cover and date	C

Calculations:
Water temperature: Draft indicator: "It has not been decided how to properly represent surface temperature data and vertical profiles. It is suggested that annual summer (July-September) average temperatures be calculated for each lake. Contours of surface water temperature for open water are visually descriptive, but average values by lake segment (2 to 4 segments per lake) may be more easily understood by most interested persons."

We suggest using GLAHF derived summaries of existing surface water and vertical profiles of temperature, and applying identical procedures to future temperature measurements. These summaries meet the stated needs of the indicator by converting daily surface temperatures into averages by season (Spring, Summer, Fall) and complex daily vertical temperature profiles into seasonal averages (Spring, Summer, Fall) within three depth bins (0-20m, 20-40m, and >40m).

Ice cover: The draft indicator does not suggest specific measures to use for this portion of the indicator. We suggest several measures similar to those included in SOLEC Indicator #4858 and NOAA technical reports. According to the 2009 SOLEC report Great Lakes data showed no conclusive trends with respect to dates of ice on and off, possibly because of known biases of pre-satellite observations. We suggest a similar analysis examining ice timing and/or duration but restricted to years with frequent satellite imagery (e.g. 1989+). Additional suggested measures include typical ice concentration, maximum ice cover and timing of maximum ice cover. If measures other than these are desired, data availability of desired measures can be addressed through review of data C in the data availability table.

1) Trends in day of 1st ice, day of last ice, and/or length of ice duration,
2) Trend Analysis: Mean ice cover (in percent) during ice duration by lake by year (see Fig 5 in GLERL Technical Report 155 as an example), and/or
3) Trend analysis: Plot of maximum Ice cover (%) and Maximum Ice Cover Date (Julian) from 1973-present (see Figure 1 in 2009 SOLEC report #4858).

Combination of components: Surface temperature data will be used as the summer corollary to winter ice conditions. Water temperature and ice cover components will likely support similar conclusions.

Spatial and temporal coverage: Calculations should be completed for each lake. Quality historical water temperature data is lacking, but ice data has a long history.

Measurement of progress: Higher temperatures and less ice cover are signs of altered condition. Higher water temperatures and less ice cover may be related to more and earlier algae blooms which damage water quality and habitat. Higher temperatures may also be related to the spread of some invasive species or reduced range of some native species. Less ice cover increases wintertime evaporation that reduces lake level and exposes the shoreline to waves generated by winter storms that accelerates erosion. In addition, less ice cover and higher temperatures may signal climate change conditions.

Data Evaluation:

Sufficiency and accessibility: Data are sufficient and easily accessible for calculation of this indicator. Note, however, that time spans for temperature and ice cover data differ substantially (i.e. 2006+ for temp, 1973+ for ice cover). Because of the short time span, it may be difficult to observe significant trends in water temperature. The time span for ice cover data should be sufficient to observe trends. We are not aware of any detailed temperature maps prior to Great Lakes Coastal Forecasting System/Great Lakes Operational Forecast System models.

Although older ice cover data has been digitized (1960-1979 ice cover was digitized in 1994 by NOAA's Earth System and Data Information Management Program and is available at http://www.nsidc.org/data/g00804.html), we do not recommend comparing these summaries to those contained in and modeled after the 1973-2002 ice cover atlas. The 1973-2011 compiled data is more comprehensive in the amount and type of information digitized. "It also differs from the earlier data set in that it is based on composite ice charts, while the earlier data set is based on synoptic ice charts. Synoptic ice charts are coincident observations, usually covering only a portion of the Great Lakes, while composite ice charts are a summary of all available ice information for the entire surface of the Great Lakes for a given date. Composite ice charts may contain estimated ice conditions in portions of the Great Lakes not observed, e.g., extrapolation from observations on earlier dates, interpolation, or climatology for areas not observed" (excerpt from NOAA technical report 121).

We are also aware of single time and repeated seasonal temperature data collected within the Great Lakes. These include temperature measures collected by buoys maintained by the Great Lakes Observing System (GLOS) and other organizations, and GLNPO collected water temperature data. However, because of the limited spatial and temporal coverage of such data, we do not feel these data would be particularly useful for the water temperature indicator.

Additional needs: No additional data needs have been identified; however the indicator components should be explicitly defined.

Required data processing and calculation effort: Potentially minor for recent temperature data; GLAHF have summarized data and a minor effort would be required to summarize recent/future data at different time or spatial scales. Minor for ice cover data; some data are presented in summarized format and might be directly applicable (depending on the specific components that are chosen for the indicator). However, some of the grid data will need to be averaged within a lake and across the desired time span.

References:

Assel, R.A., D.C. Norton and K.C. Cronk. 2002. A Great Lakes ice cover digital data set for winters 1973-2000. NOAA Technical Memorandum GLERL-121. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 45 pp. Available at http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-121

Assel, R.A. Great Lakes ice cover climatology update: Winters 2003, 2004, and 2005. 2005. NOAA Technical Memorandum GLERL-135. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 21 pp. Available at http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-135/

Wang, J., R.A. Assel, S. Walterscheid, A.H. Clites, and X. Bai. 2012. Great Lakes ice climatology update: Winter 2006-2011. Description of the digital ice cover dataset. NOAA Technical Memorandum GLERL-155. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 37 pp. Available at http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-155

Relevant 2009 SOLEC Indicators:

#4858 Climate Change: Ice duration on the Great Lakes

Indicator data:

Water temperature:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	GLAHF/CSCOR developed water surface temperature summaries	Lacey Mason, Data Analyst, 734-663-3554 ext. 12155, lmas@umich.edu Catherine Riseng, Assistant Research Scientist, 734-763-9422 criseng@umich.edu)	Calculated product available through request from contacts with potential to develop summaries for future data. Format: ESRI grid clipped by Great Lake basin with lake assignment specified	Satellite imagery depicting daily surface temperature of the Great Lakes was obtained from the NOAA's Great Lakes CoastWatch program. This program generates 1.8 km resolution data using satellite AVHRR (Advanced Very High Resolution Radiometry). Daily surface temperature images were converted to an ESRI grid clipped by Great Lake basin.	The surface temperature summaries are averaged from a daily time step into the temporal averages for: April-June (days 91-181); July-September (days 182-273) (recommended); October-December (days 274-365); and the warmest 30 day period calculated from the surface temperature during the entire calendar year (day ranges vary). 2007-2010 is currently summarized Units are degrees Celsius; Geographic Coordinate System is NAD83
B	GLAHF/CSCOR developed vertical profile temperature summaries	Lacey Mason, Data Analyst, 734-663-3554 ext. 12155, lmas@umich.edu Catherine Riseng, Assistant Research Scientist, 734-763-9422	Calculated product available through request from contacts with potential to develop summaries for future data. Format: ASCII with header information	GLOFS data was obtained from NOAA-GLERL in NetCDF format. The data was processed using Python 2.7 and the netCDF4 module downloaded from (http://code.google.com/p/netcdf4-python/). The data was converted from NetCDF	The original modeled data calculates results for every 3 hours; these were averaged into the temporal averages of April-June (days 91-181); July-September (days 182-273) (recommended); October-December (days 274-365); and the warmest

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		criseng@umich.edu)	included. Projected in Lambert and vary for each lake. Projection files included with data. Through description of Great Lakes Operational Forecast System (GLOFS) at http://www.glerl.noaa.gov/pubs/fulltext/2011/20110016.pdf	to .csv for each time step and sigma level. The data was then averaged into actual depth bins from the sigma layers, and then temporally averaged for each horizontal grid cell. Vertical temperature summary in this layer are averaged from the sigma levels for each lake into depth bins of 0-20 m, 20-40 m, and > 40 m.	30 day period calculated from the surface temperature during the entire calendar year (day ranges vary). 2006-2011 is currently summarized.
C	NOAA (GLERL)'s An Electronic Atlas of Great Lakes Ice Cover Winters: 1973 – 2002, 2003-2005, 2006-2011 (*3 separate publications*)	Contact: iceatlas.glerl@noaa.gov. Overview of the program at http://www.glerl.noaa.gov/data/ice/atlas/ Summary reports: 1973-2002: http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-121/tm-121.pdf 2003-2005: http://www.glerl.noaa.gov/ftp/publication	This Atlas contains approximately 1.4-gigabytes of data, much of which is in compressed files (about 4-gigabytes when uncompressed). Because of its large size it is not practical to download the entire atlas from the Internet. Therefore, it is also being made available on CD-ROM and DVD formats. To request a copy of the atlas on CD-ROM or DVD send an email to iceatlas.glerl@noaa.gov	A 30-winter (1973-2002) set of composite ice charts was digitized, and a multi-winter statistical analysis of the climatology of the ice cover concentration was completed. The results of this analysis are published as an electronic NOAA Great Lakes Ice Atlas. Three Analysis Products: 1) Ice charts of dates of the first reported ice, dates of the last reported ice, and ice duration for each winter, as well as, the maximum, minimum and average ice cover concentrations; 2) 30-year	In 3 separate publications by date; will continue to be published at regular intervals as NOAA Technical Memoranda 2003-2005 updates 30 year analysis by Assel and includes all of the same measures although the grids used changed in 2006 and again in 2007. Ice concentration recorded to the nearest 10% within a cell Average # of days between ice charts has varied: Approx

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		s/tech_reports/glerl-135/ 2006-2011: http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-155/	Available in a variety of formats: ASCII grids, graphic files, and Arcfeature class (2007+) No restrictions on use.	annual daily ice cover time series. Used to create computer animations of spatial patterns of ice cover for each winter and line plots of lake averaged ice cover for each lake over the 30 winters; and 3) weekly statistics of ice charts and grids of: maximum, 3rd quartile, median, 1st quartile, and minimum ice cover concentrations for the 30-winter base period. The weekly statistics are based on the original ice chart data set and not on the daily time series.	7.5 days pre 1989, 2 days from 1989-1995, 3 days from 1996-2010 and 1 day in 2011.

Water Level

Summary:

The water level indicator tracks trends in the average, timing, and variability of lake water levels. It may also include a measure of the effects of water level on ecological systems.

Spatial coverage: Includes the five Great Lakes (MI/HU combined) and Lake St. Claire.

Temporal coverage: As early as 1860 for some lakes. All monthly average lake levels are from 1918 to present. Time span of daily lake levels varies with lake and monitoring station.

Data processing needs: Monthly and yearly averages can be used as supplied; Components requiring daily values may require scaling up from station specific measures (procedure is established); Links between water levels and effects on emergent wetlands are currently being established and require further development.

Indicator Details:

The water level indicator tracks trends in the average, timing, and variability of lake water levels. It may also include a measure of the effects of water level on ecological systems. For components 1-4 for each lake (with exception of combined Lake Michigan and Lake Huron), the following information is reported:

Components:	**Component specifications:**	**Data source: (see data table)**
1) Mean lake level	Monthly mean lake level; Yearly mean lake level	A
2) Lake-wide annual range in monthly averages	Maximum of monthly average minus minimum monthly average within a calendar year	A
3) Lake-wide seasonal peak	Days after January 1	B & C
4) Lake-wide seasonal minimum	Days after September 1	B & C
5) A measure of the effects of water levels on ecological systems	Needs further development	Potential: D, E, F, G, H & I

Calculations: Calculations for components 1-4 are straightforward once the data are in the proper format (see notes on daily lake levels in data evaluation section). A comparison of component 1 to some average measure (e.g. USA & CAN compare monthly average to 1) monthly average for 1918-2011 (or desired historical time span) and 2) monthly average one year ago) is likely desired. Changes in the variability of lake levels and timing of lake peaks/minimums can also be compared to historical values, historical averages, and/or recent averages. These comparisons help us understand long and short-term trends in lake level and yearly variability in lake levels. Component five, a measure of the effects of water levels on ecological systems will likely be a qualitative description.

Combination of components: Components address both lake levels and variability in lake levels. Without knowledge of proper weighting these should be combined conceptually for now.

Spatial and temporal coverage: Lakes Superior, Michigan/Huron, Ontario, Erie and Lake St. Claire; Canadian gauges also include Georgian Bay. Temporal coverage is as early as 1860 to present. Monthly and yearly data complete for 1918-present. The earliest daily lake levels measures vary by station. Current water level data are collected in time increments as small as six minutes at certain stations.

Measurement of progress: Examine trends in components 1-4 listed above. In general, both extreme high and extreme low lake levels could have detrimental consequences to the Great Lakes Ecosystem if they are outside of known natural water level regimes. An ecosystem objective is to maintain the diverse array of Great Lakes coastal wetlands by allowing, as closely as possible, the natural seasonal and long-term fluctuations of Great Lakes water levels. Two good resources explaining how recent meteorological events have affected lake level are data sources J and K.

Data Evaluation:

Sufficiency and accessibility:
Components 1 & 2: Yes. Historic and current data are available and easily accessed and will continue to be recorded/ available in the foreseeable.

Components 3 & 4: Somewhat. Data are available now and will continue to be recorded/ available in the foreseeable, but require substantial processing to compile and "scale-up" from station to lake values. See calculation effort for more details.

Component 5: Marginally. Data are limited and need further development. May want to expand component to address effects of water level on Great Lakes ecosystems rather than limit to coastal wetlands.

Additional data needs: Component 5 requires the ability to translate lake levels into measureable impact on nearshore habitat and wetland vegetation and/or ecological systems. The current ability to translate lake levels into measurable impact varies between lakes and with vegetation type (see SOLEC Indicator #4861 for more detail). Data gaps exist and preclude a full assessment of impacts. However, five recent developments may help in these assessments. First, a recent attempt to quantify the effects of low water level on *Phragmites* is the Michigan Tech Research Institute developed and U.S. Geological Survey hosted *Phragmites* mapper. This viewer can be used to explore changes in habitat suitability for *Phragmites* with specific decreases in lake water levels. For example, quoting from the viewer's website, "At finer scales, the habitat suitability index and corridor networks provide insight to different aspects of vulnerability, and may help to guide strategic control and restoration programs. For example, in a heavily infested area, the reduced lake-level corridors identify where expansive shallow areas may become exposed and colonized. Knowledge of these locations could help prioritize intensive control efforts to reduce future expansion or assist with the establishment of restoration projects."

Secondly, a study by Jon Midwood and Pat Chow-Fraser of McMaster University sought to characterize fish habitat in coastal wetlands with respect to water quality and communities of aquatic plants, invertebrates and fish in Eastern Georgian Bay. Sites were resampled to observe changes in the fish and plant communities associated with wetlands that had been under low water levels for 10 years. The authors attributed observed declines in fish species richness and index scores to changes in fish habitat availability resulting from sustained low water levels.

A third approach may be to better understand how changes in lake levels specifically translate into changes in inundation. Although this may be possible with use of existing bathymetry maps, it may be refined using detailed nearshore maps such as those created through TRIAXUS side sonar tows and or recent LIDAR of the shoreline.

Two comprehensive studies on lake level and regulation, the Upper Great Lakes Study and the Lake Ontario St. Lawrence River study, may also provide some content for this component. "Progress" on component 5 depends entirely on which measures are chosen and data availability.

Required data processing and calculation effort:
Components 1 & 2: Essentially none.

Components 3 & 4: Extensive data processing required. Need to compile daily mean lake levels for select stations (Lake Superior Gauges: Duluth, MN; Marquette and Pt. Iroquois MI; Thunder Bay and Michipicoten, Ontario; Lake Michigan-Huron Gauges: Harbor Beach, Mackinaw City, and Ludington, MI; Milwaukee, WI; Tobermory and Thessalon, Ontario; Lake St. Clair Gauges: St. Clair Shores, MI and Belle River, Ontario; Lake Erie Gauges: Toledo and Cleveland, OH; Port Stanley and Port Colborne, Ontario; Lake Ontario Gauges: Oswego and Rochester, NY; Toronto, Cobourg, Kingston and Port Weller, Ontario). These data are available online in plain text format by station in yearly increments. They would need to be compiled by station and then "scaled-up" to lake.

The "scaling-up" process is described by the Hydrology Sub-Committee of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data: "Daily lake-wide water levels are calculated by averaging the individual gauge means. Prior to the averaging, the NOAA water level data must be rounded, using engineering rounding to the centimeter or 0.01 meters. Each gauge on a lake is averaged with the others, and then rounded again using engineering rounding to the centimeter. This rounded value is the coordinated daily lake-wide mean. If one or more of the coordinated gauges in the network is missing data, gauge pair logic is used to determine the daily lake-wide mean water level." Please see the Word document "Coordinating LWAs FINAL.doc" for more detail on this process.

Important note: IJC may have the leverage to acquire already processed daily mean lake levels, but these are not available online and my contacts at NOAA indicated compiled daily averages are not available to them even though daily averages are calculated to produce monthly and annual averages.

The best potential avenue for compiled lake-wide daily means may be U.S. Army Corps Engineers, Coordinating Committee on Great Lakes Basic Hydraulic & Hydrologic Data, Vertical Control (Water level subcommittee) co-chairs Jeff Oyler (Jeff.Oyler@noaa.gov) or Teresa Herron (terese.herron@dfo-mpo.gc.ca).

Component 5: This component, a measure of the effects of water levels on emergent wetland, is in development and a consensus needs to be reached as to how this component should be measured or assessed. There have been several discussions about whether this component would fit better within the Extent, Composition, and Quality of Coastal Wetlands Indicator. After an assessment of the data availability for the coastal wetland indicator, we feel this component should remain in this indicator. This component is outside of the scope of the Coastal Wetland Monitoring Program coordinated by Don Uzarski and would be difficult to incorporate with the summary metrics used in the coastal wetlands indicator. We suggest assessing this component through a literature review of studies exploring the effects of water level on Great Lakes ecosystems and describing status/progress rather than attempting some contrived mathematical calculation. Our data assessment includes some relevant studies.

References:

Coordination of Daily, Monthly and Beginning-of-Month Lake-Wide Mean Water Levels of the Great Lakes and Lake St. Clair. May 2010. Document produced by Hydrology Sub-Committee of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. Provided by Anne Clites.

Relevant 2009 SOLEC Indicators:

Great Lakes Water Levels: Draft 2012 report available for review at
http://www.solecregistration.ca/documents/Water%20Levels%20DRAFT%20May%202012v3.pdf

Indicator Data:

Components 1-4:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	NOAA Great Lakes Water Level Dashboard (original sources are NOAA/National Ocean Service's CO-OPS and DFO's Canadian Hydrographic Service	Anne H. Clites, Physical Scientist, NOAA Great Lakes Environmental Research Laboratory, 734-741-2282, anne.clites@noaa.gov	Download data from http://www.glerl.noaa.gov/data/now/wlevels/dbd/; Zipped Excel files; Water level data is in "levels" files/folder	2-3 files for each lake: Annual (Start, End, High, Low, & Average), Monthly (Lake-wide average, arbitrarily dated to the 1st of each month, as such dating has no significance), and pre1918 (monthly average)	Spatial coverage: SU, M/H, STC, ER, ON Temporal: 1860-1918 (all except ON and STC) and 1918-2013 (all lakes listed above) Some data missing pre-1918 but all data available from 1918 to present (with a 1-2 month lag in reporting)
B	NOAA Tides and Currents	Anne H. Clites, Physical Scientist, NOAA Great Lakes Environmental Research Laboratory, 734-741-2282, anne.clites@noaa.gov)	http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic+Great+Lakes+Water+Level+Data Daily means (in m) accessible in plain text format by station in yearly increments	To assess data availability by station: Click on station name and "data inventory" and record time frame with "Verified Daily Mean"	Recommended stations: See Table 1 in Coordinating LWAs FINAL.docx
C	DFO: The Canadian Hydrographic Service: Central and Arctic Region	Tides Currents and Water Levels Section is a unit within the Technical Services Division 1-877-247-5465) or CATCWL@dfo-mpo.gc.ca	http://www.waterlevels.gc.ca/C&A/gs_selection_e.html Hourly lake levels at each Canadian monitoring station;	Real-time last and current month data available online	Canadian Gauges: SU (5), HU & Georgian Bay (8), ER (7), and ON & STL (11)

Component 5: Effects of water levels on emergent wetland

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
D	The GLRI developed *Phragmites* Decision Support Tool Mapper hosted by USGS	Laura L. Bourgeau-Chavez, Research Scientist, Michigan Tech Research Institute,734-913-6873, laura.chavez@mtu.edu Colin Brooks, Research Scientist, Manager of the Environmental Sciences Lab, 734-913-6858, colin.brooks@mtu.edu	Viewer is available at http://cida.usgs.gov/glri/phragmites/	Can use viewer to explore how suitable habitat for *Phragmites* is affected by lower lake levels.	Limited to US coastal areas; Predicted layers can be downloaded for use in GIS.
E	TRIAXUS Side Sonar	EPA: Glenn Warren, warren.glenn@epa.gov, Peter Yurista yurista.peder@epa.gov, & Jack Kelly kelly.johnr@epa.gov	Some data is published (e.g. for Lake Huron, Environmental Management (2012) 50:664-678); Data should be publically available since it is collected by EPA	Would want habitat maps created from side-sonar	Interested in nearshore tows: Began in 2009 in Lake MI, then to Superior and Huron.
F	SOLEC Indicator #4861: Effect of alternation of Natural Water Level Fluctuations	Norm Grannemann, 517-887-8936, nggranne@usgs.gov	http://www.epa.gov/solec/sogl2009/4861waterlevels.pdf	N/A	2009: Summarizes development of SOLEC indicator and effects by lake. Future updates of this indicator may help inform IJC indicator
G	Water-level-induced changes in fish communities in coastal wetlands	Jon Midwood and Pat Chow-Fraser Department of Biology, McMaster University	Report at: http://www.iugls.org/DocStore/ProjectArchive/ECO_Ecosystem/ECO07_ChowFraser_GeorgianBa	Results of this study will help the OMNR understand the potential negative impact of sustained lower water levels on fish habitat and fish	No statistically significant changes in macrophyte species richness with decrease in lake level, but did observe declines in fish

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	of eastern Georgian Bay: Final Report	Contact Chow-Fraser, Professor, 905-525-9140, CHOWFRAS@MCMASTER.CA	yPI/Reports/ECO07-R1_MidwoodChowFraser_OMNRreport.pdf	community dynamics. Goal of sampling: To characterize fish habitat in coastal wetlands with respect to water quality and communities of aquatic plants, invertebrates and fish Sites resampled to observe changes in the fish and plant communities associated with wetlands that had been under low water levels for 10 years.	richness and fish index Observed declines in fish species richness and index scores attributed to changes in fish habitat availability resulting from sustained low water levels.
H	Lake Ontario St. Lawrence water level study (LOSL)	IJC An overview of the study and access to all documents is available at http://www.losl.org	Final report available at http://losl.org/PDF/report-main-e.pdf	Limited to Lake Ontario and St. Lawrence River. One goal of study was to "review the current regulation of levels and flows in the Lake Ontario-St. Lawrence River system, taking into account the impact of regulation on affected interests." This included an assessment of the effects of lake level regulation on ecological systems.	Reduced range and occurrences of extreme Lake Ontario levels has resulted in "a more narrowly defined transition zone within wetlands from submerged to upland plants, thus reducing the diversity of plant types along the shore and populations of animal species who feed on and live in the environments affected by the reduced water level ranges. Regulation has also caused dewatering drawdowns in the fall through early spring, to the detriment of some habitat".

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
I	International Upper Great Lakes Study (IUGLS)	IJC An overview of the study and access to all documents is available at http://www.iugls.org/	Final reports available at http://www.iugls.org/Final_Reports	Limited to Lake Superior and St. Clair River but also explored effects on Lakes MI and HU. The proposed Lake Superior Regulation Plan 2012 will reduce the Month-to-month changes in flow on the St. Marys River, giving the St. Marys River a more natural flow relationship to Lake Superior levels, an important factor in sustaining the health of the river's ecosystems.	Effects on Lake MI/HU: "Positive environmental effects would be concentrated in the wetlands of the Georgian Bay region, which have suffered during low water levels in the past and would benefit from higher Lake Michigan-Huron levels."

Meteorological effects on lake level:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
J	Environment Canada: LEVEL news	LEVELnews-infoNIVEAU@ec.gc.ca	http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=F6F3D96B-1	LEVELnews is a monthly newsletter that provides an update on Great Lakes - St. Lawrence River water levels.	Not numerical data rich, but information rich. Details lake levels and how recent Canadian weather patterns have affected lake levels.
K	USACE: Monthly Bulletin of Great Lakes Water Levels	For hard copies: Call (313) 226-6441 or email hhpm@usace.army.mil	http://www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/waterlevelforecasts/monthlybulletinofgreatlakeswaterlevels/	Monthly newsletter that provides an update on Great Lakes water levels.	Similar to Canadian LEVEL news except with meteorological data for USA.

Atmospheric Deposition of Toxic Chemicals

Summary:

This indicator will report on spatial patterns and temporal trends of persistent, bioacummulative, and toxic chemicals (e.g. PCBs, Endosulfans, DDT and metabolites, Flame retardants, and Mercury) in the atmosphere and precipitation loads to the Great Lakes region.

Spatial coverage: A binational air deposition monitoring program include 5 master stations (one for each lake) and 14 satellite stations. Environment Canada monitors air pollution at 30 stations in the Canadian Great Lakes Basin, with a concentration of stations in Southern Ontario. Mercury deposition is monitored by the USA throughout the Great Lakes Basin with concentrated monitoring in Michigan.

Temporal coverage: Binational monitoring of the deposition of toxic chemicals began in 1990 and emerging chemicals are added to the monitoring program as they arise. Air pollution monitoring in Canada began in 1969. Mercury concentrations and deposition in the Great Lakes Basin have been monitored by the USA since the mid 1990s. All of these monitoring efforts are expected to continue.

Data processing needs: Sufficient and easily accessible data from multiple sources are available for the calculation of the components of the Atmospheric Deposition of Toxic Chemicals indicator. However, consensus needs to be reached on how the components will be calculated and how spatial and temporal trends will be analyzed.

Indicator Details:

This indicator will report on spatial patterns and temporal trends of persistent, bioacummulative, and toxic chemicals in the atmosphere and loads to the Great Lakes region. Particular chemicals suggested in the draft indicator are included as components below.

Components:	Component specifications:	Data source: (see data table)
PCBs	Average annual concentrations, fluxes, and loads	A & B
Pesticides (esp. Endosulfans)	Average annual concentrations, fluxes, and loads	A & B
DDT and metabolites	Average annual concentrations, fluxes, and loads	A & B
Flame retardants (as a group, or PBDEs and TBB/TBPH)	Average annual concentrations, fluxes, and loads	A & B
Mercury	Average annual concentrations and deposition loads	C & D

Calculations: This indicator requires calculation of average annual concentration, fluxes, and loads for mercury and average annual concentration, fluxes, and loads for toxic chemical other than mercury. Spatial and temporal analyses of these components are not clearly defined in the draft indicator. The draft indicator states “Spatial and temporal trend analyses will be performed…using a variety of statistical tools (see references)." We have included these references in this data assessment report. These analyses largely include complex regression models and plots of the residuals of these regression models over time. We have included a description of these analyses in the data table. Most of these analyses are performed by researchers in Ronald Hites Laboratory at Indiana University. The International Atmospheric Deposition Network (IADN) also regularly reports some summary data for each lake for certain chemicals (e.g. annual atmospheric fluxes in ng/m^2/day for dry, wet, absorption, and volatization, Monthly fluxes in ng/m^2/day for dry, wet, absorption, and volatization, and annual loads in kg/yr for about 25 chemicals). In order to calculate each component of the indicator, a consensus needs to be reached to determine whether the indicator will be calculated with raw data or whether analyses by other parties will be used.

Combination of components: Combination of these components is not addressed in the draft indicator and is beyond the scope of this contract effort.

Spatial and temporal coverage: The International Atmospheric Deposition Network (IADN) began monitoring in 1990. Annual estimates of toxic chemical deposition at the lake level are available from 1992-2005 and will be published at regular intervals by the IADN. Raw data from the 5 master stations and 14 satellite stations are also available. The list of toxic chemicals IADN measures is regularly updated to include emerging chemicals of concern, such as flame retardants; therefore the length of monitoring varies by chemical. Environment Canada's National Air Pollution Surveillance Network (NAPS) began in 1969 with 30 stations nation-wide and has expanded to 286 stations today. About 30 of these sites are in the Canadian GL basin, concentrated in Southern Ontario. The Mercury Deposition Network (MDN) began in 1996 and has 12 active and 5 historical sites within the GL basin. The Michigan Mercury Monitoring Network (MIMMN) began in 1994 and has recently been funded by the Great Lakes Air Deposition Program to continue monitoring.

Measurement of progress: Reductions in concentrations and loads of toxic chemicals signifies progress. When possible, these assessments should be made from observation of long-term trends, as short-term atmospheric data is naturally variable and directional change is sometimes difficult to detect over short periods of time. However, with newly introduced chemicals only short term analyses are possible. It should be noted, though, that even short-term trend analysis may yield significant trends. Ma *et al.* (2012) observed significant increases in newly introduced flame retardants over a three-year period.

Data Evaluation:

Sufficiency and accessibility: Sufficient and easily accessible data are available for calculation of the Atmospheric Deposition of Toxic Chemicals indicator. Two monitoring programs, the binational Integrated Atmospheric Deposition Network (IADN) and the US-led Mercury Deposition Network (MDN), provide much of the data needed for the calculation of components for and assessment of the Atmospheric Deposition of Toxic Chemicals indicator. IADN's long-term monitoring program measures air deposition at regular intervals (as short as every 24 hours, as long as weekly) and publishes annual and monthly summaries of concentrations and deposition and annual loads by lake for around 25 toxic chemicals. Many additional chemicals are monitored but not summarized. Raw data and summary maps are available from MDN for mercury concentrations and loads.

An additional potential source of toxic air deposition measurements is Environment Canada's long running National Air Pollution Surveillance Network (NAPS). This program measures air quality for more than 340 types of chemicals with about 30 sites in the Canadian GL Basin and concentrated monitoring in Southern Ontario. NAPS may be an excellent source for additional data on dioxins and furan. The US also monitors air pollution through EPA's National-scale Air Toxics Assessment Program, but this program differs substantially from the Canadian monitoring program. Instead of measuring air pollution at stations, air pollution data is estimated from measurements from emission sources (e.g. industrial point and nonpoint emissions, vehicle emissions, regulatory program reports, etc.) and analyses are focused on risk assessment and human health effects rather than concentrations of toxic chemicals in depositions.

Additional needs: There are no additional data needs, but there does need to be consensus on exactly which toxic chemicals will be included in the indicator and how emerging chemicals will be incorporated in the indicator. There also needs to be a consensus on whether "raw" data will be used to calculate the components of the indicator or whether published summaries will suffice. Statistical approaches used in the spatial and temporal trend portion of the indicator also need to be chosen and it needs to be decided if these analyses will be completed "in-house" or whether incorporating a literature review summarizing trends will suffice.

Required data processing and calculation effort: If concentration and load calculations and spatial and temporal trend analyses are to be completed "in-house," the data processing and calculation effort will be significant. Because of the long-term history, the frequency of monitoring, and the large number of chemicals monitored, most data sources can supply thousands to millions of observations. Using published summaries will reduce the required effort.

References:

Atmospheric Deposition of Toxic Substances to the Great Lakes: IADN Results through 2005. Published by Environment Canada and the United States Environmental Protection Agency. US EPA Report Number: EPA-905-R-08-001. [+]

Ma. Y., M. Venier and R. Hites. 2012. 2-Ethylhexyl Tetrabromobenzoate and Bis(2-ethylhexyl) Tetrabromophthalate Flame Retardants in the Great Lakes Atmosphere. Environ. Sci. and Technol. 46:204-208.[*]

Prestbo, E.M. and D.A. Gay. 2009, Wet deposition of mercury in the U.S. and Canada, 1996-2005: Results and analysis of the NADP mercury deposition network (MDN). Atmospheric Environment 43: 4223-4233.[#]

Risch, M.R., D.A. Gay, K.F. Fowler, G.J. Keeler, S.M. Backus, P. Blanchard, J.A. Barres and J.T. Dvonch. 2012. Spatial patterns and temporal trends in mercury concentration, precipitation depths, and mercury wet deposition in the North American Great Lakes region, 2002-2008. Environmental Pollution 161:261-271.[#]

Salamova, A. and R. Hites. 2011. Discontinued and Alternative Brominated Flame Retardants in the Atmosphere and Precipitation from the Great Lakes Basin. Environ. Sci. and Technol. 45:8698-8706.[*]

Venier, M., H. Hung, W. Tych and R. Hites. 2012. Temporal Trends of Persistent Organic Pollutants: A Comparison of Different Time Series Models. Environ. Sci. and Technol. 46:3928-3934.[*]

Venier, M. and R. Hites. 2010a. Regression Model of Partial Pressures of PCBs, PAHs, and Organochlorine Pesticides in the Great Lakes' Atmosphere. Environ. Sci. and Technol. 44:618-623.[*]

Venier, M. and R. Hites. 2010b. Time Trend Analysis of Atmospheric POPs Concentrations in the Great Lakes Region Since 1990. Environ. Sci. and Technol. 44:8050-8055.[*]

[+]*Potential source of summarized IADN data*
[#]*potential examples of analyses for mercury analyses*
[*]*potential examples of analyses for other toxic chemicals*

Relevant SOLEC Indicators:

Atmospheric Deposition of Toxic Chemicals: Draft of 2012 indicator available at http://www.solecregistration.ca/documents/Atmospheric%20Deposition%20of%20Toxic%20Chemicals%20DRAFT%20Oct2011.pdf

Indicator Data:

"Raw" and summarized data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Integrated Atmospheric Deposition Network (IADN)	Helena Dryfhout-Clark, IADN Data Manager, Environment Canada, Science and Technology Branch, 705-458-3316, Helena.Dryfhout-Clark@ec.gc.ca Todd Nettesheim, IADN program manager, USEPA , 312-353-9153, nettesheim.todd@epa.gov)	Link to IADN data: http://www.on.ec.gc.ca/natchem/Login/Login.aspx All data (millions of measurements) are available online, but need to register a username and password online to access data; Note: We found this to be a very time-consuming, clunky interface. We suggest contacting Helena Dryfhout or Todd Nettesheim directly. Note: Can also download some preformatted graphs (annual statistics and plots across time) at the NAtChem portal. Annual/Monthly Fluxes and Annual Loads for major pollutants for 1992-2005 available in Appendices A, B, & D of	This joint United States-Canada monitoring network has been in operation since 1990. IADN consists of five master monitoring stations, one near each of the Great Lakes, (Eagle Harbor (USA) on Lake Superior, Sleeping Bear Dunes (USA) on Lake Michigan, Burnt Island (Canada) on Lake Huron, Sturgeon Point (USA) on Lake Erie and Pt. Petre (Canada) on Lake Ontario). There are also fourteen satellite stations.	Intent of IADN is to measure and evaluate more than 150 pollutant concentrations in the atmosphere (airborne vapor, airborne particles, and precipitation) at a lake-wide level of detail. Some stations collect hourly data, others every six days, others weekly. Every two years, measured concentrations for about 25 pollutants are summarized as monthly and annual fluxes (ng/m^2/day) and combined with physical parameters to estimate annual loads (kg/yr) for each of the five Great Lakes. 1992-2005 data are currently published (see accessibility). PBDEs and some non-PBDE flame retardants recently added to routine monitoring program.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			http://www.epa.gov/greatlakes/monitoring/air2/iadn/reports/IADN_Toxics_Deposition_Thru_2005.pdf		
A'	Statistical analyses of IADN data: Ronald A. Hites' School of Public and Environmental Affairs Laboratory at Indiana University	Ronald A. Hites, Distinguished Professor, Indiana University, 812-855-0193, hitesr@indiana.edu (Amina Salamova, Marta Venier, and Yuning Ma are all in Hites' Lab Group)	Published figures are available for use with proper citations; hesitant to share more. The issue of further accessibility may require additional investigation.	See references for these manuscripts. Brief description of statistical analyses: Venier & Hites 2010a: multiple linear regression equations for concentrations of PCBs, PAHs, and organochlorine pesticides; equations include time, atmospheric temperature, the human population within a 25 km radius of the site, and wind speed and wind direction. Venier & Hites 2010b: Using a multiple linear regression model of the concentrations of several persistent organic pollutants in the atmospheric vapor and particle phases and in precipitation, analyzed a data set of about 700,000 values to determine the rate at which these	Brief description of statistical analyses (cont.): Salamova & Hites 2011: A multiple linear regression model was applied to concentrations of PBDEs, DBDPE, HBB, PBEB, and BTBPE to predict halving times. Venier *et al.* 2012: Evaluation of four time series models in terms of goodness-of-fit, long-term trends, and halving times. Ma *et al.* 2012: Two relatively new flame retardants, 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (TBB) and bis(2-ethylhexyl)-tetrabromophthalate (TBPH), were identified and quantitated in gas and particle-phase air samples. TBB and TBPH increased rapidly and significantly from

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				concentrations are decreasing.	2008-2010.
B	Environment Canada's National Air Pollution Surveillance Network (NAPS)	Tom Dann, 613-991-9459, dann.tom@etc.ec.gc.ca	For general information: http://www.ec.gc.ca/rnspa-naps/Default.asp?lang=En&n=5C0D33CF-1 Data is available upon request by email to RNSPA-NAPSINFO@ec.gc.ca Annual reports (1995-2006) and a list of chemicals measured are available at http://www.etc-cte.ec.gc.ca/publications/napsreports_e.html	The National Air Pollution Surveillance (NAPS) Network was established in 1969 as a joint program of the federal and provincial governments to monitor and assess ambient air in Canadian urban centres.	About 30 sites in Canadian GL basin, concentrated in Southern Ontario (few have data as early as 1969; program has grown nationwide from 30 sites to 286). Includes more than 340 types of chemicals. Consider using this source for additional dioxins and furan sources (restricted to 40 sites nationwide from 1988+).
C	Mercury Deposition Network (MDN) (part of the USA National Atmospheric Deposition Network (NADP))	David Gay, MDN Program Coordinator, 217-244-0462 dgay@illinois.edu	All raw data is available in CSV file for download at http://nadp.sws.uiuc.edu/nadpdata/mdnalldata.asp Annual gradient maps of precipitation-weighted mean concentrations and deposition are available in PDF, KMZ, and grid formats at	Note: NADP does not include measurement of toxic chemicals other than mercury. 12 active and 5 inactive monitoring locations within the Great Lakes Basin. Trends summarized in two publications: 1) Prestbo and Gay, 2009, Wet deposition of Mercury in the USA and CAN	Length varies with station but many stations have data for early 2000s to present; MDN program began in 1996 Automated wet-deposition collectors and precipitation gages measure mercury concentrations and wet deposition on a weekly basis. Reported data: Precipitation amount (mm), total mercury

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			http://nadp.sws.uiuc.edu/MDN/annualmdnmaps.aspx	1996-2005, Atmospheric Environment 43:4223-4233, and 2) Risch *et al.*, 2012, Spatial patterns and temporal trends in mercury concentrations, precipitation depths, and mercury wet deposition in the North American Great Lakes region, 2002–2008.	concentration (ng/L), total mercury deposition (ng/m^2), and type (wet, dry, trace). In 2011, the NADP Technical Committee instituted changes in the way NADP annual concentration and deposition maps are produced. It was decided to modify the original map series from a discrete contour map style to a continuous color gradient map style while incorporating an external, highly resolved precipitation dataset.
D	Michigan Mercury Monitoring Network Operated for the Michigan DEQ by the University of Michigan Air Quality Laboratory (UMAQL)	Frank Marsik, Associate Research Scientist, Synoptic and air pollution meteorology, U of MI, 734-763-5369, marsik@umich.edu Note: Gerald J. Keeler, the long-time director of this program passed away in 2011.	Recently funded GL Air Deposition (GLAD) project description available at http://www.glc.org/glad/funded_details.php?fid=7	Description of recently funded GLAD project: “This project assesses the spatial and temporal trends in speciated atmospheric Hg in both rural and urban areas in the Great Lakes. Trace element measurements collected concurrently with the Hg concentrations will allow for site specific and regional source apportionment and transport analysis to be performed. This project will continue the long-term event based Hg	Began in 1994 as a two year study and recently funded by GLAD. Daily precipitation-event-based samples (would need to be converted to weekly values to use with MDN and IADN data)

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				deposition record at the three rural sites at Dexter and Pellston, MI, the two longest running event precipitation sites in the Great Lakes, and Eagle Harbor, MI, to allow for trend analysis. The work will extend the geographic coverage of the MDN by providing sites in the upper and lower peninsula of Michigan, and a site in Ohio where there are no MDN sites currently in operation."	

Chemicals of Mutual Concern in Water

Summary:

This indicator proposes measuring the total concentrations and temporal trends in chemicals of mutual concern (CMCs) in water at selected offshore and nearshore sites in each lake.

Spatial coverage: Ideally this indicator will include all five Great Lakes with sites that represent the diversity of aquatic habitats in each lake. In reality, the most comprehensive data are limited to offshore regions of all lakes with limited data on Lake Michigan.

Temporal coverage: The most comprehensive monitoring program began in 1986 and monitors toxic chemicals during the spring isothermal period. Other monitoring efforts are temporally and spatially limited. Differences in technique and detection level improvements severely limit trend analyses.

Data processing needs: Data for this indicator are of limited sufficiency, especially for Lake Michigan. There are also many decisions that need to be made before this indicator can be calculated. Specific CMCs need to chosen, monitoring of the lakes needs to expand beyond offshore sites, and the potential role of including passive monitoring techniques needs to be assessed.

Indicator Details:

The indicator would summarize total concentrations and temporal trends in chemicals of mutual concern in water (specific chemicals suggested in discussion below), determined at selected offshore and nearshore sites in each lake on a two-to-three-year basis.

Components:	**Component specifications:**	**Data source: (see data table)**
Chemicals of Mutual Concern concentrations and temporal trends	At minimum, they will include PCBs, dieldrin, chlordane, DDT and metabolites, hexachlorobenzene and mercury These may also include current use pesticides (such as atrazine and metolachlor), selected pharmaceuticals, personal care, and veterinary product chemicals, selected perfluorinated surfactants	A, B, C

Calculations: The indicator will be developed by integrating data from direct measurements of aqueous concentrations of various CMCs. The CMCs of interest include, but are not limited to, PCBs, dieldrin, chlordane, DDT and metabolites, hexachlorobenzene and mercury. Additional chemicals of interest would include currently used pesticides (such as atrazine and metolachlor), selected pharmaceuticals, personal care, and veterinary product chemicals, selected perfluorinated surfactants. Both concentrations and examination of temporal trends in concentrations will be used to monitor progress.

Combination of components: Components will not be combined per se. Instead the indicator will include measures of the concentrations and temporal trends of each CMC. A generalized assessment of the concentrations and trends of toxic chemicals in the Great Lakes is likely possible.

Spatial and temporal coverage: Sampling is proposed to be conducted every two-three years at selected offshore and some nearshore sites during the spring isothermal period (maximum concentrations of many priority toxics have been reported during this time). Site selection should be representative of the diversity of aquatic habitats in each lake (i.e., nearshore sites at different distances from major tributary mouths, offshore sites in different basins), building off current efforts used for SOLEC indicators. Sampling protocol could follow the current SOLEC approach (i.e., 16-24 l volume collection in field followed by extraction in the lab). Analyses could be performed at desired scale, e.g. by site, by lake, or basin-wide.

Measurement of progress: We suggest using a measure from the 2012 draft SOLEC report on Toxic Chemicals in Offshore Waters: "When concentrations of toxic chemicals associated with existing water quality criteria in the offshore waters of the Great Lakes are no longer measurable above naturally-occurring levels by current technology, or are below existing water quality criteria and show a declining trend."

Data Evaluation:

Sufficiency and accessibility: For a number of reasons explained below, data for this indicator are of limited sufficiency, the primary existing monitoring program is likely to change, and the focus of this indicator may need to shift to an emphasis on chemicals of emerging concern as toxins in the Great Lakes continue to decline. The longest-term and most comprehensive monitoring program targeted at toxics in the Great Lakes is through Environment Canada's Great Lakes Surveillance Program (EC GLSP). Since this is a Canadian program, very limited monitoring has been done in Lake Michigan (although some historical data collected by USEPA/GLNPO does exist). Other monitoring efforts, such as those by US EPA/GLNPO and efforts associated with the Cooperative Science and Monitoring Initiative (CSMI) program provide spatially and temporally limited data.

Despite 25+ years of monitoring by EC's GLSP, improvements in technique and changes of detection levels for many CMCs limit the ability to compare concentrations and perform trend analyses. As toxin concentrations have been reduced in the Great Lakes, some to non-detectable levels, several of the CMCs measured by EC'S GLSP are being evaluated and sampling frequency may be reduced or these chemical may be dropped from the program. Future assessment of long-term trends may use sediments or biota as environmental quality indicators for these compounds.

We have included several extracts from Dove's 2012 draft SOLEC report in this report. These extracts detail Dove's and EC's concerns and proposed changes in more detail.

> "In the first years of monitoring for organic contaminants, whole water samples were collected. Special studies, conducted between 1992 and 1995, recommended collecting surface, dissolved

phase samples during the spring only. Prior to 2004, samples for organic contaminants were centrifuged to separate the dissolved and particulate fractions, and the dissolved fraction was prepared for analysis immediately after collection, on board the ship, using a Goulden large volume extractor. Extracts were stored and returned to Environment Canada laboratory facilities in Burlington, Ontario, for analysis using gas chromatography/mass spectrometry. Since 2004, we have improved the technique and the 16 – 24 L samples are now stabilized in the field, and brought back to a specially constructed clean laboratory at Environment Canada for extraction. Improvements in laboratory methods have resulted in much better (i.e., lower) detection limits for many compounds including PAHs and some organochlorines. For some parameters, the improvements mean that we have greater confidence in the more recent data compared to those obtained before 2004, but this also means that longer-term trends are difficult to determine.

A water quality guideline is no longer recommended for several of the organochlorine compounds (e.g. aldrin, chlordane, dieldrin, endrin, heptachlor and PCBs). Exposure to these compounds for aquatic organisms is primarily via sediment, soil and/or tissue, therefore assessment of environmental quality relative to sediment and fish tissue guidelines is instead recommended. Indeed, these compounds are relatively hydrophobic and are difficult to measure in surface waters. Because of those difficulties, and because of the short time period of higher quality data that is available for assessing trends, it may be more useful to assess longer term trends using sediments or fish as environmental quality indicators for these compounds.

Continued refinements of field and laboratory methods have both improved the quality of the sample results and reduced the resources required to conduct the program. Despite these improvements, measuring toxic contaminants in Great Lakes surface waters remains a challenging task. Concentrations of many substances are extremely low; in the part per quadrillion (1 × 10_15) to part per trillion (1 × 10_12) range. Routine monitoring for determining trends might be better accomplished, for some parameters, using sediment and fish samples. Contaminants in sediment can be used to indicate long-term changes in contaminant concentrations, as the settling of sediments represents a long-term sink for contaminants as they are gradually buried over time. Contaminants in fish are better indicative of the exposure of aquatic organisms to toxics in lake water and through their food chain. Because many of the legacy toxics are bioaccumulative and hydrophobic, higher concentrations can be measured in sediment and fish and these media are more appropriate for assessing ecosystem health. It remains important, however, to continue periodic monitoring of Great Lakes waters to verify concentrations and trends. Monitoring water concentrations is important for assessing compounds that are soluble in water such as certain in-use pesticides, selected legacy toxics as well as many of the compounds of emerging concern. Environment Canada is currently reviewing its programs and refinements are being considered. One proposal is to primarily use fish tissue measurements for tracking contaminant trends, supplemented with the periodic review of water column concentrations at selected offshore stations."

Additional needs: Given that specific CMCs are not identified in the revised GLWQA, it is recommended that a more formal collaborative process (potentially coordinated by the IJC, and involving scientists from all sectors) be developed over the next two years to identify CMCs slated for focus under the Agreement, including monitoring efforts and reporting standards. This work should draw on efforts that have already been undertaken to prioritize organic chemicals for potential focus in the region (e.g. Howard and Muir 2010), and allow an opportunity for public input. This process should be ongoing and allow flexibility to add or drop CMCs as the science and monitoring programs dictate.

Additional factors to consider in identifying measurement parameters for the CMC indicator include consideration of ongoing sensitivity issues (including continuing declines in legacy chemical concentrations); spatial and temporal considerations (e.g. number and locations of sites in nearshore vs. offshore areas and sampling frequency); changes in ancillary factors, such as food webs and climate (e.g. Carlson *et al.* 2010); and issues of statistical power and trend detection (e.g. Chang *et al.* 2012).

In addition to direct measurement it is recommended that managers also consider the potential additional monitoring value of passive techniques, such as semi permeable membrane devices (for SOCs, e.g. Alvarez 2010) and the polar organic chemical integrative sampler (POCIS) technique for polar compounds (e.g. Li *et al.* 2010). Such techniques are already in use in selected areas, and could be phased into more spatially extensive existing monitoring programs for toxic chemicals in the Great Lakes following a method development and evaluation phase. Resulting data could assist in determining local and regional differences in CMCs as well as further monitoring and management actions that might be pursued concerning CMCs in the Lakes.

Required data processing and calculation effort: Note: We are only able to assess the data processing and calculation effort for existing data sources and currently monitored CMCs. Although the process of comparing concentrations and performing trend analyses is relatively simple and straight-forward, knowing what data should and should not be included in these analyses requires detailed knowledge of the changes in chemical techniques used in EC's GLSP. This knowledge will need to be supplied by personnel such as Alice Dove at Environment Canada.

References:

Alvarez, D.A. 2010. Guidelines for the use of the semi-permeable membrane device (SPMD) and the polar organic chemical integrative sampler (POCIS) in environmental monitoring studies: U.S. Geological Survey, Techniques and Methods 1–D4, 28 p. Available at http://pubs.usgs.gov/tm/tm1d4/pdf/tm1d4.pdf.

Carlson, D.L., D.S. De Vault and D.L. Swackhamer. 2010. On the rate of decline of persistent organic contaminants in lake trout (*Salvelinus namaycush*) from the Great Lakes, 1970-2003. Environmental Science and Technology 44:2004-2010.

Chang, F., J.J. Pagano, B.S. Crimmins, M.S. Milligan, X. Xia, P.K. Hopke and T.M. Holsen. 2012. Temporal trends of polychlorinated biphenyls and organochlorine pesticides in Great Lakes fish, 1999–2009, Science of the Total Environment 439:284-290.

Howard, P.H. and D.C. Muir. 2010. Identify new persistent and bioaccumulative organics among chemicals in commerce. Environmental Science and Technology 44: 2277-2285.

Li, H.X., P.A. Helm and C. Metcalfe. 2010. Sampling in the Great Lakes for pharmaceuticals, personal care products, and endocrine-disrupting substances using the passive polar organic chemical integrative sampler. Environmental Toxicology and Chemistry 29:751-762.

Relevant SOLEC Indicators:

Toxic Chemicals in Offshore Waters: Draft 2012 SOLEC indicator available for review at http://www.solecregistration.ca/documents/Toxic%20Chemicals%20In%20Offshore%20Waters%20DRAFT%20Oct2011.pdf

Indicator data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Environment Canada: Great Lakes Surveillance Program	Alice Dove (905) 336-4449 Alice.Dove@ec.gc.ca at the Canada Centre for Inland Waters (Burlington, ON) or email GLSP-PSGL@ec.gc.ca An overview of the program is at http://www.ec.gc.ca/scitech/default.asp?lang=en&n=3F61CB56-1	Need to request data from Alice Dove or use general email request address All Great Lakes Surveillance Program data are stored at the Canada Centre for Inland Waters in Burlington, Ontario, in the Storage and Retrieval Database and can be retrieved upon request.	Water quality samples for the analysis of toxics have been collected from the Great Lakes since 1986 and the program is ongoing. However, the program is currently under review and it is likely that a number of toxic chemicals will be dropped from monitoring. Monitoring will continue to include contaminants that are not bioaccumulative or that are of greater concern due to direct toxicity, such as some of the currently-used pesticides.	Includes about 15 sites on SU, 6 on MI, 23 on HU+Georgian Bay+North Channel, 32 on ON, and 22 on ER Toxic chemicals are monitored during spring cruises only Current monitoring of metals and organics includes: 1) trace metals (includes silver, aluminum, arsenic, boron, barium, beryllium, bismuth, cadmium, cobalt, chromium, copper, iron, gallium, lanthanum, lithium, manganese, molybdenum, nickel, lead, rubidium, antimony, selenium, strontium, thallium, uranium, vanadium, zinc), 2) total mercury, 3) trace organics (including chlorinated benzenes, organochlorine pesticides, polycyclic aromatic hydrocarbons and polychlorinated biphenyls), and 4) current-use pesticides

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
B	Cooperative Monitoring and Science Initiative: Lake Michigan 2006	Alice Dove, Water Quality Monitoring and Surveillance, Environment Canada, 905-336-4449, Alice.Dove@ec.gc.ca	Alice Dove is not the source of these data but she has the data as evidenced by the draft 2012 SOLEC report.	Limited sampling for toxics in water was conducted: Six stations in Lake Michigan in 2006; Sampled toxics include, but are not limited to, PCBs, PAHs, dieldrin, heptachlor epoxide, a-chlordane, g-chlordane, and a-endosulfan	Additional sampling of toxic chemicals may be occurring during some years through CSMI efforts on various lakes.
C	EPA/GLNPO Lake Michigan Mass Balance (LMMB) Study	Glenn Warren, GLNPO project officer, 312-886-2405, warren.glenn@epa.gov Final LMMB reports on PCBs/trans-nonachlor, atrazine, and mercury available at http://www.epa.gov/glnpo/lmmb/results-pubs.html	From LMMB final reports: Summary data by station: Hg: Table 5.2 in final report Atrazine: Not included PCBs/trans-nonachlor: Tables 5.9-5.10 and 5.11-5.12. Raw Data for 1994-1995 on PCBs, atrazine, and mercury can be downloaded through EPA-CDX portal: https://cdx.epa.gov/FAQ Note: We were unable to locate raw data for trans-nonachlor at the EPA CDX portal website	The Lake Michigan Mass Balance Study measured PCBs, mercury, trans-nonachlor, and atrazine in rivers, the atmosphere, sediments, lake water, and the food chain. For the purpose of this indicator we recommend focus on the measurements in lake water. Data are from 4-7 cruises: April 1994, June 1994, August 1994, October/November 1994, March/April 1995, August 1995 and Sept/Oct 1995 (Note: the 2012 draft SOLEC indicator also implies data are available for the 2000s, but we were not able to identify or locate those data)	Hg: Particulate and total Hg collected at 15 sampling locations in Lake Michigan, 1 location in Green Bay and 1 location in Lake Huron. PCBs/trans-nonachlor: Dissolved and particulate PCBs and trans-nonachlor measured at 38 sampling locations in Lake Michigan, 2 locations in Green Bay, and 1 location in Lake Huron. Atrazine: Atrazine and breakdown products DEA and DIA measured at 35 sampling locations on Lake Michigan, 2 sampling locations in Green Bay, and 1 sampling location on Lake Huron.

Phosphorus Loads and In-Lake Concentrations

Summary:

This indicator tracks the magnitude and trends in total phosphorus (TP) and dissolved reactive phosphorus (DRP) loads delivered to the Great Lakes from multiple sources. The fate of delivered TP and DRP are reflected in measurements of in-lake concentrations and trends in concentration from nearshore and offshore areas in the Great Lakes. Measurement of loads and in-lake concentrations are supplemented with TP and DRP mass balance models.

Spatial coverage: Data are available for TP loads, TP/DRP concentrations, and TP mass balance for the five Great Lakes with a particular focus on Lake Erie. TP load data is available for all lakes and can be summarized at the lake level or within smaller subunits (except Superior). The load data summarizes input from multiple sources including atmospheric, tributary, and various point sources. TP and DRP concentrations are point data collected by USA and CAN agencies as part of annual lake monitoring programs and can be summarized for bays, sub-basins, or at the lake scale. The TP mass balance model reports predictions of annual average TP concentration within lake subunits (subbasins or bays).

Temporal coverage: TP load estimates are available for the five Great Lakes as early as 1967 for Lake Erie to as late as 2008 for all lakes. TP mass balance model results are from 1800 to early 2010. Reliable, standardized TP and DRP offshore concentrations are available as early as 1974.

Data processing needs: Data is sufficient and available for TP loads and TP concentrations for offshore, and a widely accepted TP mass balance model has been developed and refined. DRP load and mass balance models need to be developed to include in this indicator, but measurements of offshore DRP concentrations are sufficient. Severe bias in concentration measurements towards offshore sampling locations suggests a need for increased nearshore monitoring of TP and DRP. Load and mass balance model calculations and processing needs are significant, while summary and analysis of in-lake concentrations of TP and DRP are minor to moderate.

Indicator Details:

The first component of this indicator tracks the amount and trends in amount of both TP and DRP phosphorus loads to each of the Great Lakes, including specification of loads to major embayments/basins of the lakes. A second component of the indicator is to track and understand the spatial and temporal trends of TP and DRP concentrations in the lakes and embayments/basins in response to the external loads. A third component is to continue calculation of model results for an already developed and refined TP mass model and to develop a similar model for DRP.

Components:	Component specifications:	Data source: (see data table)
P Loads:	TP	Loads in A-E; F&G are monitoring programs to improve load calculations
	DRP	Load calculations not currently available, but F &G could provide data for development of load estimates
In-Lake Concentration:	TP	H-K
	DRP	H-K
Phosphorus Budgets:	TP phosphorus mass balance model	L; data to support modeling effort in A-K
	DRP phosphorus mass balance model	Not currently available; could be modeled after L; data to support modeling effort in A-K

Calculations:

Loadings: For each lake and Lake Erie's three sub-basins: Annual measurements of TP load (metric tons/year) as calculated by Dolan and Chapra 2012. Total load is the sum of monitored, unmonitored, industrial, municipal, and atmospheric loads and any additional load received from other lake(s). Additionally, these calculations may be done for targeted areas, such as Green Bay, Georgian Bay and Saginaw Bay.

Concentrations: Annual spring (pre-stratified) and summer (stratified) TP and DRP concentrations from the average of water column samples collected by USEPA/GLNPO; spring and summer surface water TP and spring surface water DRP collected by EC. Average all locations within a season for a summary by lake or lake sub-basin, either using combined USA and CAN data or separately for USA and CAN data. Note: Water chemistry experts are of mixed opinion as to whether differences in GLNPO and EC sampling methods preclude combining USA and CAN measures. These differences may have arisen because of how GLNPO and EC typically summarized concentrations of TP and DRP for a site. GLNPO has traditionally averaged concentrations from all samples within the vertical profile and EC has typically reported only the surface water concentration. Since IJC is planning to calculate summary TP and DRP from raw data, it may be possible to standardize summary methods and combine data collected by the two countries. Alice Dove and Glenn Warren could help determine if this is indeed possible, and if so, the best way to summarize phosphorus concentrations at a site (e.g. average of water column or surface water only).

Phosphorus Budgets: The TP mass balance models developed by Chapra (1977) and revisited by Chapra and Dolan (2013) would need to be extended from 2008 to present (or most recent year with available model inputs); a budget model for DRP would need to be developed using historical and current data.

Combination of components: How these components will be combined is not addressed in the draft of indicator and beyond the scope of this contract.

Spatial and temporal coverage: All components are calculated on a seasonal or annual basis except for TP budgets. TP budgets are calculated on a five-year rotating basis in association with the CSMI process. Loads are available as early as 1967 for Lake Erie to as late as 2008 for all lakes; the most reliable and consistent basin-wide data are from 1981-2008. Annual load and average concentrations for each season can be calculated for each lake and the three subbasins in Lake Erie. Load and concentrations can also be examined for smaller, targeted areas like bays and specific sub-basins (Lakes Michigan and Huron). The TP mass balance model uses different parameters for major basin, subbasins, and/or bays within a lake and model predictions of annual average concentration are also calculated at this subunit scale.

Measurement of progress: Comparisons of annual loads and off-shore concentrations of TP to targets listed in GLWQA (see tables below). Reductions in loads and off-shore concentrations in Lake Erie, especially Western Lake Erie, will help meet annual phosphorus loading targets. Since loadings, and thus concentrations, can vary with meteorological events, general trends in loadings should be examined as well as year to year changes. Targets for open water phosphorus concentrations may need to be revisited given the current oligotrophication trend in the upper Great Lakes.

2012 Great Lakes Water Quality Agreement Phosphorus concentration and load targets

Interim Substance Objectives for Total Phosphorus Concentration in Open Waters (ug/l) (as represented by Spring means)	
Lake Superior	5
Lake Huron	5
Lake Michigan	7
Lake Erie (western basin)	15
Lake Erie (central basin)	10
Lake Erie (eastern basin)	10
Lake Ontario	10

Interim Total Phosphorus Load Targets (Metric Tonnes Total P Per Year)	
Lake Superior	3400
Lake Michigan	5600
Main Lake Huron	2800
Georgian Bay	600
North Channel	520
Saginaw Bay	440
Lake Erie	11000
Lake Ontario	7000

Data Evaluation:

Sufficiency and accessibility: Data is sufficient and available for TP loads and concentrations offshore, and for much of the TP mass balance modeling. However, increased nearshore TP sampling would supplement offshore sampling programs and help develop a quantitative understanding of the nearshore-offshore gradients and phosphorus retention relationships that are observed in all of the Great Lakes except Superior. Historical and current DRP loads are not widely available, although some load calculations are currently being developed for Lake Erie (see load calculation programs listed in Burrows 2013). A DRP mass balance model has not been developed for the Great Lakes although existing tributary and in-lake sampling could support such an effort. Sufficient offshore and limited nearshore measures of DRP are collected by GLNPO and Environment Canada.

Because of ongoing problems with excess phosphorus in Lake Erie, watershed, nearshore and offshore areas are the target of many loading and concentration sampling efforts. The efforts are enumerated in Appendix A of the 2013 Council of Great Lakes Research Managers Work Group Report, 'Assessment of Total Phosphorus and Dissolved Reactive Phosphorus Monitoring Programs within the Lake Erie Basin' (Burrows 2013). We do not include all of the monitoring programs in our data table; instead, we chose to include only those programs we felt had the most comprehensive spatial and temporal samples or programs that sampled areas neglected by major monitoring programs.

Additional needs:
Loadings: Recommend continuation of the annual load computation and reporting program that Dave Dolan has employed and recently updated for all the Great Lakes (Dolan and Chapra, 2012). However, this program should be expanded to include both TP and DRP. In order to improve the accuracy of this load estimation for each lake basin and embayments, the following data collection approach is recommended for the major tributaries to each basin (major tributaries are those that taken together contribute >80% of the TP load to the system of concern): daily flow measurement by USGS gauge station with at least between 12 and 24 TP and DRP concentration measurements annually (depending on flashiness of the tributary) with an emphasis (~2/3 of samples) on high-flow/wet weather events in late fall and spring.

In-lake Concentrations: Most samples are from offshore areas, largely because of the draft limitations of the vessels collecting those samples. Therefore targeted water sampling in nearshore would complement the abundance of offshore samples. Revisit the placement of stations and the depth resolution of sampling to better capture nearshore-offshore gradients in the system and improve the accuracy of basin-wide average concentrations of both TP and DRP.

Phosphorus budgets: On a five-year rotating basis in association with the CSMI process, conduct an intensive, external load and lake-wide monitoring program for both TP and DRP that would permit development of a phosphorus mass balance model that can serve as an indicator of how each lake is processing phosphorus to develop a quantitative understanding of the nearshore-offshore gradients and phosphorus retention relationships that are observed in the system. This is important to better understand and manage the nearshore eutrophication-offshore oligotrophication that seems to be resulting from ecosystem changes in the lakes. Also, it can be inserted into the CSMI process with virtually no additional expense in additional data collection and relatively little additional expense for model application. A pilot study, perhaps for the data collected in Lake Huron during 2012 by making some revisions to the existing Chapra TP model (Chapra and Dolan 2012), could help better define the required sampling resolution for such a program.

Required data processing and calculation effort:
Loadings: Loading estimates through 2008 are calculated and available in the appendices of Dolan and Chapra 2012. The GLAHF project has organized these data in Excel files which can be provided to IJC. The data processing and calculation efforts varying from none to significant is the loads that are provided by outside sources versus calculating loads from tributary monitoring.

In-lake Concentrations: A small amount of effort will be required to summarize TP and DRP vertical water samples from GLNPO and average the values for a lake or lake sub-basin. The GLAHF project has summarized 1996-2011 GLNPO water chemistry by season and for select depths; these summaries may or may not be of use to IJC depending on how IJC is advised to summarize phosphorus concentrations at a site. Minimal effort will be required to extract surface water TP and DRP measures from Environment Canada and average for a lake or sub-basin.

Phosphorus budgets: Current TP mass balance models should be improved to better incorporate nearshore to offshore TP dynamics. DRP mass balance models need to be developed. These efforts will require significant processing and calculation effort.

References:

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Dolan, D.M. and K.P. McGunagle. 2005. Lake Erie total phosphorus loading analysis and update: 1996-2002. Journal of Great Lakes Research 31 (Suppl. 2): 11-22.

Dolan, D.M. and S.C. Chapra. 2012. Great Lakes total phosphorus revisited: 1. Loading analysis and update (1994-2008). Journal of Great Lakes Research. 38:730-740.

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Fraser, A.S. 1987. Tributary and point source total phosphorus loading to Lake Erie. Journal of Great Lakes Research 13: 659-666.

Lesht, B.M., T.D. Fontaine III and D.M. Dolan. 1991. Great Lakes total phosphorus model: post audit and regionalized sensitivity analysis. Journal of Great Lakes Research 17:3-17.

GLNPO. 2010. Sampling and Analytical Procedures for GLNPO's Open Lake Water Quality Survey of the Great Lakes. Prepared by U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago IL. EPA 905-R-05-001, March 2010.

Relevant SOLEC Indicators:

Nutrient Concentrations: Draft 2012 SOLEC indicator available for review at
http://www.solecregistration.ca/documents/Nutrients%20in%20Lakes%20DRAFT%20Oct2011.pdf

Indicator Data:

Loadings:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Dolan and Chapra 2012 (JGLR 38:730-740)	David Dolan, Professor of Mathematics, University of Wisconsin Green Bay, 920-465-2986, doland@uwgb.edu, Steven Chapra, Professor of Civil and Environmental Engineering, Tufts University, 617-627-3654, steven.chapra@tufts.edu	Downloaded and compiled from Journal of Great Lakes Research article appendices We had to compile these data from numerous appendices to assess the data. Data are in Excel files with multiple tabs	In Excel files: One file for annual loads for all lakes and additional files for each lake by major tributary or state contributions (Erie); Annual loads are by main lake for SU and ON; All other lakes have data at smaller units (subbasins or selected areas) that can be scaled up to the whole lake	HU, ON, & SU: 1981-2008; MI: 1980-2008; ER: 1981-95 & 2003-2008 (missing 1996-2002 by subbasin but total load can be entered from Tables in Dolan and Chapra 2012; These data exist, just not included in the appendices; Contact Dolan and Chapra for missing data.
B	GLWQB Annual reports to IJC	IJC and online	1978 available online; Unsure about the availability of other years.	Annual loads (Direct industrial, direct municipal, total tributary, atmospheric and connecting channels) for each lake	1974-1979
C	A.S. Fraser (1987)		Note: Data are in graphical forms, not tabular.	Lake Erie	1967-1982
D	Lesht *et al.* 1991	N/A	Table 2	Total P loadings by lake and selected subbasins/bays (e.g. Lower and Upper Green Bay, Georgian Bay, Saginaw Bay, Lake Erie subbasins)	1974-1986
E	Dolan & McGunagle 2005	N/A	Table 2 and Appendix 1	Lake Erie (entire) and by subbasin (1981-2001)	1981-2002

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
F	Heidelberg University, National Center for Water Quality Research	Dave Baker, Director Emeritus & Founder NCWQR, 419-448-2941, dbaker@heidelberg.edu	Expressed willingness to share with IJC	Spatially limited but temporally intense sampling on Lake Erie tributaries:	Includes Detroit, River Raisin, Maumee, Sandusky, Cuyahoga, and Grand (OH) rivers Daily measures of TP and DRP on tributaries and thrice daily during wet weather events (exception is River Raisin, sampled daily 6 days/week).
G	GLRI funded USGS Tributary Monitoring Program	Dan Sullivan, djsulliv@usgs.gov	Publicly funded research; Should be available to IJC Not able to assess data format as this is a newly funded program.	Water samples collected at the 30 tributary monitoring sites; Sites distributed in tributaries across all five lakes and one on St. Clare River These sites are being monitored to provide baseline information, provide support for measuring restoration progress, and demonstrate the ability to reduce monitoring costs through the use of real-time sensors.	Ortho-phosphorus and TP: At each site, monthly base flow samples are being collected, plus up to eight storms, with 6 samples submitted per storm (60 environmental samples per site).

In-lake concentrations:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
H	USEPA GLNPO: offshore TP and DRP concentrations	Glenn Warren, GLNPO project officer, 312-886-2405,	Can download desired data from https://cdx.epa.gov/;	About 75 sites sampled each year throughout the five Great Lakes.	ER, HU, and MI: 1983-2011; ON: 1985-2011 (SU only in 85 & 89; SP only in 92-93); SU:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		warren.glenn@epa.gov	Must have login to access In Excel files: Vertical water sample profiles. We will provided TP and DRP for 1996 to 2011 in an Excel file.	Sampling restricted to off-shore because of 11+ foot draft of RV Guardian. Concentrations available: Spring and Summer TP and DRP water column profiles; Filtrate is DRP and Total/Bulk is TP. Sampling and analytical procedures provided in GLNPO 2010.	1992-1993 (SP only in 1992): EXCEPTIONS: NO data for any lakes from 1994 and 1995. The data reporting format (especially depth codes) changed beginning in 1996; Data from 1983-1993 and 1996-present may need to be summarized separately. Excel files need careful examination before calculating TP and DRP values for each site each year. Excel files include all values from all samples (including composite samples, blanks and duplicates, and values for samples that did not meet quality control requirements.
I	Great Lakes Surveillance Program, Environment Canada: offshore TP and DRP concentrations	Alice Dove (905) 336-4449 Alice.Dove@ec.gc.ca at the Canada Centre for Inland Waters (Burlington, ON) or email GLSP-PSGL@ec.gc.ca An overview of the program is at http://www.ec.gc.ca/s	Need to request data from Alice Dove or general email request address All Great Lakes Surveillance Program data are stored at the Canada Centre for Inland Waters in Burlington, Ontario, in the Storage And	About 275 sites: SU ~50-73 (more stations pre 1990s); ON~100; ER~55; HU~68; Each lake monitored every 2nd year. Spring and summer cruises; DRP is sampled in spring only and TP is sampled in both spring and summer Methods for EC's Great Lakes Surveillance Program are	Standardization of data began in 1974; Older data are available but are not as comprehensive and not necessarily comparable to post 1974 data. Includes off-shore and some nearshore locations.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		citech/default.asp?lang=en&n=3F61CB56-1	Retrieval Database and can be retrieved upon request.	described in Dove 2009.	
J	Ontario Ministry of the Environment: Great Lakes Intakes Program	Not able to identify a contact; Mark Burrows may have this information as this program is included in the Lake Erie P 2013 monitoring program report	Unknown	TP and DRP sampled year round from raw intake water at 18 water treatment plants that draw water from the Great Lakes; six locations in Lake Erie, others along Canadian Great Lakes shoreline.	Measures nearshore concentrations at a small number of locations along Canadian Great Lakes Coastline.
K	Ohio EPA Nearshore Monitoring Program	Ohio Environmental Protection Agency, Surface Water – Gail Hesse, 419-621-2039, gail.hesse@lakeerie.ohio.gov Julie Letterhos, Julie.letterhos@epa.state.oh.us Rick Wilson, Rick.Wilson@epa.state.oh.us	Ohio EPA completed the first round of sampling in 2011 and will continue additional sampling rounds in 2012 and 2013. Results from the first two rounds of sampling will be summarized in Ohio EPA's 2014 Integrated Report.	Ohio EPA was awarded a Great Lakes Restoration Initiative (GLRI) grant in 2010 to develop a comprehensive Lake Erie nearshore monitoring program. This project will design and implement a monitoring program for the Ohio Lake Erie nearshore zone (including bays, harbors and estuaries) that can be maintained on an annual basis.	Sampling limited to Lake Erie nearshore. Ambient stations sampled every year (approximately monthly, depending on stratification). 11 stations sampled 3X during 2010. Locations have changed slightly during development of program and two stations were added. Plan is to continue sampling at these 13 stations.

Phosphorus budgets:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
L	Chapra and Dolan 2012: Great Lakes total phosphorus revisited: 2. Mass	David Dolan, Professor of Mathematics, University of Wisconsin Green Bay,	Contact Dolan and Chapra; both have a history of sharing data and model results	1977: A parsimonious TP budget model was developed to assess the impact of population and land-use	Models simulations fit well until 1990; after 1990 models simulations diverge from observed data (e.g. lower

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	balance modeling (JGLR 38:741-754)	920-465-2986, doland@uwgb.edu, Steven Chapra, Professor of Civil and Environmental Engineering, Tufts University, 617-627-3654, steven.chapra@tufts.edu		trends on Great Lakes eutrophication (Chapra 1977) This study extends model results to 2010; some refinements adopted in current models.	than expected P) for offshore waters of all lakes except Superior. Divergence is most dramatic in Lake Ontario. To match simulations to observed data model's apparent settling velocity, which parameterizes the rate that total P is permanently lost to lake's deep sediments, was increased. These results suggest dreissenid mussels have enhanced GL P assimilation capacity.

Aquatic Invasive Species (AIS)

Summary:

This indicator measures the status and impact of aquatic invasive species (AIS) currently in the Great Lakes and tracks additions, rate of invasion, and pathways of new invaders.

Spatial coverage: Analysis is usually at the lake or basin-wide scale. Whenever feasible, this indicator will also include major routes of introduction and interchange such as Lake St. Clair and connecting channels.

Temporal coverage: The Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) currently includes invasions from 1839 to 2006, and will include future invasions. Three measures that quantify impacts of Sea Lamprey impacts have been calculated on an annual basis since the 1980s.

Data processing needs: Most of the indicator subcomponents can be calculated from the GLANSIS database with minimal calculation and processing effort. However, the accuracy of the GLANSIS database relies on effective sampling of current AIS, monitoring for new invasive species, rapid identification of new invasive species, and timely reporting of new introductions. Specific organisms need to be chosen for the "impact of selected AIS", but data are sufficient for an assessment of three we suggest (Sea Lamprey, dreissenids, and Viral Hemorrhagic Septicemia (VHS)). There is limited data to support the subcomponent "biomass of AIS relative to native species of equivalent trophic position," but this component could be modified to allow calculation from some existing data.

Indicator Details:

This indicator measures the status and impact of aquatic invasive species (AIS) currently in the Great Lakes and tracks additions, rate of invasion, and pathways of new invaders.

Components:	**Possible subcomponents:**	**Data source: (see data table)**
Status and impact of current AIS:	Table: Number of harmful AIS by lake or water body	A
	Maps: Distribution and density of all or selected harmful AIS	A, F & G
	Biomass of AIS relative to native species of equivalent trophic position	B-D (potential sources)
	Impact of selected AIS (measures will vary; for selected organisms such as Sea Lamprey, dreissenids, and Viral Hemorrhagic Septicemia)	E-G
New AIS:	Number of new AIS since last assessment	A

Components:	Possible subcomponents:	Data source: (see data table)
	Analysis of the trend in the rate of invasion (e.g. trends in a plot of # over time or the slope of cumulative # of AIS over time)	A
	Retrospective analysis to identify the likely pathway by which the species arrived	A

Calculations: The *current species* component is defined as status and impact of aquatic invasive species having detrimental effects. It specifically excludes non-native species that are benign or perceived to be desirable species. Status will be generally measured as biomass of AIS relative to native species of equivalent trophic position (e.g., zooplankton, planktivorous fishes). Impact may be anything that prevents the achievement of any of the General Objectives (Article 3) of the GLWQA, or that contributes to a Beneficial Use Impairment (Annex 1, GLWQA) and may be quantified differently for different AIS, e.g., impact of sea lampreys may be quantified as wounding rates on a species of interest and/or contribution to mortality or food web impacts of dreissenid mussels. The *new species* component includes the number of new species arriving in the Great Lakes since the last assessment, a temporal evaluation to quantify trends in the rate of invasion, and a retrospective analysis to identify the likely pathway by which the species arrived.

Combination of components: The combination of subcomponents within a component is not addressed in the draft indicator. The two components will be treated as two separate elements of this indicator. However, an overall assessment of progress on this indicator should be included as well.

Spatial and temporal coverage: The spatial scale of the calculations and analyses varies with the components and subcomponents. Most subcomponents will be calculated either basin- or lake-wide. Whenever feasible, this indicator should also include major routes of introduction and interchange such as Lake St. Clair and connecting channels (e.g. Detroit River, St. Clair River, and St. Lawrence River).

Measurement of progress: Ideal progress would be to eliminate new introductions and reduce the negative effects of already established AIS. In reality, reasonable goals would include a reduction in the number and rate of introduction of new AIS and severe impacts of established AIS.

Data Evaluation:

Sufficiency and accessibility:

Summary: Much of the data required for this indicator is currently maintained at the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS). The accuracy of the GLANSIS database relies on effective sampling of current AIS, monitoring for new invasive species, rapid identification of new invasive species, and timely reporting of new introductions. Specific data required for the "impact of select AIS" could not be fully assessed since no target taxa were selected for the draft indicator. We suggested three possible targets: Sea Lamprey, dreissenids, and VHS. Many studies draw similar conclusions on the impacts of dreissenids and immediate/potential impacts of VHS, and long-term measures are available to assess the impact of Sea Lamprey. In general, few biological monitoring programs include measures of biomass so there is limited data to support the subcomponent "biomass of AIS relative to native species of equivalent trophic position" for fish and benthos. This subcomponent could be modified to fit with existing data for benthos and fish (i.e. % invasive species calculated from readily available abundance measures or taxa lists), but the taxonomic resolution of phytoplankton and zooplankton identifications may not permit distinction between invasive and native species. Some of these data limitations for the two indicator components are discussed in more detail in the following sections.

Current AIS: This component requires broad-spectrum biological monitoring program sampling of plankton, benthos (nearshore and offshore), wetland plants and fauna, zooplankton, and fish. Secondary processing of samples beyond simple counting and measuring would be required to identify alien pathogens. Therefore, operational definition of this indicator should build on monitoring activities put in place for other reasons, rather than require new and redundant sampling efforts. For example, this indicator should capitalize on data collected for other indicators, e.g.

1. Fish species of interest: Trawl, gillnetting, and other sampling activities should be used to record the fraction of AIS relative to native species. Typically reported measures include Catch per Unit Effort.
2. Lower food web productivity/health: The contribution of AIS and native species to total phytoplankton, zooplankton, and benthos should be recorded. Typically reported measures include abundance for phytoplankton, abundance and some length measures for zooplankton, and densities for benthos. The taxonomic resolution of identification of phytoplankton and zooplankton may not permit the distinction between invasive and native species across all existing monitoring programs.
3. Coastal wetlands: The contribution of AIS and native species to biological sampling of plants, invertebrates, and fish, should be recorded. Reported values at a site include % invasive cover and frequency for plants, abundance for invertebrates, abundance and % non-native richness in the "*Schoenoplectus* Zone" for fish.

Additional sampling programs that should contribute to this effort include proposed special monitoring for new AIS in high risk areas, data currently collected on larval lamprey abundance and wounding rates, and sampling conducted as part of the Cooperative Science Monitoring Initiative. In the future, DNA-based monitoring may become commonplace and it becomes possible to integrate molecular methods into monitoring for AIS relative abundance (Darling and Mahon 2011; Dejean *et al*. 2011).

New AIS: This component depends on the timely detection and reporting of new AIS. To support rapid response programs being planned and implemented, sites that are likely invasion points (harbours, marinas, city waterfronts, city parks connected to Great Lakes) should be selected and monitored. The selection of sites and the type of monitoring to be conducted at those sites should be based on risk assessment. A pilot program that is widely considered to be state of the art has been implemented at Duluth (USGS 2007, Dupré 2011). The current state of AIS monitoring activity in the Great Lakes was reviewed by Dupré (2011 and data source H) and recent monitoring efforts by Canada (part of the Canadian Aquatic Invasive Species Network (CAISN II)) are described in data source I. DNA-based monitoring is a focus of many current research projects and is likely to complement traditional monitoring approaches in the future. In 2012, US EPA awarded three Great Lakes Restoration Initiative grants totaling ≈1.8 million to investigate DNA-based monitoring for AIS (more detailed descriptions at http://www.epa.gov/greatlakes/glri/invasives.html) and CAISIN II includes 2 molecular-based monitoring projects.

Additional needs: Additional monitoring, detection, and data needs were addressed in the previous section.

Required data processing and calculation effort: Data processing and calculation efforts should be minimal for all subcomponents except "Biomass of AIS relative to native species of equivalent trophic position" and "Impact of selected AIS." For the biomass subcomponent, lists of native and nonnative species would need to be developed and linked to existing biological data and the subcomponent would need to be calculated for each data source. Specific AIS need to be chosen for inclusion in the "impact" subcomponent.

References:

Darling, J.A. and A.R. Mahon. 2011. From molecules to management: adopting DNA-based methods for monitoring biological invasions in aquatic environments. Environmental Research 111: 978-988.

Dejean T., A. Valentini, A. Duparc, S. Pellier-Cuit and F. Pompanon. 2011. Persistence of environmental DNA in freshwater ecosystems. PLoS ONE 6(8): e23398.

Dupré, S. 2011. An assessment of early detection monitoring and risk assessments for aquatic invasive species in the Great-Lakes St. Lawrence Basin. IJC report. 120 pp. Available online at http://meeting.ijc.org/sites/default/files/workgroups/RAandMonitoringJuly29.pdf

Holeck, K.T., E.L. Mills, H.J. MacIsaac, M.R. Dochoda, R.I. Colautti and A. Ricciardi. 2004. Bridging Troubled Waters: Biological Invasions, Transoceanic Shipping, and the Laurentian Great Lakes. BioScience 54: 919-929.

Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: is an "invasion meltdown" occurring in the Great Lakes? Canadian Journal of Fisheries and Aquatic Science 58:2513-2525.

USGS Field notes, available at http://www.fws.gov/fieldnotes/regmap.cfm?arskey=22338

Relevant SOLEC Indicators:

#9002 Non-native Species – Aquatic (2009)

Aquatic Nonnative Species: Draft 2012 indicator available at http://www.solecregistration.ca/documents/Aquatic%20Non-Native%20Species%20DRAFT%20Oct2011.pdf

Dreissenid Mussels – Zebra and Quagga mussels: Draft 2012 SOLEC indicator available at
http://www.solecregistration.ca/documents/Dreissenid%20Mussels%20DRAFT%20Oct2011.pdf

Sea Lamprey: Draft 2012 SOLEC indicator available at
http://www.solecregistration.ca/documents/Sea%20Lamprey%20DRAFT%20Oct2011.pdf

Indicator data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	NOAA’s Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) (Note: GLANSIS functions as a Great Lakes specific node of the USGS Nonindigenous Aquatic Species (NAS) national database.)	Dr. Rochelle Sturtevant, NOAA Great Lakes Environmental Research Laboratory & Michigan Sea Grant, 734-741-2235, rochelle.sturtevant@noaa.gov	An overview of GLANSIS is available at http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html A query of the online database begins at http://nas.er.usgs.gov/queries/greatlakes/Search.aspx Online database is fully accessible, but is limited in content (see additional information); Results of a query can be viewed in a table on the web or converted to a CSV spreadsheet Additional information is available from Dr. Rochelle Sturtevant, rochelle.sturtevant@noaa.gov	The present database consists of three lists: 1) a core list of species nonindigenous to the Great Lakes basin (not native to any part of the basin), 2) a list of range expansion species (native only to a portion of the basin), and 3) a watchlist (not currently found in the Great Lakes but assessed in the peer-reviewed scientific literature as of 2010 as likely to invade via current pathways). GLANSIS does not include species which have been reported but not established, failed introductions, cryptogenic species for which evidence is considered insufficient, range expansions, and species native to the Great Lakes which have invaded other regions of the U.S.	Database query can be customized to search by species category (e.g. nonindigenous (N), range expanders (RE), N&RE, and watchlist), group (e.g. Algae, Fish, etc.), and Lake HUCs (All, individual lakes (SU, HU, MI, ER, ON, STC) or lake and surrounding drainages). Columns in the web-based table include photo, taxonomic group, family, scientific name with link to technical fact sheet, common name with link to nontechnical fact sheet, continent of origin, year first collected, and status (collected, established, etc). CSV spreadsheet is limited to taxonomic group, family, scientific name, common name, continent of origin, year first collected, and status. Technical fact sheets provide additional information about specific locations and spatial

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
					accuracy of these locations, ecology, means of introduction, and impact of introduction.
B	Central Michigan University (CMU) and various researchers affiliated with GLCWC	Don Uzarski, CMU Associate Professor and Director of CMU Institute for Great Lakes Research, 989-774-2504, uzars1dg@cmich.edu	For IJC: No restrictions on raw data or summaries of condition; lay public only has access to summarized data Contact Don for access to historical, current, and future data and summaries	Data collected prior to 2011: Don indicates he has access to or can supply contacts to provide access to much of the data collected prior to 2011; This includes work by Denny Albert (vegetation), Don Uzarski (inverts and fish), Thomas Burton (fish), and Crewe and Timmermans (birds and amphibians). 2011-2015: Don is also the contact; Data, complete metadata, and biannual reports to GLNPO will be compiled and housed at the Natural Resources Research Institute (NRRI) at the University of Minnesota-Duluth under the direction of Valerie Brady. NRRI database will be dedicated to GLCWC monitoring data and include 1) GIS polygons with sampled wetlands and sampling locations within each wetland, 2) water quality data, 3) macrophyte ID, cover	Historical data includes the following studies: Vegetation: Albert 2008: only metrics available, no raw data; 40 wetlands across four regional areas of lakes Erie, Ontario, and Huron. Invertebrates: Uzarski *et al.* 2004: 22 wetlands in Lakes Michigan and Huron during 1997-2001. Fish: Uzarski *et al.* 2005 and Uzarski *et al*. 2008: 61 wetlands across five lakes, nine ecoregions, four wetland types in 2002. Birds and amphibians: Crewe & Timmermans 2005: sampled 88 bird and 87 amphibian Great Lakes coastal wetlands; Based on Canadian Marsh Monitoring Program collected data from 1995-2003.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				%s and FQIs, 4) macroinvertebrate IDs, counts, and IBIs, 5) fish IDs, counts, and IBIs, and 6) amphibian IDs and IBIs, and 7) bird IDs and IBIs.	
C	GLNPO Phytoplankton and Zooplankton tows and benthic grab samples	See Lower Food Web Productivity/Health indicator			
D	USGS and Canadian Fish trawl, gillnetting, and other sampling activities	See Lower Food Web Productivity/Health and Fish Species of Interest indicators			
E	Great Lakes Fisheries Commission (GLFC): Sea Lamprey Control Program (SLCP)	Bob Adair, Program Manager, Sea Lamprey Control Program, 612-713-5109, Bob_Adair@fws.gov Paul Sullivan, Dept. of Fisheries and Oceans, Sea Lamprey Control Centre, 705-941-3010, Paul.Sullivan@dfo-mpo.gc.ca	An overview of the program is at http://www.glfc.org/sealamp/ and can be further explored via Sea Lamprey specific tabs near the top of the webpage. Annual reports to the GLFC summarize activities in the integrated management of sea lampreys conducted by Fisheries and Oceans Canada (Department) and the	Two of the three SLCP components are directly relevant to the current AIS component of the indicator. These include: 1) The spawning-phase component annually assesses the stock size of spawning-phase sea lampreys in each lake and 2) The parasitic-phase component annually assesses the rates of lake trout wounding inflicted by sea lamprey in each of the lakes. Time series data are used to assess the effectiveness of the SLCP for each lake. In	Available data (summarized yearly and by lake) include: spawning-phase sea lampreys abundance, Lake Trout fish wounding rate, and Lake Trout abundance; Most lakes have data for 1980 to present for all measures and some historical abundance estimates for sea lamprey. In 2011 the Commission began a process to create an updated lake trout wounding database that incorporates the most recent data and regenerates the lake-wide

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			United States Fish and Wildlife Service (Service) in the Great Lakes	addition, several indices of relative abundance of parasitic-phase sea lampreys are used to monitor sea lamprey populations over time.	wounding rate graphs. The SLCP program compiles data from many sources (including NYSDEC, Canadian commercial fisheries, MI DNR, and WI DNR); The sources vary by lake, but generally provide similar data.
F	GLIN: Summary of information and research on Zebra and Quagga Mussels	Two good contacts for information on Zebra and Quagga Mussels: Thomas Nalepa, Scientist Emeritus, NOAA/GLERL, 734-741-2285 ext. 2024, thomas.nalepa@noaa.gov Anthony Ricciardi Associate Professor/Invasive Species Biologist, McGill University, 514-398-4089, Tony.Ricciardi@McGill.ca	Overviews of Zebra and Quagga Mussel information and programs: http://www.great-lakes.net/envt/flora-fauna/invasive/zebra.html http://www.great-lakes.net/envt/flora-fauna/invasive/quagga.html	Example statement on zebra mussel impacts from GLIN: "Zebra mussels have had deleterious effects on local ecosystems. They reduce the amount of phytoplankton available for other organisms and increase water clarity, causing changes to the ecological structure of the lake community. In addition, zebra mussels accumulate contaminants within their tissues to levels greater than concentrations in the water column, increasing the exposure of wildlife to contaminants. Zebra mussel infestations also threaten native mussel populations by attaching to the native species and essentially smothering them."	Example of statement on quagga mussel impacts from GLIN: "Quaggas are extremely effective in filtering water for food, removing large amounts of phytoplankton and suspended particulate, decreasing the food supply for zooplankton and forage fishes, and thereby impacting the entire food web. … There have been significant impacts to the spring bloom of diatoms (silica based algae) by quagga infestations, disrupting the lower food web. … In addition to altering food webs, quagga mussels accumulate contaminants within their tissues, which can affect wildlife that feed on the species."

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
G	GLIN: Summary of information and research on Viral Hemorrhagic Septicemia (VHS) in the Great Lakes Region	Two good contacts for information on VHS are: Mohamed Faisal, Michigan, Professor at State University, 517-884-2019, faisal@msu.edu Gary Whelan, MI DNR Fisheries Division, 517-373-6948, whelang@michigan.gov	A summary of research on VHS is available at http://www.great-lakes.net/envt/flora-fauna/invasive/vhsv.html	"VHS was found in the Great Lakes in 2005 and 2006 with the occurrence of large fish kills in lakes Huron, St. Clair, Erie, Ontario, Michigan, and the St. Lawrence River. …VHS can be deadly to more than 15 fish species and can infect at least another 10 species in the Great Lakes basin. …This is the first time a virus has affected so many different species across such a wide range of Great Lakes fish families."	
H	Samantha Dupré: An Assessment of Early Detection Monitoring and Risk Assessments for Aquatic Invasive Species in the Great Lakes-St. Lawrence Basin	IJC commissioned report (2011)	Available at http://meeting.ijc.org/sites/default/files/workgroups/RAandMonitoringJuly29.pdf	Thorough analysis of all US and Canadian efforts in the Great Lakes region aimed at early detection of AIS and AIS risk assessment.	Identified and described binational, federal, multistate cooperative, and state/provincial active and passive monitoring programs.
I	Canadian Aquatic Invasive Species Network (CAISN) (2006-2011) and Canadian Aquatic Invasive Species Network II (CAISN II) (2011-2016)	CAISN, Great Lakes Institute for Environmental Research (GLIER) University of Windsor, 519-253-3000 ext. 3751, caisn@uwindsor.ca	Overview of the program at http://www.caisn.ca/en Note: CAISN I & II are not sources of data required for the calculation of indicator components; Instead	CAISN: Established with the goal of identifying and quantifying the vectors and pathways by which AIS enter Canada, determining factors that affect their colonization success, and developing risk assessment models for potential and existing AIS.	Currently includes six programs under the "Early Detection" Theme: 1) Surveillance for AIS Throughout Canada's Coastal Waters, 2)Early Detection of AIS Using State-of- the-Art Technology, 3) Reconciling Large-Scale Model

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			this source provides a summary of Canadian efforts at early detection of AIS and supplements Dupré 2011.	CAISN II: Will address remaining information gaps by focusing on four new core themes: Early Detection, Rapid Response, AIS as Part of Multiple Stressors, and Reducing Uncertainty in Prediction and Management.	Predictions with Small-Scale Observations of AIS Distributions to Inform Early Detection, 4) Optimal Methods of Early Detection Based on Life History Traits Brian Leung, Ladd Johnson, Sarah Bailey, 5)Establishment and Distribution of Water Lettuce (*P. stratiotes*) and Water Hyancinth (*E. crassipes*) in the Laurentian Great Lakes and their Tributaries, and 6) Plankton Biodiversity in Major Canadian Ports as Revealed by Next Generation Sequencing: Sensitivity

Harmful and Nuisance Algae (HNA)

Summary:

The HNA indicator quantifies the effects of harmful and nuisance algae on the Great Lakes through two metrics on harmful algae (toxicity and taxonomic dominance), four metrics on nuisance algae (offensive odor or taste, benthic coverage, effects of pelagic algae, and beach closures), and one metric from satellite derived algal bloom maps. Current Lake by Lake assessments are largely qualitative because of the lack of long-term data or rigorous monitoring programs in place across most of the lakes.

Spatial coverage: Ideally, lake by lake assessments of all seven metrics. Currently, most HNA metrics can only be calculated for Lake Erie and Lake Ontario.

Temporal coverage: The lack of comprehensive long-term data limits trend analysis. Microcystine toxins are a relatively new phenomenon in the Great Lakes.

Data processing needs: The data processing needs for this indicator are many and substantial effort will be required to calculate the indicator. Current data is insufficient to provide a full application of the indicator to all five lakes (also see note below).

Note: This indicator was proposed by Sue Watson with Environment Canada and Greg Boyer at State University of New York. It is currently in the early stages of development and has not yet been used to monitor the effects of HNA on the Great Lakes. Watson and Boyer acknowledge identifying and assessing the data needed for calculation of this indicator is particularly challenging. They have requested funding in two recent proposals to hire an intern to more fully evaluate data availability and sufficiency. As such, this data analysis report is preliminary and the IJC should remain in close contact with Watson and Boyer as the index is developed and implemented.

Indicator Details:

The following table identifies the individual metrics of Harmful Algae (HAI) and/or Nuisance Algae (NAI) which can be combined to evaluate HNA. The individual metrics can be measured from biweekly samples (or more frequently during high risk periods if feasible) taken at high risk and reference monitoring sites from discreet surface (0.5-1m) samples and/or euphotic zone integrated samples and/or benthic mats from June-November (except HNAI_7, below). The sampling period should be adapted to local conditions and previous records of HNA seasonality, and may include winter (under ice) sampling if warranted.

Components:	Component specifications:	ER &ON data sources: (see data table)	MI, HU & SU data source: (see data table)
HAI_1: Toxicity	i) annual % samples with Microcystin-LR (MC-LR) concentrations > 10ug/L (pelagic) or >20ug/L (benthic) and ii) seasonal/ long term changes in MC-LR concentrations at focal monitoring sites	A & B	Practically none (exceptions are drowned river mouths in Lake MI and Saginaw Bay, source C)
HAI_2: Cyanobacterial (or other HNA taxa) dominance	a) % samples with chlorophyll-a (chl *a*) > 30 ug/L and HNA dominance (> ~80%), evaluated using microscope, flow cytometric or fluorometric methods or b) taxonomic index (e.g. Downing *et al.* 2001; Kane *et al.* 2009)	D (Lake Erie only), E	E
NAI_3: Pelagic chlorophyll with offensive malodour or taste	% samples with chl *a* > 30 ug/L and levels of common algal odour compounds (geosmin, 2-MIB, b-cyclocitral, decadienal) greater than human odour threshold concentrations or malodour or taste unacceptable to sensory screening (sniff tests or standardized Flavour Profile Analysis; e.g. Dietrich 2004).	A& B	None
NAI_4: % or absolute benthic NA areal coverage	% coverage of nearshore (up to 15m depth) of NAs at high risk and reference sites, sampled from quadrants; or % coastline with > 50% coverage or 50gm dwt/m^2 (Auer *et al.* 2010)	Limited data for Western Lake Erie	Practically none; occasional *Cladophora* studies
NAI_5: Benthic NA resulting in beach closures or similar negative shoreline impact	% positive scores where, if at a given site, there is a beach posting or closure due to excess algal material.	F	F
NAI_6: Pelagic or benthic NA with other harmful effects	Using quantitative or qualitative criteria; these may be site specific; Index is % positive scores for one or more of these harmful effects	Anecdotal accounts only	None
HNAI_7: Satellite-derived algal bloom metrics	Timing, intensity (average chl *a* concentration), duration, aerial extent (e.g. Binding *et al.* 2012).	Possibly G	Possibly G (but not Superior)

Calculations: Details are included in the table above. Refinements will be made by Watson and Boyer.

Combination of components: To be determined by Watson and Boyer.

Spatial and temporal coverage: Analyses should be at the lake level. HNA problems are largely confined to shoreline areas, bays, and drowned river mouths in Lake Michigan and to Lakes Erie and Ontario. Microcystin toxins were first reported in 1995 in the Great Lakes and few long term datasets exist making long-term trend analysis on harmful algae difficult.

Measurement of progress: Progress could be measured by improvements in individual metric scores and/or improvement in a multimetric index that incorporates several to all of these metrics.

Data Evaluation:

Sufficiency and accessibility: Many of the suggested metrics can be calculated for Lake Erie and some can be calculated for Lake Ontario using data from current monitoring programs. Data gaps preclude calculation of the metric for Lakes Michigan, Huron, and Superior. Monitoring for harmful and nuisance algae outside of Lakes Erie and Ontario is sporadic and is largely driven by independent research projects in specific, often small, areas. The lack of any systematic, Great Lakes-wide monitoring program limits currently limits the ability to calculate this indicator basin-wide. This lack of consistent monitoring also limits the ability to monitor trends and assess year-to-year variability in the occurrence of harmful and nuisance algae in areas of high abundance. Coordinated sharing of data produced by existing monitoring programs is also lacking. For example, both the Canadian Limnos and US EPA Lake Guardian monitoring vessels now employ monitoring devices that can provide phytoplankton class abundance (required for HAI_2), but it is not clear to us who is responsible for processing and providing that data. As mentioned, Watson and Boyer acknowledge identifying and assessing the data needed for calculation of this indicator is particularly challenging. They have requested funding in two recent proposals to hire an intern to more fully evaluate data availability and sufficiency. As such, this data analysis report is also preliminary and the IJC should remain in close contact with Watson and Boyer as the index is developed and implemented.

Additional needs: Application of cost effective and feasible measures such as the metrics proposed in this indicator could ensure long-term continuity of monitoring programs to evaluate trends and stochasticity. Currently, differences in sampling regimes and analytical protocols affect data compatibility and the resolution of long term trends, and sampling regimes can miss spatial and temporal peaks in HNA abundance. Most focus is on shoreline mats of attached algae or surface mats of buoyancy-regulating cyanobacteria. These can appear/disappear rapidly with changes in mixing, currents and wind, producing significant spatial/temporal variance in biomass and toxins which is difficult to sample, quantify or predict, and is ‘smoothed out’ by seasonal means.

Required data processing and calculation effort: This indicator requires dramatically increased monitoring effort, and substantial data processing and calculation effort. Many recent advances, such as computer mapping of algal blooms may reduce this effort, but these efforts are largely disparate and often in an early demonstration-only stage.

References:

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Downing, J.A., S.B. Watson and E. McCauley. 2001. Predicting Cyanobacteria dominance in lakes. Canadian Journal of Fisheries and Aquatic Science. 58:1905-1908.

Kane, D.D., S.I. Gordon, M. Munawar, M.N. Charlton and D.A Culver. 2009. The Planktonic Index of Biotic Integrity (P-IBI): An approach for assessing lake ecosystem health. Ecological Indicators 9:1234-1247.

Relevant SOLEC Indicators:

Harmful Algal Blooms (HABS): Draft 2012 SOLEC report available at
http://www.solecregistration.ca/documents/HABs%20DRAFT%20Nov2011.pdf

Cladophora: Draft 2012 SOLEC report available at
http://www.solecregistration.ca/documents/Cladophora%20DRAFT%20Oct2011.pdf

Indicator data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Environment Canada Cruises (2 kinds) and another relevant sampling program Lake Erie	LEMELEE cruise: Rick Bourbonniere, Environment Canada, 905-336-4547, Rick.Bourbon@ec.gc.ca Water Quality Cruise: Sue Watson, Research Scientist, Environment Canada, 905-336-4759 (office), 905-336-4726 (Lab), sue.watson@ec.gc.ca Thomas Bridgeman, University of Toledo, Lake Erie Center, 419-530-8360, Thomas.Bridgeman@utoledo.edu	Contact Rick, Sue, and Tom for access.	Environment Canada annual cruise: Lake Erie Microbial Ecology of Lake Erie Ecosystem (LEMELEE). Focus is usually hypoxia and the dead zone – but have also included cyanobacterial toxins in recent years (thought it is not a major focus of the effort). Early surveys were systematic but in recent years effort has been focused on Western Lake Erie only. Number of stations varies with year, usually about 15-20 stations. Environment Canada Water Quality Monitoring Cruise: This goes several times over the course of the summer (usually three) – focus is the general water quality but in recent years, it has had a heavy interest in cyanobacteria and their toxins.	From Bridgeman: "Since April 2002 we have been conducting monitoring cruises at 10-14 day intervals between April and October with the objective of establishing baseline water-quality conditions in Maumee Bay and western Lake Erie. These data will be used to establish seasonal trends and to understand the influence of the Maumee River in determining offshore water quality."

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
B	Environment Canada: Annual Taste and Odor Cruise Lake Ontario	Sue Watson, Research Scientist, Environment Canada, 905-336-4759 (office), 905-336-4726 (Lab), sue.watson@ec.gc.ca Greg Boyer, SUNY-College of Environmental Science and Forestry, 315-470-6825, glboyer@esf.edu	Contact Sue or Greg for access. A maps of some of these stations can be viewed at http://canamglass.org/low/files/BoyerHABgrandIsland28Mar07.pdf	The Taste &Odor cruise program began in earnest in 2003 and continue today; Up to 100 stations and includes separate monitoring for the Bay of Quinte and Hamilton Harbor; Cruises in late summer to early fall.	Focus of cruise is cyanobacteria metabolites including toxins.
C	Other microcystine sampling programs	Saginaw Bay: Julie Dyble Unable to identify additional contacts or contact information	http://www.glerl.noaa.gov/res/Centers/HABS/sampling_data.html	Limited largely to Saginaw Bay, Bear Lake, Muskegon Lake	
D	Lake Erie Plankton Abundance Surveys (LEPAS)	Dave Culver, Professor, Ohio State University, 614-292-6995, culver.3@osu Joseph Makarewicz, distinguished professor, Brockport SUNY, 585-395-5747, jmakarew@brockport.edu	Contact Dave Culver for more information; Joseph Makarewicz also has access to these and older data	Began in 1995 and continues today. International, multi-agency, intensive sampling program: Goal is to determine the abundance and biomass of phyto- and zooplankton along with chlorophyll a concentration, water temperature, dissolved oxygen and Secchi depth throughout Lake Erie.	Semi-monthly samples generally collected annually from May through September. Phytoplankton samples taken from integrated water column samples to twice Secchi depth Enumeration of the phytoplankton samples generally followed the Utermöhl technique; All phytoplankton genera identified and counted.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
E	USEPA GLNPO spring and summer plankton surveys; water quality surveys (chlorophyll *a*)	Plankton: Euan D. Reavie, University of Minnesota Duluth, 218-235-2184, ereavie@d.umn.edu Chemistry: Glenn Warren, GLNPO project officer, 312-886-2405, warren.glenn@epa.gov	Summer plankton data is likely relevant to this indicator Plankton data is in a database but the database is not publicly available at the moment. A final report on GLNPO collected plankton from 2001-2010 is due to EPA at the end of April 2013.	Three objectives of the phytoplankton program are to: 1) collect phytoplankton from the Great Lakes in spring and summer excursions on board the R/V Lake Guardian; 2) identify and enumerate phytoplankton, maintaining quality assurance standards; and 3) maintain and provide a database of phytoplankton data.	Includes both soft algae and diatom analyses Measures for each taxa include density (cells/ml) and biovolume (μm^3/ml). Chlorophyll *a* concentrations measured in water column profiles during SP and SU cruises. Reavie notes that Caution is required when using these two datasets (e.g. pre 2001 compiled by Barbiero and post 2001-2010 compiled by Reavie) to test for temporal trends, particularly when taxonomic details are important.
F	Beach closures due to excessive algae	County health departments (USA), Public Health Units (CAN), or municipal health departments	Need to contact each health department/unit for data. Possibly use BEACON 2.0 (see overview and details at http://watersgeo.epa.gov/BEACON2/about.html)	Although beach closures for excessive fecal pollution (e.g. *E. coli)* are monitored and routinely reported to US EPA and OMNR, there is no such reporting for closures due to algae; These closures do not appear easy to identify or summarize.	Recent improvements in beach monitoring in the Great Lakes, BEACON 2.0 , may allow one to tease out beach closure information due to algae. However, this looks very difficult. May want to Email ebeaches@induscorp.com for more information.
G	Michigan Tech Research Institute	Colin Brooks, Research Scientist, Manager of	Overview of the project and additional contact	A depth-invariant algorithm developed at MTRI was first	The SAV in the Great Lakes is predominantly *Cladophora*,

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	(MTRI) *Cladophora* mapping	the Environmental Sciences Lab, 734-913-6858, colin.brooks@mtu.edu Michael Sayers, Research Engineer, 734-913-6852, mjsayers@mtu.edu	information at http://www.mtri.org/cladophora.html	used successfully with satellite imagery to map *Cladophora* and other submerged aquatic vegetation (SAV) on the bottom of the Sleeping Bear Dunes National Lakeshore in Lake Michigan under NASA funding. Under a GLRI grant, we have recently mapped the near-shore extent of SAV for Lakes Michigan, Huron, Erie and Ontario (*Cladophora* is not yet a significant issue in Lake Superior).	with localized areas of vascular plants, other filamentous algae, and diatoms. The maps have a 30 meter resolution and were generated using Landsat satellite data from 2008-2011 collected during the vegetative growing season (April-May).

Lower Food Web Productivity/Health

Summary:

The purpose of the Lower Food Web Productivity/Health indicator is to measure the trophic efficiency of the food web at transferring algal production to fish. This indicator has four components: 1) phytoplankton biomass and community structure; 2) zooplankton biomass and community structure; 3) benthos abundance and diversity; and 4) prey fish abundance and diversity.

Spatial coverage: This indicator will include the five Great Lakes with analysis at the lake level.

Temporal coverage: Most components of the indicator are supported by long-term monitoring programs. Water chemistry based subcomponents and preyfish abundance have been measured since at least the 1970s, reliable zooplankton and benthos since 1998, and consistently processed phytoplankton since 2001.

Data processing needs: The purpose and definition of this indicator need modification before the indicator can be calculated. Measures of productivity (e.g. measures of density or biomass of food web components) support the stated purpose of the indicator but have less supporting data. Measures of Biotic Integrity such as Benthos Diversity are available for most of the food web components but are less applicable to measures of productivity. Depending on the specific subcomponents chosen for this indicator and how the data are supplied (i.e. raw or already processed), this indicator may require substantial processing and calculation effort.

Indicator Details:

The purpose of this indicator is to measure the trophic efficiency of the food web at transferring algal production to fish. This indicator has four components: 1) phytoplankton biomass and community structure; 2) zooplankton biomass and community structure; 3) benthos abundance and diversity; and 4) prey fish abundance and diversity.

Components:	**Component specifications:**	**Data source: (see data table)**
1) Phytoplankton biomass and community structure:	Ratio of chlorophyll *a* to TP	A & B
	Plankton stoichiometry: The ratios of C/P, C/N, and N/P (requires current and historical records of POC, PON, and PP)	none
	Fv/Fm ratio (measure of the efficiency of photosynthesis to diagnose the productivity of phytoplankton)	No historical record; could be added to buoys

Components:	Component specifications:	Data source: (see data table)
	Measures of the relative abundance of major phytoplankton phyla (particularly the relative abundance of Cyanobacteria versus diatoms and flagellates) and/or the Plankton Index of Biotic Integrity (Kane *et al.* 2009) and/or diatom transfer functions (Reavie *et al.* 2006).	C, D, & E
	Particulate phosphorus size-distribution (PP slope): slope of particulate P fraction against size	Few historical data in GL
	Normalized Size-Spectra: Similar to PP slope but depends on biomass determination across the particle spectrum from phytoplankton to fish. Has been used to compare GL and estimate productivity.	(Sprules *et al.* 1991, Sprules and Goyke 1994)
	Particle-size conversion efficiency: Expresses the efficiency with which energy moves up the pelagic size-spectrum. Can be estimated by concentrations of PBTs at different trophic level (e.g. zooplankton and predatory fish)	See PBTs in fish and bird indicator; Not aware of any PBT measures on zooplankton
2) Zooplankton biomass and community structure:	Zooplankton mean size and zooplankton biomass	E & F
	Ratio of calanoid copepod abundance to cyclopoid copepods plus cladocerans	E & F
3) Benthos abundance and diversity	Densities of major taxa groups; Condition Indices including several measures of richness and evenness, *Diporeia* density, proportion oligochaetes, oligochaete chironomid ratio, and chironomid and oligochaete trophic indices.	G & H
4) Preyfish abundance and diversity	Preyfish abundance and biomass	I & J

Calculations: Some details of the necessary calculations are included in the table above. These will need to be refined and detailed once specific measures are chosen for the indicator.

Combination of components: The stated purpose of this indicator is to measure the trophic efficiency of the food web at transferring algal production to fish. How the components will be combined has not been specified in the draft indicator and is beyond the scope of this contract.

Spatial and temporal coverage: For most of the components and subcomponents listed above, measures are available in all of the lakes. Additional water chemistry and plankton data are available for Lake Erie. Analyses can be performed at the lake level. Water chemistry based subcomponents and preyfish abundance have been measured since at least the 1970s, reliable benthic data since 1998, zooplankton since 1998, and consistently processed phytoplankton since 2001.

Measurement of progress: How progress will be measured largely depends on which metrics are included in the indicator. Improvements in IBI, condition indices and diversity measures will signify progress for some plankton metrics and benthic metrics but are not good measures of food web productivity. The SOLEC indicator for "Zooplankton Populations" uses mean length of zooplankton captured with a 153um net with an endpoint of 0.8mm, but use of this proposed endpoint may lack sound rationale. Fish Community Goals and Objectives for preyfish in each lake (in Great Lakes Commission reports) can be applied as endpoints for the preyfish abundance and diversity metric. Endpoints for other plankton metrics and some zooplankton metrics will need to be established.

Data Evaluation:

Sufficiency and accessibility: Data are available to calculate at least some measure of each component of the indicator (phytoplankton, zooplankton, benthos, and preyfish). Plankton biomass can be estimated from existing monitoring surveys that collect chlorophyll *a*. In addition, a relatively simple metric, Planktonic Index of Biotic Integrity (P-IBI), has been developed for phytoplankton and applied to Lake Erie (Kane *et al.* 2009), and could be applied to other Great Lakes. A unique nearshore study of diatoms has also been done (Reavie *et al.*2006) although there is no current monitoring program in place to continue these assessments. Biomass and/or density data are available for zooplankton, benthos, and preyfish although some efforts to assemble data will be required. Note we were not able to identify Canadian sources for zooplankton or prey fish data, however, we suspect these do exist. Summary Biotic Integrity metrics for benthos and preyfish are also available.

Additional needs: The indicator purpose and definition needs modification before the indicator can be calculated. The draft indicator proposes many phytoplankton related subcomponents, of which only a limited number are supported by data. Two major types of subcomponents are included in the indicator, measures of productivity and measures of biological health (measures of Biotic Integrity). Although the later are more widely available, they do not directly support the stated purpose of the indicator, to measure the trophic efficiency of the food web at transferring algal production to fish. Currently it is unclear how the components of the indicator will be combined into one indicator. This indicator also requires expanded definitions of how progress will be assessed. Although trends in data could be observed for many subcomponents, most lack well justified end points. Euan Reavie (personal communication) expressed serious concern about analysis of trends in phytoplankton. He is concerned that we simply do not have a long enough monitoring history to know what an "undisturbed" or "natural" state is for Great Lakes phytoplankton assemblages. He is currently developing paleo-reconstructions of the diatoms community from pre-settlement times.

The data available for this indicator are largely from monitoring programs at pelagic stations, and although spatially comprehensive, these monitoring programs are often limited to sampling once or twice per year. These limitations may hinder our understanding of lower food web dynamics. For example, although we know that phytoplankton biomass can vary dramatically within days or weeks, monitoring by EPA GLNPO is limited to twice per year. More temporally intensive sampling programs such as the Lake Erie Plankton Abundance Studies are limited spatially. Adding or augmenting nearshore monitoring of plankton, benthos, and fish in CSMI intensive field years may help remedy some of these issues.

Required data processing and calculation effort: Depending on the specific subcomponents chosen for this indicator and how the data are supplied (i.e. raw or already processed), this indicator may require substantial processing and calculation effort. At minimum, several measures of biotic integrity will need to be calculated for phytoplankton and benthos.

References:

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Sprules, W.G. and A.P. Goyke. 1994. Size-based structure and production in the pelagia of Lakes Ontario and Michigan. Canadian Journal of Fisheries and Aquatic Science 51: 2603-2611.

Relevant SOLEC Indicators:

Benthos Diversity and Abundance: Draft 2012 report available at http://www.solecregistration.ca/documents/Benthos%20Diversity%20and%20Abundance%20DRAFT%20Oct2011.pdf

Preyfish Populations: Draft 2012 report available at
http://www.solecregistration.ca/documents/Preyfish%20Populations%20DRAFT%20Oct2011.pdf

Zooplankton Biomass: Draft 2012 report available at
http://www.solecregistration.ca/documents/Zooplankton%20Biomass%20DRAFT%20Oct2011.pdf

Indicator data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	USEPA GLNPO: offshore water monitoring (including measures of chlorophyll *a* and TP)	Glenn Warren, GLNPO project officer, 312-886-2405, warren.glenn@epa.gov	Can download desired data from https://cdx.epa.gov/; Must have login to access In Excel files: Vertical water sample profiles. Standard operating procedure manuals provide more information and are available at http://www.epa.gov/grtlakes/monitoring/sop/index.html	About 75 sites sampled each year throughout the five Great Lakes. Sampling restricted to off-shore because of 11+ foot draft of RV Guardian. Concentrations available: Spring and Summer chl *a* and TP water column profiles; (Total/Bulk is TP).	ER, HU, and MI: 1983-2011; ON: 1985-2011 (SU only in 85 & 89; SP only in 92-93); SU: 1992-1993 (SP only in 1992): EXCEPTIONS: NO data for any lakes from 1994 and 1995. The data reporting format (especially depth codes) changed beginning in 1996; Data from 1983-1993 and 1996-present may need to be summarized separately. Excel files need careful examination before calculating chl *a* and TP values for each site each year. Excel files include all values from all samples (including composite samples, blanks and duplicates, and values for samples that did not meet quality control requirements).

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
B	Environment Canada: Great Lakes Surveillance Program (including measures of chlorophyll a and TP)	Alice Dove, 905-336-4449 Alice.Dove@ec.gc.ca at the Canada Centre for Inland Waters (Burlington, ON) or email GLSP-PSGL@ec.gc.ca An overview of the program is at http://www.ec.gc.ca/scitech/default.asp?lang=en&n=3F61CB56-1	Need to request data from Alice Dove or use general email request address All Great Lakes Surveillance Program data are stored at the Canada Centre for Inland Waters in Burlington, Ontario, in the Storage and Retrieval Database and can be retrieved upon request.	About 275 sites: SU ~50-73 (more stations pre 1990s); ON~100; ER~55; HU~68; Each lake monitored every 2nd year. Spring and summer cruises; Chl a and TP are sampled in both spring and summer. Methods for EC's Great Lakes Surveillance Program are described in Dove 2009.	Standardization of data began in 1974. Includes off-shore and some nearshore locations.
C	USEPA GLNPO phytoplankton monitoring	Euan D. Reavie, University of Minnesota Duluth, 218-235-2184, ereavie@d.umn.edu Richard P. Barbiero, CSC, 1359 W. Elmdale Ave Suite 2, Chicago, Il, 60660, 773-878-3661, gloeotri@sbcglobal.net	Standard operating procedure manuals provide more information and are available at http://www.epa.gov/grtlakes/monitoring/sop/index.html Plankton data is in a database but the database is not publicly available at the moment. A final report on GLNPO collected plankton from 2001-2010 is due to EPA	Three objectives of the phytoplankton program are to: 1) collect phytoplankton from the Great Lakes in spring and summer excursions on board the R/V Lake Guardian; 2) identify and enumerate phytoplankton, maintaining quality assurance standards; and 3) maintain and provide a database of phytoplankton data. Integrated (INT) phytoplankton samples are created from a composite of water samples taken at	Includes both soft algae and diatom analyses; Measures for each taxa include density (cells/ml) and biovolume (μm^3/ml). Euan Reavie can provide phytoplankton data going back to 1996. Richard Barbiero has older data as far back as the early 1980s. Reavie (personal communication) stresses these two datasets (e.g. pre-2001 compiled by Barbiero and 2001+ compiled by Reavie) should not be

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			at the end of April 2013.	discrete depths with the Rosette from the euphotic zone of the water column. Additional discrete samples from the deep chlorophyll layer (DCL) are taken during the summer at stations exhibiting marked horizontal discontinuities in chlorophyll concentration.	combined to test for temporal trends or compared, particularly when taxonomic details are important. There are substantial differences in methods, taxonomy, and quality assurance procedures.
D	Diatom samples from coastal Great Lakes wetlands (NEARSHORE data)	Euan D. Reavie, University of Minnesota Duluth, 218-235-2184, ereavie@d.umn.edu	See Reavie *et al.* 2006 for more information. Contact Euan Reavie for access to data and analyses.	This study developed and tested several diatom based transfer functions derived from a training set of coastal surface sediment and epilithic samples from the U.S. portion of the five Laurentian Great Lakes. The diatom indicators were derived from data collected as part of a larger study designed to develop and test indicators of ecological condition for Great Lakes coastal ecosystems (the Great Lakes Environmental Indicators (GLEI) project	155 samples from five coastal ecosystem types: Embayments, high-energy shorelines, coastal wetlands, riverine wetlands, and protected wetlands. Field sites were sampled from June to September 2002 and May to August 2003. Taxa were counted and identified to the lowest taxonomic level possible using numerous diatom checklists and iconographs. Multivariate data exploration revealed strong responses of the diatom assemblages to stressor variables, including total phosphorus (TP). Spatial variables such as lake,

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
					latitude and longitude also had notable relationships with assemblage characteristics.
E	Lake Erie Plankton Abundance Surveys (LEPAS)	Dave Culver, Professor, Ohio State University, 614-292-6995, culver.3@osu Joseph Makarewicz, distinguished professor, Brockport SUNY, 585-395-5747, jmakarew@brockport.edu	Contact Dave Culver for more information; Joseph Makarewiz also has access to these and older phytoplankton data.	Began in 1995 and continues today. International, multi-agency, intensive sampling program: Goal is to determine the abundance and biomass of phyto and zooplankton along with chlorophyll *a* concentration, water temperature, dissolved oxygen and Secchi depth throughout Lake Erie. Semi-monthly samples generally collected annually from May through September.	Phytoplankton samples taken from integrated water column samples to twice Secchi depth. Enumeration of the phytoplankton samples generally followed the Utermöhl technique; All phytoplankton genera identified and counted. Zooplankton sampled from the entire water column and volume sampled was calculated from flow meter readings and net cross-sectional area; Four cubic meters of water typically sampled in the western basin. Proportionately larger volumes sampled from deeper areas of the lake. Enumeration: Cladocerans and copepods identified to species and sex while rotifers and dreissenid veligers identified to genus. Lengths of 20 of each taxa measured. Calculated biomass by taxa

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
					and summed for a total crustacean zooplankton biomass per site per date.
F	USEPA GLNPO Zooplankton tows	Glenn Warren, GLNPO project officer, 312-886-2405, warren.glenn@epa.gov Richard P. Barbiero, CSC, 1359 W. Elmdale Ave Suite 2, Chicago, Il, 60660, 773-878-3661, gloeotri@sbcglobal.net	Data for 1998-2006 available from GLNPO; Contact Glenn Warren; Data are largely in Excel files	Zooplankton are sampled on the spring and summer cruises. Two sampling tows are performed at each station. One tow is from 20 meters below the water surface to the surface using a 63-µm net. The other tow is from 100 meters below the surface to the surface using a 153-µm net. If the station depth is less than the specified depth, the tow is taken from two meters above the bottom to the surface. The tow net, with a screened sample bucket attached at the bottom, is lowered to the desired depth, and raised at 0.5 meters per second to collect zooplankton from the water column.	Data available for 1998-2006; Monitoring also occurred in 2006-2011 but there have been major problems with the sample processing. It is unclear when, or if, those data will be available. At minimum, taxa identified to major group, e.g. non-daphnids, daphnids, predatory cladocerans, immature cyclopoids, adult cyclopoids, immature calanoids and adult calanoids; Measures include biomass and average size.
G	USEPA GLNPO and Great Lakes Aquatic Habitat Framework: Summarized benthic samples	Catherine Riseng, Assistant Research Scientist, 734-763-9422 criseng@umich.edu) Beth Sparks-Jackson,	Incorporated into GLAHF Three benthos summaries: Spring *Hexagenia* density, Summer average density by major taxa, and	Three separate samples of benthic invertebrates are taken with a Ponar grab sampler at each designated sample site in each lake. Each sample is processed, preserved and stored	Average density (number per square meter) of the burrowing mayfly Hexagenia for 2 to 6 stations (varies by year) across Lakes Erie, Huron, and Michigan from 2001-2011.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		University of Michigan, sparksb@umich.edu	condition indices All data are in Excel files and can be joined to spatial and station information.	separately. Elutriation may be used when the samples contain large amounts of sand, zebra mussel shells, or other debris that prevent sediment from quickly passing through a 500-µm mesh. During the summer cruise, a fourth Ponar sample is taken for grain size and chemical analysis. During the summer cruise, all stations are sampled and analyzed for all benthic invertebrates. During the spring cruise, samples are taken at five sites (Saginaw Bay, Green Bay, and the Western Basin of Lake Erie) and are analyzed specifically for the mayfly *Hexagenia*.	Average density (number per square meter) of major groups of benthic invertebrates for ~75 stations across Lakes Erie, Ontario, Huron, Superior, and Michigan annually for 1997-2011. Condition indices including several measures of richness and evenness, *Diporeia* density, proportion oligochaetes, oligochaete chironomid ratio, and chironomid and oligochaete trophic indices. Measures are for ~75 stations across Lakes Erie, Ontario, Huron, Superior, and Michigan annually for 1997-2010.
H	Environment Canada benthic samples	Lee Grapentine, Research Scientist, Water Science and Technology Directorate, Environment Canada, 905-336-6479, Lee.Grapentine@ec.gc.ca	As long as there is attribution of their source no restrictions of use.	Benthic data from about 200 nearshore sediment sites in the Great Lakes and upper St. Lawrence River, sampled from 1990 to the present. Of these site, 164 are being resampled for monitoring and associated sediment assessments at 12 Areas of Concern (AOCs). For the AOC assessments, over 400	Benthic invertebrates were sampled according to standard protocols from the upper 10 cm of sediment using a mini-box corer, "Tech Ops" corer, or petite Ponar grab. Mini-boxer corer samples were subsampled by tubes of the same diameter (6.5 cm) as the Tech Ops cores. Reference site samples

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				nonreference sites have also been sampled in the AOCs. Samples for each site have been analyzed for benthic macroinvertebrate community structure, sediment physiochemistry, overlying water chemistry, and (usually) sediment toxicity.	were identified to the lowest possible level (genus or species for mature individuals of most taxa). AOC site samples were identified mostly to the family level.
I	USGS Great Lakes Science Center: Compiled Trawl Surveys	Jeff Schaeffer, Research Fishery Biologist, 734-214-7250, jschaeffer@usgs.gov	Depends largely on whether IJC wants raw data or summarized data. Contact Jeff Schaeffer for more information. Excel files for each lake with trawl location, catch, effort, etc.	Trawl boat, equipment, and technique vary by lake and have changed over time. Correction factors can be applied to standardize the data across time. Includes USGS and other organizations (such as NYDSEC) collected data.	Note: Absence of fish does not imply low abundance or lack of fish. The data is limited by boat and catch technique. Data must be treated carefully by knowledgeable staff. USGS plans to intensively sample multiple trophic levels in each of the Great Lakes over 2010-2014 to improve Ecopath with Ecosim food web models.
J	Great Lakes Fishery Commission (GLFC)	Lake Committees, Lake Technical Committees, and Task Groups State of the Lake, and Fish Community Objective reports	Most data available in publicly available documents on the website at http://www.glfc.org/pubs_out/communi.php and http://www.glfc.org/pubs_out/lcpubs.php	Each State of the Lake report addresses individual fish species. Reports also include management objectives and targets (for measuring progress).	SOLEC report authors (often also members of GLFC committees and task groups) can also assist with acquiring the data needed for this indicator. For preyfish the author of the 2012 SOLEC report is Owen T. Gorman, USGS Great Lake Science

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
					Center, Ashland, WI, 715-682-6163 ext. 16, otgorman@usgs.gov

Fish Species of Interest

Summary:

The Fish Species of Interest indicator measures annual relative abundances for adult lake trout, Chinook salmon, Atlantic salmon, and walleye, and riverine spawning status for lake sturgeon for each lake. These measures will be based on data from fisheries management agencies, and reporting by commercial and recreational fisheries.

Spatial coverage: Reporting of abundance/spawning status is summarized by lake and relevant lakes will vary with fish species.

Temporal coverage: Widely available commercial catch records begin in 1860 and recreational catch records are available from the mid-1980s. Most of these fish species have, at minimum, several decades of fisheries management abundance estimates.

Data processing needs: The most difficult and time consuming task in calculating this indicator is locating and compiling fisheries data from numerous sources. Calculation efforts should be minimal. However, fisheries experts have recommended inclusion of additional metrics, clarification of the “spawning success” metric for lake sturgeon, and selection of an appropriate time interval for calculating each component of the indicator (e.g. 5 – 10 year intervals).

Indicator Details:

The Fish Species of Interest indicator measures annual measures of adult relative abundances for each lake for lake trout, Chinook salmon, Atlantic salmon, and walleye, and riverine spawning status for lake sturgeon. These measures will be based on data from fisheries management agencies, and reporting by commercial and recreational fisheries.

Components:	**Component specifications:**	**Data source: (see data table)**
Lake Trout	Annual measures of adult relative abundances	Commercial: A & B Recreational: D Fisheries management: F
Chinook Salmon	Annual measures of adult relative abundances	Commercial: A & B Recreational: D Fisheries management: F, G, & I
Atlantic Salmon	Annual measures of adult relative abundances	Commercial: None Recreational: D Fisheries management: F, H, & I
Walleye	Annual measures of adult relative abundances	Commercial: A & B Recreational: D Fisheries management: F

Components:	Component specifications:	Data source: (see data table)
Lake Sturgeon	Riverine spawning status (as a surrogate for abundance because of low abundance)	F & J (Historical commercial catch: A)

Calculations: For the first four species, abundance measures are regularly compiled/calculated on an annual basis for each lake by fisheries management units as reported by authors of SOLEC and Great Lakes Fishery Commission reports. How commercial, recreation, and fisheries management data will be integrated is not addressed in the draft indicator and beyond the scope of this data assessment report.

Combination of components: Components will not be combined as each species represents unique ecosystems and/or interests in the Great Lakes and management efforts are often species specific. Each species will be assessed individually for this indicator.

Spatial and temporal coverage: Lake trout, walleye, and lake sturgeon are in all five Great Lakes, although abundance can vary dramatically between Lakes. Atlantic salmon is largely restricted to Lake Ontario and Chinook salmon is largely restricted to Lakes Michigan, Ontario, and Huron. Most of these fish species have, at minimum, several decades of abundance estimates. Widely available commercial catch records begin in 1860 and recreational catch records are available from the mid-1980s.

Measurement of progress: Assessment of progress will vary with species although generally, increases in abundance and/or commercial and recreation catches could signify progress. Increases in spawning and recruitment of lake sturgeon could signify progress for this species. For all five species, current condition may also be compared to historical abundance, or to performance targets established in Fish Community Objectives or other management plans. Alternatively, a goal of self-sustaining, naturally reproducing populations that support target yields to fisheries could be set as a measure of progress.

Data Evaluation:

Sufficiency and accessibility: The data are largely sufficient and accessible for calculation of this indicator. Commercial catch, and to a slightly lesser extent, recreational fishery catches are easily accessible and widely available. We had to take a slightly different approach to the analysis of abundance and spawning status data for this indicator than we have for other indicators. Annual lake-wide estimates of fish abundance are based on the coordinated efforts of state, federal, tribal, and provincial agencies and are largely contained in non-peer reviewed reports to the Great Lakes Fishery Commission (GLFC). Therefore, we did not assess "raw" data sources and instead focused on these "summary" sources. The primary sources of data include GLFC reports and excellent resources include the fisheries experts responsible for writing SOLEC fisheries reports. Atlantic and Chinook salmon are generally exceptions to this rule. Sources of data on these species include individuals and management programs. Since stocking can complicate interpretation of status we have also included the Great Lakes Fish Stocking Database in our data assessment (row K).

Additional needs: During our data investigations several fisheries experts expressed concerns that only using abundance estimates as a metric may limit the ability of the indicator to measure actual progress in fish populations in the Great Lakes. In additional to or instead of abundance, metrics that can measure the ability to build potentially self-reproducing stocks, should be considered. For Lake Trout, an index of wild recruits may be more meaningful than estimates of adult populations. Fisheries experts also warned the lake sturgeon metric "spawning success" will need to be more specifically defined. Lastly, several experts were concerned about duplication of effort and questioned how this indicator will differ from the SOLEC indicator (case in point, we were often directed to the SOLEC reports as sources of data).

The time interval for calculating this indicator also needs to be identified. Although annual estimates of abundance and spawning status are common, intervals between the compilations of these estimates varies between 1-10 years. We suggest the indicator be calculated every five years, about the same interval as GLFC State of the Lake reports.

Despite repeated attempts to contact Canadian fisheries personnel we were unable to specifically address how Canadian fisheries management programs could contribute to this indicator. We are also unable to provide contact and additional information for Canadian commercial catch after 2007 and any Canadian recreational fisheries catch (rows C & E in the data table). Because the recreational fisheries data we have identified is limited to the MI DNR, we were unable to located recreational fisheries data for Lake Ontario.

Required data processing and calculation effort: The most difficult and time consuming task in calculating this indicator is locating and compiling fisheries data from numerous sources. Calculation efforts should be minimal.

Relevant SOLEC Indicators:

#8 Salmon and Trout (2009)

Status of Lake Sturgeon in the Great Lakes: Draft 2012 SOLEC indicator report available for review at http://www.solecregistration.ca/documents/Lake%20Sturgeon%20DRAFT%20Nov2011.pdf

Lake Trout: Draft 2012 SOLEC indicator report available for review at http://www.solecregistration.ca/documents/Lake%20Trout%20DRAFT%20Oct2011.pdf

Walleye: Draft 2012 SOLEC indicator report available for review at http://www.solecregistration.ca/documents/Walleye%20DRAFT%20Nov2011.pdf

Indicator data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Commercial Catch compiled by Norman S. Baldwin, Robert W. Saalfeld, Margaret Ross Dochoda, Howard J. Buettner, and Randy L. Eshenroder for the Great Lakes Fisheries Commission (GLFC)	Great Lakes Fisheries Commission	1867-2006 data available for download by Lake or for all lakes as Excel or Access files. Data and very useful info on the data available at http://www.glfc.org/databases/commercial/commerc.php Database updated at five-year intervals, and is intended for open use by the public. GLFC asks only for acknowledgment when data are used in presentations and publications.	Commercial fish catch data were first published by the Great Lakes Fishery Commission in 1962 (Technical Report No.3) and covered the period 1867-1960. A supplement covering the years 1961-1968 was released in 1970, and a revised edition covering the years 1867-1977 was published in 1979. This second update of a web-based version covers the period 1867-2006, but also has more-recent data where available. Much more information is included at website but this excerpt explains what the data are: "Production amounts were rounded to the nearest thousand pounds after sums were calculated….A blank indicates no catch report. A lake total for the species in question is computed when the lack of a catch report is assumed attributable to zero catch."	Includes both USA and CAN commercial catch. Spatial coverage: All five lakes and St. Clair. Summary unit: Catch data available at state, lake, USA, CAN, and Grand Total (USA+CAN) units for each lake. Temporal coverage: As early as 1867 to 2006 in current download. Fish species include chinook salmon, lake trout, siscowet, walleye, and lake sturgeon (historical catch only).

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
B	USGS Great Lakes Science Center: Commercial Catch Database	Limei Zhang, IT Specialist, 734-214-7211, lzhang@usgs.gov	http://www.glsc.usgs.gov/main.php?content=products_data_fishingreports&title=Data0&menu=products Downloadable as txt files for each year.	Summaries from USA commercial catch database in lbs and value. Relevant species include Chinook salmon, lake trout, siscowet, and walleye.	1971-2010 currently available (updated annually). Weight and catch reported by states within lake and summarized in totals for each lake. Also include catch classes (human food, animal food, no sale, and bait) and totals by catch class.
C	Ontario Ministry of Natural Resources: Commercial Catch				
D	MI DNR Statewide Angler Survey Program (SASP)	Tracey Kolb, MI DNR, Charlevoix Fisheries Research Station, 231-544-2914 ext. 222, KolbT@Michigan.gov	The primary purpose of SASP is to collect harvest (number of fish caught), effort (number of hours anglers fished), and biological (weight, length, and age) data from all of the Great Lakes Much of this data is available online at http://www.dnr.state.mi.us/chartercreel/ for download as Excel files. However, we feel the interface is clunky; creel data requires downloads	Catch and effort estimates are made for each port or fishing area by month and is often summarized for a year (or "season"). Catch is number of fish and effort is measured three ways; 1) #Anglers, 2) Angler hours, and 3) total excursions. Catch/effort reported as catch/hr or catch/excursion. Charter Boat Catch reported as either "Total Harvest" or "Targeted Harvest"	Collecting data since the early 1980's Charter Boat data available online for chinook salmon, lake trout, and walleye for 1990-2011 Not able to fully detail creel data availability as we could only access data by port, rather than by Lake; Includes data for ER, HU, MI, SU and St. Clair System; Data from 1985 to 2011; Species include altantic and chinook salmon, lake trout, and walleye.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			by port rather a summary by lake (except Lake Erie which is summarized for the whole lake); Tracey Kolb should be able to supply data to IJC in desired format		
E	Ontario recreational fisheries data				
F	Great Lakes Fishery Commission (GLFC) Lake Committees, Lake Technical Committees, and Task Groups State of the Lake, fishery objectives, and rehabilitation strategy reports	Lake MI Trout Task Group and Lake Sturgeon Task Group Lake ER Walleye Task Group: Khahy Ho, 519-873-4647, Khahy.Ho@ontario.ca Lake SU, HU, and MI Lake Technical Committees Lake ON: Andy Todd, Lake Manager, Lake Ontario Management Unit, OMNR, 613-476-3147, andy.todd@ontario.ca	Most data available in publicly available documents on the website at http://www.glfc.org/pubs_out/communi.php and http://www.glfc.org/pubs_out/lcpubs.php Reports with data applicable to this indicator go by various names and include State of the Lake reports, Restoration Plans/Guides, Rehabilitation Plans, and Fish Community Objectives.	Sources of compiled and summary abundance data for each lake, especially for lake trout and walleye. Each State of the Lake report addresses individual fish species. Reports also include management objectives and targets (for measuring progress).	These SOLEC report authors (often also members of GLFC committees and task groups) can also assist with acquiring the data needed for this indicator. Salmonids: John Dettmers, GLFC, Senior Fishery Biologist, 734-662-3209, jdettmers@glfc.org Lake Trout: Chuck Bronte, USFWS Green Bay, 920-866-1717, charles_bronte@fws.gov Lake sturgeon: Robert Elliot, USFWS Green Bay, 920-866-1762, Robert_Elliott@fws.gov

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
					Lake sturgeon: Henry Quinlan, USFWS Ashland, 715-682-6185 Ext. 203, Henry_Quinlan@fws.gov Mark Holey, USFWS, Green Bay, 920-866-1760, mark_holey@fws.gov
G	Chinook Salmon fisheries management abundance estimates (MI & HU)	Michael L. Jones, Professor and chairperson, Dept. of Fisheries & Wildlife, Quantitative Fisheries Center, Michigan State University, 517-432-0465, jonesm30@msu.edu	Not assessed	Modeled population estimates for wild and hatchery Chinook salmon in Lakes Michigan and Huron	
H	Atlantic salmon fisheries management estimates (ON)	Andy Todd, Lake Manager, Lake Ontario Management Unit, OMNR, 613-476-3147, andy.todd@ontario.ca James (Jim) H. Johnson, USGS GLSC Tunison Laboratory of Aquatic Science, 607-753-9391 ext. 7530, jhjohnson@usgs.gov	Not assessed	Products of OMNR's Atlantic Salmon Restoration Program	

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
I	USGS Great Lakes Science Center: Compiled Trawl Surveys	Jeff Schaeffer, Research Fishery Biologist, 734-214-7250, jschaeffer@usgs.gov	Depends largely on whether IJC wants raw data or summarized data. Contact Jeff Schaeffer for more information. Excel files for each lake with trawl location, catch, effort, etc.	Trawl boat, equipment, and technique vary by lake and have changed over time. Correction factors can be applied to standardize the data across time. Includes USGS and other organizations (such as NYDSEC) collected data.	Note: Absence of fish in the database does not imply low abundance or lack of fish. The data is limited by boat and catch technique. Data must be treated carefully by knowledgeable staff. Example: Quality of Chinook salmon trawl data varies by Lake. It is good for Lake MI, but very poor for Lake HU
J	USFWS hosted Great Lakes Lake Sturgeon Collaboration	For information on the Lake Sturgeon Tributary Database and GIS please contact Betsy Trometer, 585-948-5445 ext. 2227, Betsy_Trometer@fws.gov	http://www.fws.gov/midwest/sturgeon/resources.htm Lake Sturgeon Tributary Database: http://www.fws.gov/midwest/sturgeon/tribdata	This website is simply a place for researchers studying lake sturgeon to post their work. Participation is entirely voluntary and not all researchers participate. It does however provide a fairly through list of people and projects on lake sturgeon.	
K	Great Lakes Fish Stocking Database (GLFSD)	No specific contact information available The Great Lakes Fish Stocking Database (GLFSD) is a continuation of a project initiated by the Great Lakes Fishery Commission (GLFC) to provide fishery managers,	Fish stocking database: Information and data download available through tabs at http://www.glfc.org/fishstocking/index.htm Query can be for a range of data or specific stocking events. Results of query in Microsoft Excel or tab-delimited	A single record or observation in the database represents a single stocking event of a unique group or number of fish at a particular site on a particular day. The GLFSD includes all stocking events that contribute to Great Lakes fish populations. The database is intended to provide raw data on stocking	Includes stocking data from as early as 1950 to current stocking efforts. Includes about a dozen reporting agencies. Includes 18 fish species including all five species of interest in this indicator.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		scientists and other interested parties with access to a centralized, comprehensive database of all fish stocked into the Great Lakes from artificial propagation.	text formats. Citation of data from this database should be credited as follows: FWS/GLFC 2010. Great Lakes Fish Stocking database. U.S. Fish and Wildlife Service, Region 3 Fisheries Program, and Great Lakes Fishery Commission.	events from which the user outside this web site can perform summaries or analyses. Annual updates are attempted but complete updates to include all stocking events for the last complete calendar year are unlikely since release dates for data vary among agencies. Like all databases, errors or omissions will occur. It is the responsibility of each agency providing data to transfer complete and accurate records.	

Persistent Bioaccumulative Toxic (PBTs) Chemicals in Fish

Summary:

The PBTs in Fish indicator (see note below) is an assessment of the trends in the concentrations of persistent, bioaccumulating and toxic substances in whole fish. Target fish species include top predators lake trout and walleye, and forage fish rainbow smelt and spottail shiner (suggested for consideration).

Spatial coverage: Spatial coverage includes the five Great Lakes for lake trout, Western Lake Erie for walleye, all Canadian bordered Great Lakes for rainbow smelt, and Lakes Erie and Superior for spottail shiner.

Temporal coverage: This indicator uses several long-term data sets which began as early as 1975 and are ongoing. Long-term storage of fish tissue samples allows for potential retrospective analysis of emerging chemicals of concern.

Data processing needs: Trend analyses using first-order log-linear regression models of annual median concentrations to estimate percent annual declines require minimal/moderate effort. Development of an effects-based indicator will require considerable effort.

Indicator Details:

Components: The PBTs in fish indicator is an assessment of the trends in the concentrations of persistent, bioaccumulating and toxic substances in whole fish. Contaminants to be measured include PCBs, organochlorine pesticides, dioxins and furans, trace metals including mercury, and chemicals of emerging concern such as brominated flame retardants, fluorinated compounds, and synthetic musks. Since several biological factors affect the annual concentrations of PBTs in biota, ancillary data is required for detailed interpretation of the whole fish trend data. Ancillary data include fish age, length, weight, sex, and lipid content of the fish collected.

Note: For this data assessment we have removed bird related components (e.g. herring gulls and bald eagles) and restricted these to the Biological Integrity of Fish-Eating and Colonial Nesting Birds Indicator. Accordingly we have changed the name of this indicator to PBTs in fish. We suggest exclusion of birds from this indicator for three reasons: 1) From discussions with an expert studying herring gulls and bald eagles (Bill Bowerman, personal communication), concentrations of PBTs have been reduced to an extent that concentrations are sometimes undetectable and often do not have measurable **direct** effects on an organism's health; 2) The bird indicator is designed to measure any **direct and indirect** effects of PBTs on birds, providing a better measure of the effects of PBTs on bird than this indicator; and 3) We feel it would give disproportional weight to concentrations of PBTs in birds to include these data in two indicators. However, we understand that this is ultimately not our decision. We have included an analysis of bird related components in the Biological Integrity of Fish-Eating and Colonial Nesting Birds indicator data report.

Component:	Component specifications:	Data source: (see data table)
Concentrations of PBTs in Great Lakes whole fish	Lake trout (*Salvelinus namaychush*)	A, B, C (historical only), D, E
	Walleye (*Sander vitreus*)	A, B, C (historical only), D, E
	Rainbow Smelt (*Osmerus mordax*)	D, E
	Might also consider including spottail shiners (*Notropis hudsonius*)	D, E

Calculations: To calculate this indicator, concentrations of PBTs need to be scaled-up from individual or composite sample values to annual median concentrations for each lake or lake subunit (e.g. for Lake Erie or Western Basin of Lake Erie). 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. For reference, please see Gerwurtz *et al.* (2011); the "Empirical models for assessing temporal trends" section describes several possible analytical approaches, including log-linear regression models.

Combination of components: Data from USA and CAN sources cannot be combined because of differences in methodology (e.g. analysis of individual fish in CAN versus composite fish samples in the USA). All analyses and summary statistics should be reported separately for EPA and EC datasets. However, differences in methodology do not appear to influence overall contaminant trends (Gewurtz *et al*. 2011). It is possible that overall trends be normalized and reported together, but the raw data should not be combined.

Spatial and temporal coverage: The most comprehensive data sets are for mature lake trout (Lakes Ontario, Huron, Michigan, Superior, and eastern Lake Erie) and walleye (western Lake Erie). Monitoring began in as early as the mid 1970's and continues today. Only EC collects data on forage fish. We were unable to determine the exact spatial or temporal extent of these data. For rainbow smelt the dataset is likely long-term and includes all lakes except Lake Michigan. For spottail shiner, the dataset will likely be less extensive and limited to Lakes Erie and Superior.

Measurement of progress: Reductions in concentrations of PBTs especially to levels that do not pose a risk to the heath of Great Lakes fish populations, to fish-eating wildlife populations, and to human consumers.

Data Evaluation:

Sufficiency and accessibility: Data are sufficient and accessible for lake trout and walleye, and more limited for forage fish species. Lake trout and walleye data are collected by three organizations, EPA GLNPO, Environment Canada, and OMNR. Methodological differences preclude combining data from the two countries. Data on forage fish are only collected by Canadian organizations and therefore do not include Lake Michigan. Long-term storage of fish tissue samples by both the USA and CAN allows for retrospective analysis of emerging chemicals of concern.

Additional needs: The authors of the draft PBTs in biota indicator, Jeff Ridal, Michael Murray, and Conrad deBarros originally recommended that an effects-based indicator be developed as part of the IJC Great Lakes indicator suite, either associated with the PBTs in biota indicator, the fish community assessment indicator, or as a standalone indicator. They suggest the effects-based indicator should be based on a well-accepted measure that can be tied to specific chemicals of concern (e.g. a biomarker or other manifestation of injury). This should still be considered, only the scope should be limited to fish.

Consideration by the program managers should also be given to including a warmwater fish species (e.g. largemouth bass) to greater represent the whole fish community. Criteria for selection could include significance as a food source, relevance of the species to the whole lake community, and ease of monitoring (e.g., via existing contaminant monitoring in state and provincial programs, assuming a similar protocol is adopted).

Required data processing and calculation effort: To scale-up from raw data to lake-wide or subbasin wide averages will require minimal processing and calculation effort. Trend analyses using first-order log-linear regression models of annual median concentrations to estimate percent annual declines require minimal/moderate effort. Development of an effects-based indicator will require considerable effort.

References:

Furdui, V.I., P.A. Helm, P.W. Crozier, C. Lucaciu, E.J. Reiner, C.H. Marvin, D.M. Whittle, S.A. Mabury and G. T. Tomy. 2008. Temporal Trends of Perfluoroalkyl Compounds with Isomer Analysis in Lake Trout from Lake Ontario (1979–2004). Environmental Science & Technology 42: 4739-4744.

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

Relevant SOLEC Indicators:

#4201 Contaminants in Sport Fish (2009)

Contaminants in Whole Fish, Draft 2012 SOLEC indicator for review, available at http://www.solecregistration.ca/documents/Contaminants%20in%20Whole%20Fish%20DRAFT%20Oct2011.pdf

Indicator data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	US EPA/GLNPO Great Lakes Fish Monitoring and Surveillance Program (GLFMSP) Open Lakes Trend Monitoring Program (OLTMP)	Elizabeth Murphy , Environmental Scientist, EPA Great Lakes National Program Office, 1-800-621-8431 ext 34227, murphy.elizabeth@epa.gov	No use restrictions Data produced by the GLFMSP can be obtained through the Great Lakes Environmental Database Query System (see below) or through the University of Illinois Extension website EPA CDX Portal: https://cdx.epa.gov/; Must have login to access File format: Excel file of individual composite samples	The Great Lakes Fish Monitoring and Surveillance Program (GLFMSP) collects fish from each Great Lake annually and analyzes them for contaminants that bioaccumulate to assess trends in the open waters of the lakes. The GLFMSP consists of two separate programs, the Open Lakes Trend Monitoring Program and the Emerging Chemical Surveillance Program. Note: The Sport Fish Fillet Monitoring Program was eliminated in 2008. Current OLTMP analyte list aldrin, oxychlordane, cis-nonachlor, p,p'-DDD, delta-BHC, p,p'-DDE, dieldrin, p,p'-DDT, endosulfan I, PBDE congeners, endosulfan II, PCB Congeners, endosulfan sulfate, polychlorinated dibenzodioxins, endrin, polychlorinated dibenzofurans, heptachlor epoxide, total toxaphene & homologs, hexachlorobenzene, trans-	10 stations: 2 in each of the five major lakes Fish samples are collected in the fall of each year.; Samples from 1977 to present (Note: Lake trout in Lake Erie limited to late 1980s and 1990s) No data for forage fish is included. Lake trout (*Salvelinus namaycush*) between 600 and 700 mm in length are collected and analyzed from Lakes Michigan, Ontario, Huron, Superior and the eastern basin of Erie; Walleye (*Stizostedion vitreum*) between 400 and 500 mm in length are collected from both basins in Lake Erie.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				chlordane, mercury, trans-nonachlor, mirex, α-BHC, o,p'-DDT, β-BHC, octachlorostyrene, and δ-BHC (Lindane)	
B	US EPA/GLNPO Great Lakes Fish Monitoring and Surveillance Program (GLFMSP) Emerging chemical surveillance program (ECSP)	Elizabeth Murphy , Environmental Scientist, EPA Great Lakes National Program Office, 1-800-621-8431 x34227, murphy.elizabeth@epa.gov	General overview and some analyses at http://www.epa.gov/glnpo/monitoring/fish/health.html Not currently available for download from CDX portal. Contact Elizabeth Murphy for more information and data.	In 2009, an ad-hoc binational group was formed to bring together government representatives and researchers working on identifying new chemicals in the Great Lakes ecosystem with the objective to facilitate best management practices and sharing of information and resources. Recent chemicals of interest include perfluorinated acids and synthetic musks.	Since fish tissue samples are stored, some retrospective analyses are possible. An example of one such analysis is Furdui *et al.* 2008.
C	US EPA/GLNPO Great Lakes Fish Monitoring and Surveillance Program (GLFMSP) Sport Fish Fillet Monitoring Program	Elizabeth Murphy , Environmental Scientist, EPA Great Lakes National Program Office, 1-800-621-8431 x34227, murphy.elizabeth@epa.gov	General overview and some data available at: http://www.epa.gov/glnpo/monitoring/fish/sport.html No use restrictions Data are available through the EPA CDX Portal: https://cdx.epa.gov/; Must have login to	This component of the Great Lakes Fish Monitoring and surveillance Program began in the early 1980s and was eliminated in 2008 to allow for the ECSP. Directed at monitoring potential human exposure to contaminants through consumption of popular sport fish species in the Great Lakes Basin.	The program provided for the collection of skin-on fillets from Coho (*Oncorhynchus kisutch*) or Chinook (*Oncorhynchus tshawytscha*) salmon in Lakes Michigan, Superior, Ontario, and Huron and for rainbow trout (*Salmo gairdneri*) in Lake Erie. Fish samples composited and analyzed for contaminants, including PCBs, toxaphene,

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			access File format: Excel file of individual composite samples of fillets		chlordanes, PBDEs and other organochlorine compounds.
D	Environment Canada: National Fish Contaminants Monitoring and Surveillance Program (FCMSP)	Daryl McGoldrick, Environmental Scientist, 905-336-4999, Daryl.McGoldrick@ec.gc.ca	All biological, physical and chemical data generated by the FCMSP are maintained in a database at the Canada Centre for Inland Waters in Burlington, Ontario. To request data please send inquiry to: NABSB@ec.gc.ca 19,000+ samples representing 53 fish species archived at the Great Lakes Fisheries Specimen Bank, now known as the National Aquatic Biological Specimen Bank	Lake trout (*Salvelinus namaycush*) are the ideal species for contaminant monitoring in the Great Lakes. In areas where lake trout do not occur other predatory species such as walleye (*Sander vitreus*) are targeted instead. Frequently sampled lower trophic level fish include forage or YOY spottail shiners, rainbow smelt, slimy sculpin, and alewives In the lab, large predatory fish (e.g., lake trout age 4+-6+) are homogenized whole. Smaller forage fishes (e.g., rainbow smelt) are combined by length, then homogenized whole to form composite samples. A maximum of 20 sub-samples are generated for each individual or composite sample, some of which are sent for chemical	12 stations: 3 in SU, 1 in HU, 1 in North channel, 1 in Georgian Bay, 4 in ON, and 2 in ER. Program began in 1975 and continues today Specific measures and chemical analyses performed by the FCMSP vary dependant on current priorities. The following are some of the parameters measured in recent years: Biophysical Parameters: Weight, length, sex, age, percent lipid Organochlorine Compounds: α-chlordane, γ-chlordane, dieldrin, p,p'-DDE, o,p'-DDT, p,p'-DDD, heptachlor epoxide, hexachlorobenzene, lindane, mirex, total polychlorinated biphenyls (PCBs)

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				analyses and the rest are stored in a specimen bank.	Trace Metals: Aluminum, antimony, arsenic, barium, beryllium, bismuth, caesium, chromium, cobalt, copper, gallium, iron, lanthanum, lead, lithium, manganese, mercury, molybdenum, nickel, rubidium, selenium, silver, strontium, thallium, tin, uranium, vanadium, zinc Chemicals of Emerging Concern: Polybrominated diphenyl ethers (PBDEs), other halogenated flame retardants, perfluorooctane sulfonate (PFOS) and its salt and precursors, perfluorooctanoic Acid (PFOA) and its salts and precursors, Long-Chain (C9-C20) Perfluorocarboxylic Acids (PFCAs), their Salts, and their Precursors
E	Sport Fish Contaminant Monitoring Program; Ontario Ministry of the Environment; Database=Ontario Fishbase	Satyendra Bhavsar, MOE Sport Fish Contaminant Monitoring Program, 416-327-5863, satyendra.bhavsar@ontario.ca	Database is called the Ontario Fishbase and is an Oracle database (see note below though). Dataset must be requested from Satyendra Bhavsar. The data is spread across a	Dataset includes THg, additional pollutants (including PCBs, Toxaphene, DDT, mirex/photomirex), and morphometrics for whole body and fillet samples from sport fish of edible size. (Dataset also contains some data from smaller fish, birds,	1977-2010 data is currently available, recent data is also available but provisional; Program is ongoing. Fish collected during summer and fall from sites within Province of Ontario and boundary waters of Great

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
			dozen linked tables in normal form, but the data can also be provided in Access. More information available at http://mercnet.briloon.org/projects/ON_MOE_-_Ontario_Sport_Fish_Contaminant_Database/140/	invertebrates and herptiles.) Most measurements are from individuals (fillet and whole fish). Quality assurance consists of remark codes in dataset.	Lakes; 3400 historical sites Fish species include lake trout and walleye Ancillary data included includes sex, weight, length, and additional pollutants

Biological Integrity of Fish-Eating and Colonial Nesting Birds

Summary:

This indicator measures biological integrity of fish-eating and colonial birds and links biological integrity to both chemical integrity and physical integrity (indicators of physical and chemical stress). Establishing cause-effect relationships between biological outcomes and chemical, biological, and physical stressors for each species allows for direct comparison of health across spatial and temporal scales. This indicator will be calculated for bald eagles and herring gulls.

Spatial coverage: The scale of analyses can be determined by the user and may include by colony or subpopulation, State/Province, major hydrologic units, by lake, or across the entire Great Lakes basin. Long-term, basin-wide data exist for both herring gulls and bald eagles.

Temporal coverage: Monitoring of herring gull contaminants began in 1977 and continues today. Bald eagle populations have been surveyed since 1961. Measures of biological and chemical integrity are usually measured on an annual basin while measures of physical integrity have decadal or multi-decadal intervals.

Data processing needs: Data are sufficient and accessible to calculate most of this indicator. Although the conceptual foundation of this indicator is well established, the indicator needs to be refined to detail how the indicator will be calculated for each species. Specific measures for each subcomponent should be chosen and models developed establishing cause-effect relationships based on expert opinion and available data.

Indicator Details:

This indicator measures: biological integrity using population measures or indices that are tied to the health of individuals, colonies, or populations of fish-eating and colonial birds at multiple geographic scales; and, links biological integrity to both chemical integrity and physical integrity, which are measurable stressors (causes) to biological integrity (effects). Because of wide-spread availability of data, this indicator can be calculated for bald eagles and herring gulls and possibly other bird species (three suggestions are included below).

Components:	**Component specifications:**	**Data source: (see data table)**
Herring Gulls:		
Biological Integrity	Reproductive output, rate of developmental deformities, distribution and number of nesting pairs, and physiological biomarkers	A
Chemical Integrity	Contaminant concentrations of eggs	A
Physical Integrity	Population trends	D

Components:	Component specifications:	Data source: (see data table)
Bald Eagles:		
Biological Integrity	Reproductive success, rates of developmental deformities, chronology of nest timing	B
Chemical Integrity	Contaminants in nestling blood plasma and feathers; some adult feathers and tissue samples	B
Physical Integrity	Habitat survey; population trends	B, C
Colonial Waterbird Census	Size and locations of colonies	D
Additional possible bird species:		
Tree Swallows	Not addressed	E
Black-Crowned Night Herons and Caspian Terns	Not addressed	F

Calculations: This indicator is calculated for both herring gulls and bald eagles, although available data necessitates the emphasis of different subcomponents in the effects model for each species. For example, measures of physical integrity for herring gulls are limited to location and colony size while assessment of habitat, population trends, and changes in the timing of nesting are available for bald eagles. For each species, the applicable subcomponents are calculated and causal pathways estimated in an effects model. The indicator needs to remain flexible to adapt to continued reductions in toxic chemical concentrations. As contaminant concentrations continue to be reduced to where gross ecological effects are no longer apparent, the indicator may need to be modified to increase reliance on physiological and genetic biomarkers (Weseloh and Moore 2011).

Bill Bowerman (personal communication) suggested that this effects model approach can be expanded for use on any number of species. One justification for such an expansion is that although a comprehensive historical dataset exists for herring gulls, herring gulls are highly tolerant of persistent contamination and may underestimate biological effects in other species. To facilitate discussion of expansion of the indicator to other species, we have provided additional information and contacts for monitoring programs on tree swallows, terns, and night herons.

Combination of components: Assessment for each species should occur separately. Assessment of progress within individual components (e.g. biological, physical, or chemical integrity observed as reductions in contaminants, developmental deformities, population increases, etc.) can also be measured for each species. The ability to combine the components in an effects-based model offers advantages over assessment of individual components. Establishing cause-effect relationships between biological outcomes and chemical, biological, and physical stressors for each species allows for direct comparison of health across spatial and temporal scales.

Spatial and temporal coverage: The scale of these analyses can vary and will be determined by the user. Possible spatial units for analyses are at the colony or subpopulation, State/Province, by major hydrologic units, by Lake, or across the entire Great Lakes basin. Long-term, basin-wide data sets for both herring gulls and bald eagles provide good temporal and spatial coverage. However the interval between sampling varies with component and species. Blood, feathers, eggs and tissues for bald eagles are collected annually (Bowerman *et al.* 1995; Stromberg *et al.* 2007; Best and Wilke 2009; Route *et al.* 2011). Annual sampling of bald eagle productivity should continue in current areas. Sampling of herring gull eggs occurs annually and should continue. Colonial waterbird surveys have been completed at approximately decadal intervals and should continue every 10 years. Great Lakes habitat should be assessed every 10 years although it has not been assessed for bald eagles since 1992.

Measurement of progress: Progress should be measured by improvements in the biological, chemical, and/or physical integrity of fish-eating and colonial nesting birds in the Great Lakes. These may be observed in multiple ways, e.g. reductions in contaminants in eggs or blood, reductions in rates of developmental deformities, decreases in stress physiological biomarkers, improved habitat, or increases in reproductive success.

Data Evaluation:

Sufficiency and accessibility: Data are sufficient and accessible to calculate most subcomponents of this indicator. Long-term and multi-facetted monitoring programs provide measures of biological, chemical, and physical integrity of herring gulls and bald eagles. For some subcomponents, there are multiple measures for certain subcomponents. For example, biological integrity of herring gulls has been documented using various physiological biomarkers (e.g. measures of Vitamin A levels, immune and thyroid function, growth hormone levels, stress steroids, liver enzyme induction, and genetic/chromosomal abnormalities). The measurement of physical integrity for herring gulls is limited to colony location and size.

The sufficiency and accessibility of models linking subcomponents using cause-effect relationships is unclear. Although the importance of linking contaminant levels to biological effects has been a priority of the IJC since the late 1990s (see http://www.ijc.org/php/publications/html/ehwptstrends.html) we were unable to determine exactly how these models are constructed and whether they have been established for the Great Lakes.

Additional needs: Although the conceptual foundation of this indicator is well established, it needs to be refined to detail how the indicator will be calculated for each species. Specific measures for each subcomponent should be chosen based on expert opinion and available data. A time interval between assessments also needs to be established. The time interval must acknowledge differences in data interval collection (e.g. annually for many variables, decadal and multi-decadal for others).

Required data processing and calculation effort: A full assessment of the data processing and calculation effort is not possible until the indicator is more thoroughly detailed. However, through cooperation of multiple agencies and individuals, datasets on the biological, chemical, and physical integrity of herring gulls and bald eagles have been compiled and are well-organized. The Canadian Wildlife Service also has a remarkable program to analyze and store biological samples (McGoldrick *et* *al.* 2010). These efforts should facilitate extraction of desired data and calculation of the indicator components and sub components once the indicator is refined.

References:

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Stromberg, K., D. Best, P. Martin, and W. Bowerman. 2007. Contaminants affecting productivity of bald eagles, Indicator 8135, SOLEC 2007, accessed at www.epa.gov/solec/sogl2007/8135_bald_eagles_contaminants.pdf

Relevant SOLEC Indicators:

#8135 Contaminants Affecting Productivity of Bald Eagles (included in 2009 but last update in 2005)

Contaminants in Waterbirds: Draft 2012 SOLEC indicator for review, available at http://www.solecregistration.ca/documents/Contaminants%20in%20Waterbirds%20DRAFT%20Oct2011.pdf

Indicator data:

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
A	Biological and chemical integrity of Herring Gulls (relies heavily on the Great Lakes Herring Gull Monitoring program and the National Wildlife Specimen Bank and MI DEQ)	Bill Bowerman, Professor and Chair Department of Environmental Science & Technology, University of Maryland, 301-405-1306, wbowerma@umd.edu Pamela (Pam) Martin, Canadian Wildlife Service(CWS), Environment Canada, 905-336-4879, pamela.martin@ec.gc.ca Dennis Bush, MI DEQ, 517-335-3308, bushd6@michigan.gov	Bill Bowerman expressed that all of this data is sharable and available for use. Please contact all three contacts as each has knowledge of the overall program but each has responsibility over some portion of the program. An overview of EC's National Wildlife Specimen Bank: http://www.ec.gc.ca/faunescience-wildlifescience/default.asp?lang=En&n=5D89D9FF-1&xsl=privateArticles2,viewfull&po=386BE2F4	Chemical Integrity, Canada: Herring gull eggs have been collected annually on all 5 lakes and connecting channels since 1973; 15 colonies + 8 alternates = 23 sites; Contaminant measures include, but are not limited to, organochlorine pesticides, PBTS, PCDFs, PCDDs, metals, dioxins and furans. Samples are housed at the National Wildlife Specimen Bank and can be used to retrospectively test for emerging contaminants. Chemical Integrity, MI: In 2001 MI DEQ water bureau added 10 colonies to the program to complement the EC program. This program follows the same procedures as EC and are eggs are processed by CWS.	Biological Integrity: The Canadian Wildlife Service also collects biomarkers as part of SWAT analysis; Pam Martin is the contact for these data

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
B	Biological, chemical and physical integrity of Bald Eagles (relies heavily on MI DNR and Canadian Wildlife Service)	Bill Bowerman, Professor and Chair Department of Environmental Science & Technology, University of Maryland, 301-405-1306, wbowerma@umd.edu Pamela (Pam) Martin, Environment Canada, 905-336-4879, pamela.martin@ec.gc.ca Dennis Bush, MI DEQ, 517-335-3308, bushd6@michigan.gov	Bill Bowerman expressed that all of this data is sharable and available for use. Please contact all three contacts as each has knowledge of the overall program but each has responsibility over some portion of the program Data are compiled by Clemson University in Excel spreadsheets; MI DEQ also provides summary reports at http://www.michigan.gov/deq/0,4561,7-135-3313_3686_3728-32394--,00.html	Long-term monitoring on the biological, chemical, and physical integrity has been occurring throughout the Great Lakes. More recent data are available online but Bowerman has access to all the data. Sampling efforts on bald eagles in 2011 are summarized at http://www.glc.org/lmmcc/pdf/Dingledine-FWS.pdf Chemical Integrity: Contaminants (same toxins as for Herring Gulls except does not include dioxins and furans) measured annually in nestling blood plasma and feathers, tissues, and a smaller number of adult feathers. Since 1999 data are summarized in annual reports by Clemson University personnel and posted on the MI DEQ website.	Physical and Biological Integrity: Bald eagle population surveys have been conducted along most Great Lakes shorelines and interior areas since 1961. These surveys continue along the US shorelines of all 5 lakes, and along Lakes Erie and Ontario in Canada, and statewide in Michigan and New York. These surveys include measures of reproductive success, rates of developmental deformities, and nest timing (changes in which have been linked to climate warming).
C	Physical integrity of Bald Eagles: Habitat Surveys	Bill Bowerman, Professor and Chair Department of Environmental	Maps of classified habitat for 1992 available from Bill Bowerman	Study area included habitat within 1.6 km of the United States and Canadian shorelines of the five Great	Habitat was classified as either good, marginal, or unsuitable, based on six habitat attributes: Study

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
		Science & Technology, University of Maryland, 301-405-1306, wbowerma@umd.edu	Reports on 1992 survey and statistical analyses available at http://www.fs.fed.us/rm/pubs/rmrs_rp056.pdf and http://www.fs.fed.us/rm/pubs/rmrs_rp045.pdf Bill is planning to repeat this habitat assessment soon, probably using Google Earth aerial photography.	Lakes, including all islands and connecting channels, bounded on the west by the Harbor of Duluth/Superior at the western end of Lake Superior and on the east by the International Bridge spanning the St. Lawrence River at Ivy Lea, Ontario, Canada. Used fixed-wing aircraft in 1992 to survey the entire shoreline for potential bald eagle nesting habitat within 1.6 km of the United States and Canadian shorelines of the five Great Lakes.	considered six habitat attributes: Tree cover, proximity to and type of human disturbance, foraging habitat and/or shoreline irregularity, potential perch trees, and potential nest trees Also used Bayesian statistical model to determine habitat quality. Tree cover greater than 10 percent, human disturbance more than 0.8 km away, a ratio of total to linear shoreline distance greater than 2.0, and suitable perch and nest trees were prerequisite for good eagle habitat. The estimated prob-ability of good habitat was high (96 percent) when all attributes were optimal, and nonexistent (0 percent) when none of the model attributes were present. Of the 117 active bald eagle nests along the Great Lakes shorelines in 1992, 82 percent were in habitat classified as good.
D	Binational Colonial waterbird census (joint effort of	Francie Cuthbert, Professor & Department Head,	Contact Francie Cuthbert for more information	The census is conducted along the U.S. shoreline of the Great Lakes (lakes	Began in the 1970s and occurs approximately every 10 years (four done to date,

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
	Canadian Wildlife Service and US Fish and Wildlife Service	Department of Fisheries, Wildlife and Conservation Biology, University of Minnesota, 612-624-1756, cuthb001@umn.edu	Data summarized in an annual report (not yet available).	Superior, Michigan, Huron, Erie, and Ontario) and connecting rivers (St. Marys, St. Clair, Detroit, and Niagara). More than 100 cooperators assisted in data collection. The purpose of the census is to get an accurate count of the number of nests for each species of waterbird that nests in the Great Lakes and their connecting channels.	1970s, 1980s, 1990s, and 2000s). Able to assess changes at a number of scales, from the basin, to lakes, to particular sites. Census species include: American white pelican, Double-crested cormorant, Great blue heron, Black-crowned night heron, Great egret, Cattle egret, Snowy egret, Common tern, Forster's tern Caspian tern, Herring gull, Ring-billed gull and Black-backed gull.
E	Thomas and Christine Custer: Data on Tree Swallows Great Lakes Restoration Initiative (GLRI) Project 80	Thomas Custer, USGS Wildlife Biologist, 608-781-6375, tcuster@usgs.gov Christine M. Custer, USGS Wildlife Biologist (Research), 608-781-6247, ccuster@usgs.gov	Not assessed Details at http://www.umesc.usgs.gov/wildlife_toxicology/glri_project80.html and http://cida.usgs.gov/glri/projects/toxic_substances/birds_as_indicators.html	Goals of project: Use tree swallows and colonial waterbirds in the Great Lakes to evaluate contaminant exposure (geographic and spatial), trends through time(temporal), effects (reproductive, physiological, genetic), and monitor cleanup actions Greater than 85% of swallow's diet are benthic aquatic insects and they feed within ~ 1 km of their nest	Anticipated five year project depending on funding. Monitoring began in 2010 and each year more sites are added. Sites are along the US shoreline of the Great Lakes and across different habitats (natural, urban, industrial). Measures include location of nest boxes, reproductive success, inorganic elements, organic contaminants (new and emerging), biomarkers, and ecological endpoints.

Ref.	Data Source	Contact	Accessibility	Processing information	Additional information
				box so contamination in their tissues are closely tied to sediment contamination and the cleanup of those sediments.	
F	Keith Grasman: Data on Herring Gulls, Black-Crowned Night Herons and Caspian Terns	Keith Grasman, Professor, Calvin College, 616-526-6024, kag4@calvin.edu	Not assessed	For 20 years, Grasman has studied the effects of pollution on Great Lakes colonial waterbirds, focusing on three species: Herring Gulls, Black-Crowned Night Herons and Caspian Terns. By testing these birds, he provides the data needed to guide cleanup efforts and inform government agencies, like the U.S. Fish and Wildlife Service which sponsors his work, of the magnitude of the problem.	Studies have included immunological responses of prefledgling chicks to organochlorine contamination (primarily polychlorinated biphenyls),

Note: Chip Weseloh has recently retired from the Canadian Wildlife Service, Environment Canada