# Appendix 1

This section contains the descriptions for all indicators in the Great Lakes Suite. They are listed in numerical order.

# Indicator Descriptions

# Fish Habitat (Indicator ID: 6)

***NOTE: This indicator has not received expert review, and has not undergone the SOLEC screening for necessary, sufficient and feasible. It is merely a place holder.***

***Measure***
1) Quality, quantity (area), and distribution of aquatic habitat (e.g., shore, spawning shoals, tributaries, wetlands, etc.); 2) percent disturbed habitat and3) population of sentinel fish species. For example, the measures for tributary quality could include the number of dams, number of miles of river channel that is impounded, number of miles of (formerly) high-gradient stream channel that is impounded, and the number of miles between the river mouth and the first dam. The number and location of fish passage facilities (up- and downstream) that could be used successfully by species or communities of concern (for example, lake sturgeon, or other anadromous fishes listed in FCGO) could also serve as measures.

***Purpose***
This indicator will assess the quality, quantity and location of aquatic habitat in the Great Lakes ecosystem, including the percent of habitat that has been disturbed or destroyed, and will be used to infer progress in rehabilitating degraded habitat and associated aquatic communities.

***Ecosystem Objective***
This indicator addresses the general Fish Community Goals and Objectives (FCGO) to protect and enhance fish habitat, achieve no net loss of the productive capacity of habitat supporting fish communities, and restore damaged habitats. Annex 2 of the GLWQA calls for the restoration of lost or damaged habitat. The indicator also supports the policy position of the Great Lakes Fishery Commission (GLFC), Habitat Advisory Board, presented in their 1998 Draft Binational Policy and Action Plan for the Protection and Enhancement of Aquatic Habitat in the Great Lakes.

***Endpoint***
The endpoints will need to be specific to habitat types and FCGO. In the Great Lakes and connecting channels, for example, the U.S. Environmental Protection Agency and Ontario Ministry of Environment numerical guidelines for dumping of contaminated dredged sediments can be used to protect aquatic habitat quality.

***Features***
This indicator will measure/calculate changes in aquatic habitat by area, by type, by location, by Lake. Significant losses and degradation of aquatic habitat have occurred in the Great Lakes aquatic ecosystem since the late 1800s when European settlement of the region was completed. Logging, navigation projects, dam construction, shoreline development, agriculture, urbanization, municipal and industrial waste disposal, and water withdrawal by power generation facilities for once-through cooling have all acted to reduce the amount and quality of aquatic habitat in the system. These affected habitats include the Great Lakes proper, their connecting channels and coastal wetlands, and the tributaries that provide linkages with inland aquatic habitats and terrestrial habitats via the surface water continuum.

Wetland losses in the region have been reasonably well documented and quantified, but losses of the other major habitat types have not. Recent efforts to relicense hydropower dams in the United States have led to a reconsideration of the habitat losses associated with these dams and a useful picture is emerging which allows an assessment of the adverse impacts of habitat fragmentation on anadromous and resident stream-fish communities. Data for tributary habitat are being developed in connection with FERC dam relicensing procedures in the United States. Data are presently available for Michigan, New York State, and Wisconsin.

Large volumes of water are withdrawn from the Great Lakes and their connecting channels for use by industry and municipalities. Steam-electric power plants using once-through cooling, and pumped-storage hydropower plants withdraw the greatest volumes of water. Fish of all sizes are entrained with this water and substantial mortality occurs basin-wide among the entrained population. Rates of water withdrawal and associated fish mortality rates are known for existing steam-electric power plants using once-through cooling and for pumped-storage hydropower plants. Reduction in water withdrawal rates or the addition of effective screening devices at existing facilities would reflect an improvement in fish habitat, and hence a reduction in fish entrainment mortality.

***Illustration***
Certain anadromous fish species e g Atlantic salmon and walleye depend on unimpeded access to spawning habitats in streams. In many cases dams and other obstructions
[e g roads and culverts] prevent mature fish from reaching spawning habitat and thus compromise stock and species diversity, losses in annual recruitment and reduced production and harvests. In either case not even fish passing facilities will mitigate these effects because walleye cannot jump and even large female salmon are unable to use fishways. As well, many other stream-dwelling species of fish [e g suckers and minnows] suffer discontinuity in their ranges because of barriers

***Limitations***
Restoration ecology is an emerging scientific discipline requiring an understanding of multiple disciplines and partnerships. Comprehensive, detailed habitat inventory, classification, and mapping of Great Lakes aquatic habitats has not been undertaken. Much more research will be required to recognize critical fish habitat and to understand the relationship between quantity of habitat

and aquatic production. Interpretation of habitat measurements is confounded by issues such as interacting species and connectivity of habitat between life stages.

***Interpretation***
Dam removal, switching from peak-power generating flow mode to run-of-the-river flow mode, and provision of fully functional upstream and downstream fish passage facilities consistent with state management strategies or FCGO would be considered to be rehabilitation of habitat and beneficial to the riverine and anadromous fish communities using dammed tributaries.

***Comments***
Further development and ratification of the Great Lakes Fishery Commission, Habitat Advisory Board ***(what's the update on this?),*** 1998 Draft Binational Policy and Action Plan for the Protection and Enhancement of Aquatic Habitat in the Great Lakes should contribute significantly to furthering the goals of aquatic habitat protection and restoration in the Great Lakes basin. Indicators 4510 & 4511 contribute to this indicator, as does indicator 72. Sentinel species should be the same for each of these indicators.

***Unfinished Business***
- Need to develop a list of sentinel fish species.
- Quantifiable endpoints and/or reference values need further development work.
- The method of graphically displaying this indicator needs to be determined. Will bar graphs or maps be used to depict trends over time? What will appear on the graphs or maps?
- There needs to be more information added to help better understand the trends presented by this indicator.

***Relevancies***
Indicator Type: state
Environmental Compartment(s): water, fish
Related Issue(s): habitat
SOLEC Grouping(s): open waters, nearshore waters, coastal wetlands
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s): Ontario, Erie, Huron, Michigan, Superior
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
July, 2002

# Salmon and Trout (Indicator ID: 8)

***Measure***
1) Productivity, yield, or harvest of Pacific salmon, rainbow trout and brown trout individual stocks (need to explain this for non-fish people) using abundance (e.g., catch of each species in a given unit of sampling effort), or biomass metrics; and 2) populations of these stocked and naturally produced fish.

***Purpose***
This indicator will show trends in populations of introduced trout and salmon populations, as well as species diversity, and it will be used to evaluate the potential impacts on native trout and salmon populations and the preyfish populations that support them.

***Ecosystem Objective***
"To secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for: wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic ecosystem. In addition, this indicator supports Annex 2 of the GLWQA.

***Endpoint***
The current Fish Community Goals and Objectives (FCGO) for introduced trout and salmon species establish harvest or yield targets consistent with FCGO for lake trout restoration, and in Lake Ontario, for Atlantic salmon restoration. The following index targets for introduced trout and salmon species were provided in the FCGO for the listed lake.

Lake Ontario (1999): *Salmon and trout catch rates in recreational fisheries continuing at early-1990s levels.*

Lake Erie (1999 draft – ***is this still draft?***): *Manage the eastern basin to provide sustainable harvests of valued fish species, including . . . lake trout, rainbow trout and other salmonids.*

Lake Huron (1995): *A diverse salmonine community that can sustain an annual harvest of 2.4 million kg (5.3 million lb) with lake trout the dominant species and anadromous (stream-spawning) species also having a prominent place.*

Lake Michigan **(*year?*)**: *A diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout.*

Lake Superior (1990): *Achieve . . . an unspecified yield of other salmonid predators, while maintaining a predator/prey balance which allows normal growth of lake trout.*

Salmonine abundance should be great enough to keep alewife abundance below levels associated with the suppression of native fishes, but should also be below levels where predatory demand threatens the forage base and the integrity of the system.

***Features***
This indicator will assess trends of Pacific salmon and rainbow and brown trout populations over time. These species were introduced into the Great Lakes ecosystem, are reproducing successfully in portions of the system, and can be considered to be permanent, "naturalized" components of the system. Stocking of these species continues to augment natural reproduction and enhance fishing opportunities, which is generally viewed favourably by the angling public. However, diversification of the salmonine component of the fish community is a significant departure from the historic dominance by lake trout; the impacts of diversification on native species and ecosystem function is not yet fully understood.

***Illustration***
Rainbow trout stocks in the Lake Ontario Basin have declined in the last decade, with fewer fish in harvests and in spawning runs. Some stocks are from natural reproduction and others from regular fish plantings. Declines may be related to habitat changes, lower stream and lake productivity, losses/reductions of specific gene pools, over harvest, climate warming, drought, and/or groundwater withdrawals.

***Limitations***
The data for this indicator are collected annually by the states for certain segments of the fishery (e.g., Michigan's segment of the Lake Michigan charter boat fishery) and are available for reporting, but there is no coordinated, basin-wide data collection program. Reporting occurs as news releases and as reports to the Lake Committees of the Great Lakes Fishery Commission. More analysis of existing data and evaluation of management alternatives through mathematical modelling is needed before more detailed species-by-species harvest can be defined.

***Interpretation***
To be developed

***Comments***

Pacific salmon and rainbow and brown trout are introduced species. Some of these are now naturalized but stocking still occurs. Atlantic salmon, which were native to Lake Ontario, have been introduced at times to the other four Great Lakes. Atlantic salmon introductions to the upper four Great Lakes should be treated as potentially beneficial range extensions of the species within the basin. This valuable species is in decline in most of its historical Western Atlantic range, and the establishment of naturalized populations in the Great Lakes would help ensure the survival of the Western Atlantic gene pool. The salmonine community will consist of both wild and planted salmonines and exhibit increasing growth of, and reliance on, natural reproduction. Short-term restrictions of harvest may be required to achieve long-term goals of natural reproduction.

The measure of abundance of individual stocks will give a clue as to diversity within a species.

***Unfinished Business***
To be developed

***Relevancies***
To be developed

***Sources***
GLFC SGLFMP; FCGO;
[1] Great Lakes Fishery Commission. 1997. A Joint Strategic Plan for Management of Great Lakes Fisheries, Ann Arbor, Mi.

# Walleye (Indicator ID: 9)

***Measure***
Relative abundance, biomass, or annual production of walleye populations in historical, warm-cool water, mesotrophic habitats of the Great Lakes.

***Purpose***
This indicator will show the status and trends in walleye populations in various Great Lakes' habitats, and it will be used in conjunction with the Hexagenia indicator, to infer the basic structure of warm-cool water predator and prey communities, the health of percid populations, and the health of the Great Lakes ecosystem.

***Ecosystem Objective***
Historical mesotrophic habitats should be maintained as balanced, stable, and productive elements of the Great Lakes ecosystem with walleye as the top aquatic predator of the warm-cool water community [and Hexagenia as a key benthic invertebrate organism in the food chain]. (Paraphrased from *Final Report of the Ecosystem Objectives Subcommittee*, 1990, to the IJC Great Lakes Science Advisory Board.) In addition, this indicator supports Annex 2 of the GLWQA.

***Endpoint***
Appropriate quantitative measures of relative abundance, yield, or biomass should be established as reference values for self-sustaining populations of walleye in mesotrophic habitats in each lake. The indicator for walleye can be based on the following index target abundances provided in the Fish Community Goals and Objectives:

Lake Huron (1995): *Reestablish and/or maintain walleye . . . with populations capable of sustaining a harvest of 0.7 million kg*

Lake Michigan (1995): *Expected annual yield: 0.1-0.2 million kg*

Lake Erie (1999): *Manage the western, central and eastern basin ecosystems to provide sustainable harvests of valued fish species, including walleye*

No reference values available for Lakes Superior and Ontario.

The walleye is a highly valued species that is usually heavily exploited by recreational and (where permitted) commercial fisheries, and harvest or yield reference values established for self-sustaining populations probably represent an attempt to fully utilize annual production; as a result, harvest or yield reference values for these populations can be taken as surrogates for production reference values.

***Features***
The historical dominance of walleye in mesotrophic habitats in the Great Lakes provides a good basis for a basin wide evaluation of ecosystem health. Maintaining or reestablishing historical levels of relative abundance, biomass, or production of self-sustaining populations of walleye throughout their native range in the basin will help ensure dominance of this species in the ecosystem and the maintenance of a desirable and balanced aquatic community in warm-cool water mesotrophic habitats. Historical data can be used to develop status and trend information on walleye populations. Commercial catch records for walleye in the Great Lakes extend back to the late 1800s; recreational catch data and assessment fishing data supplement these commercial catch records in some areas in recent years and are especially useful in areas where the commercial fishery for the species has been closed.
*Illustration*
To be developed
*Limitations*
Walleye abundance can be reduced by overfishing; harvest restrictions designed to promote sustained use are required if the species is to be used as an indicator of ecosystem health.

The walleye indicator cannot reliably diagnose causes of degraded ecosystem health.

Target reference values for the indicator have not been developed for Lakes Ontario and Superior.

***Interpretation***
The desired trend is increasing dominance to historical levels of the indicator species in mesotrophic habitats throughout the basin. If the target values are met, the system can be assumed to be healthy; if the values are not met there is health impairment.

***Comments***
To be developed

***Unfinished Business***
The method of graphically displaying this indicator needs to be determined. For example, will bar graphs or maps be used to depict trends in walleye populations over time?

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota, fish
Related Issue(s): contaminants & pathogens, nutrients, exotics, habitat
SOLEC Grouping(s): open waters, nearshore waters
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s): Ontario, Erie, Huron
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 6: Degradation of benthos

***Last Revised***
July, 2002

# Preyfish Populations and Communities (Indicator ID: 17)

***Measure***
Abundance and diversity, as well as age and size distribution, of preyfish species stocks (i.e., deepwater ciscoes, sculpins, lake herring, rainbow smelt, and alewives) in each lake.

***Purpose***
This indicator will assess the abundance and diversity of preyfish populations, and it will be used to infer the stability of predator species necessary to maintain the biological integrity of each lake.

***Ecosystem Objective***
To maintain a diverse array of preyfish populations to support healthy, productive populations of predator fishes as stated in the Fish Community Goals and Objectives (FCGOs) for each lake. For Lake Michigan, the Planktivore Objective (GLFC, 1995) states: *Maintain a diversity of prey (planktivore) species at population levels matched to primary production and to predator demands*. This indicator also relates to the 1997 Strategic Great Lakes Fisheries Management Plan Common Goal Statement for Great Lakes Fisheries Agencies and to Annex 2 of the GLWQA.

***Endpoint***
This indicator will refer to index target abundances for preyfish — the values used to regulate the amount of predator fish stocked in each lake — provided in the FCGO for each lake as quantitative reference values that represent the necessary diversity and structure of the preyfish community. Lakes Huron, Michigan and Superior provide general guidelines for prey species prioritizing species diversity and a return to historical population levels. Lake Michigan FCGO proposed a lakewide preyfish biomass of 0.5 to 0.8 billion kg (1.2 to 1.7 million lbs.). Lake Ontario FCGO proposed an average annual biomass of 110 kilogram/hectare for the production of top predators.

***Features***
An inadequate preyfish base might signal the need for reduction in predator species abundance by increasing harvest or reducing number of predator fish stocked. If preyfish populations also support a major recreational or commercial fishery, or are reduced significantly by entrainment mortality at water withdrawal sites in the Great Lakes, curtailment of these losses would be appropriate. Maintaining species diversity in the preyfish base may also require more detailed consideration and management of the predator species mix in the lake. Preyfish populations in each of the lakes is currently monitored on an annual basis. Changes in species composition, as well as changes in size and age composition of the major preyfish species, are available for Review from long-term databases. Changes in prey fish biomasses and age distributions could also be early warnings of changes in quality and quantity of essential habitat.

***Illustration***
Lake-wide annual trends are displayed for each lake in bar chart format. A GIS-based reporting system is under development that will show annual trends at multiple sampling locations within each lake.

***Limitations***
Index target abundances, the quantitative reference values for this indicator, have not been established for all preyfish species in each lake.

***Is it possible to have an endpoint for stock diversity?***

***Interpretation***
To be developed

***Comments***
Diversity in preyfish species imparts some overall stability to the forage base by minimizing the effects of year-to-year variations typically experienced by a single species; therefore, managing the preyfish resource for the exclusive benefit of a single preyfish species, such as alewife, is not recommended. A substantial component of native preyfish species should be maintained, especially if new research implicates thiaminase in introduced preyfish species, such as alewives and rainbow smelt, as a major factor contributing to reproductive failure in lake trout and Atlantic salmon in the Great Lakes. There is interest expressed in some FCGOs in protecting or reestablishing rare or extirpated deepwater cisco preyfish species in their historic habitats in the Great Lakes. This should be reflected in future reference values for affected lakes.

***Unfinished Business***
A discussion on how this indicator will be interpreted using the endpoint(s) is needed. For example, this indicator may need to be analyzed in conjunction with an indicator on primary production and/or predator species abundance and diversity.
- Develop an endpoint for stock diversity (if possible).

***Relevancies***

Indicator Type: state
Environmental Compartment(s): fish
Related Issue(s): contaminants & pathogens, nutrients, non-native species, habitat
SOLEC Grouping(s): open waters, nearshore waters
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring IJC Desired Outcome(s): 6: Biological community integrity and diversity GLFC Objective(s): Ontario, Erie, Huron, Michigan, Superior Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations.

***Last Revised***
April 7, 2004

# Sea Lamprey (Indicator ID: 18)

***Measure***
Number of spawning run adult sea lampreys; wounding rates on large salmonids.

***Purpose***
This indicator will estimate sea lamprey abundance and assess their impact on other fish populations in the Great Lakes.

***Ecosystem Objective***
This indicator relates to the 1997 Strategic Great Lakes Fisheries Management Plan Common Goal Statement for Great Lakes Fisheries Agencies: *To secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for: wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic ecosystem.*

The 1955 Convention of Great Lakes Fisheries created the Great Lakes Fishery Commission "to formulate and implement a comprehensive program for the purpose of eradicating or minimizing the sea lamprey populations in the Convention area."

In addition, this indicator supports Annex 2 of the GLWQA.

***Endpoint***
This indicator will refer to the index target abundances for sea lamprey populations provided in the most current Fish Community Goals and Objectives (FCGO) for each lake. The following objectives are listed in the FCGO with the date of issue for each lake.
Lake Huron (1995): *75 % reduction by 2000; 90 % reduction by 2010.*
Lake Ontario (1999): *Suppression of sea lamprey populations to early-1990s levels, and maintaining sea lamprey marking rates <0.02 marks per fish for lake trout.*
Lake Michigan (1995): *Suppress the sea lamprey to allow the achievement of other fish-community objectives.*
Lake Erie (1999 draft): *Unspecified Objective.*
Lake Superior (1990): *50 % reduction in parasitic-phase sea lamprey abundance by 2000; 90 % reduction in parasitic-phase sea lamprey abundance by 2010.*

***Features***
Control of sea lamprey populations is necessary to achieve other fish-community objectives because of the high mortality rates inflicted by lampreys on other fish. Spawning-run data are collected annually in selected streams; wounding data are collected annually in each lake. Long-term status and trend data are available.

***Illustration***
Annual status and trend data on sea lamprey abundance and wounding rates are displayed in bar charts and tables by geographic area of interest.

***Limitations***
Spawning-run estimates of parasitic populations must be based on a representative sampling of streams and must include large rivers. Reliable trapping and run estimates are often difficult or impossible to make for large rivers. Direct mark and recapture data for parasitic or larval phase sea lampreys is needed to provide better estimates and error terms, but these reliable, direct estimates may only be obtained in areas of high population abundance where large numbers of individuals can be marked and recaptured. Explicit estimates of variance is critical. Relating estimates of the spawning population to the resulting parasitic population assumes insignificant or at least constant mortality between the parasitic and spawning phases.

Wounding rates may be influenced by the abundance of prey in the suitable size range and may vary among major prey species depending on the mix of these fishes in an area. The season of data collection (e.g., spring or fall) affects the interpretation of the measure and must be kept constant. Classification of sea lamprey wounds (i.e., wounds or scars, Type A or Type B) is subjective and may vary among individuals and agencies making the observation. The GLFC and cooperating biologists attempt to standardize evaluations as much as possible through workshops and other opportunities to share information.

***Interpretation***
Increasing trap catches of spawning-run sea lampreys, numbers of streams with larval populations, and overall abundance of larvae in streams may indicate an expanding sea lamprey population. Increasing wounding rates in the presence of stable prey populations indicates an increase in sea lamprey abundance and in the amount of damage to prey populations. Data regarding total mortality in trout and salmon is also needed to properly interpret this indicator, since increasing total mortality in trout and salmon populations reduces the number of older fishes and the reproductive potential of these populations.

***Comments***

Efforts are underway to improve the precision and accuracy of the measures of sea lamprey abundance and of the damage they inflict on trout and salmon populations in the Great Lakes. Improved measures will allow more precise interpretation of status and trend data and will help determine appropriate control measure responses.

***Unfinished Business***

- Need a more quantifiable endpoint for Lake Michigan.
- Can an endpoint for wounding rates be developed?

***Relevancies***

Indicator Type: pressure
Environmental Compartment(s): fish
Related Issue(s): exotics
SOLEC Grouping(s): **open waters**, **nearshore waters**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s): Ontario, Erie, Huron, Michigan, Superior
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations

***Last Revised***

March 7, 2000

# Native Freshwater Mussels (Indicator ID: 68)

***Measure***
Distribution and abundance, reported as number of individuals per unit of sampling effort; soft tissue weight; and reproductive output of the Native Unionid mussel.

***Purpose***
This indicator will assess the population status of native Unionid populations, and it will be used to infer the impact of the invading Dreissenid mussel on the Unionid mussel.

***Ecosystem Objective***
The diversity of native invertebrate fauna should be maintained in order to stabilize ecosystem habitats throughout the Great Lakes and their tributaries and connecting channels. In addition, this indicator supports Annex 2 of the GLWQA.

***Endpoint***
Reestablish diverse, self-sustaining populations of native mussels in all historical habitats in the Great Lakes where they have been extirpated by the zebra mussel. Population characteristics should be equivalent to those in reference populations in these or similar habitats prior to the establishment of zebra mussels or where zebra mussels do not occur.

***Features***
Native Unionids are the largest and longest-lived invertebrates in the Great Lakes basin and are key players in the movement of organic and inorganic particulate matter between the sediment layer and overlying water column. Native Unionid populations are generally highly vulnerable to extinction by invading Dreissenids. Unionid mortality results both from attachment of Dreissenids to Unionid shells (biofouling) and from food competition with Dreissenids. Mortality can occur within two years of the initial Dreissenid invasion and extinction rate generally varies directly with Dreissenid population density. The type of habitat occupied by the Unionids also strongly influences their risk of extinction. For example, Unionids may be able to escape extinction in soft-bottomed habitats where they can burrow deeply and suffocate Dreissenids that attach to their shells. Unionids may also survive better in free-flowing streams than in streams with dams. In streams with dams, Dreissenids are most abundant in impoundments and tailrace areas. In free-flowing stream reaches and in streams without dams, Dreissenid populations rarely reach densities high enough to adversely affect Unionid populations.

***Illustration***
This indicator will be presented as a map showing population locations and population metrics throughout the Great Lakes basin.

***Limitations***
There is very little historical data on the distribution and abundance of Unionids in the Great Lakes basin and the available information (mainly from inland surveys conducted in the 1930s-1950s) is not quantitative. The highly clumped distributions typical of most Unionid populations makes sampling and population estimates problematic, and the difficulty in locating young animals impedes assessment of reproductive output.

***Interpretation***
Distribution and abundance of each Unionid species, reported as number of individuals per unit of sampling effort, provide a simple and direct measure of population status. Because Unionids tend to have clustered distributions, stratified, quadrat-timed searches or extinction search patterns performed by SCUBA divers offer the most promise for developing good population estimates. Soft tissue weight of individuals can be used as a measure of individual and population health. Tissue dry weight varies with season and reproductive status, but simple regressions comparing body weight to shell length can reliably reflect population health under each of these conditions. Individuals are considered at risk when tissue weight is less than 10% of the total (shell plus tissue) weight. Reproductive output can also be used as a measure of population health. Quantitative estimates of reproductive output are difficult to develop because young Unionids are traditionally very difficult to locate even in good habitat. However, the simple presence of young Unionids seems to be a reliable indicator of a healthy, reproducing population.

Additional data including total organic particulate matter in the water column and data about Dreissenid mussel populations are needed to interpret this indicator. Sites without Dreissenid mussels, with >12 species of Unionids, and with young Unionids present would be considered healthy sites where Dreissenids were having negligible impact. Sites where the Unionids are biofouled and the weight of attached zebra mussels is equal to or greater than the weight of the Unionid are sites where the Unionids can be expected to become extirpated shortly. Sites where total organic particulate matter in the water column averages less than 2 mg/L are sites where food resources are too limited to support remaining Unionid populations.

***Comments***
The first step is to document where Unionids are located and what species are present. The second step is to determine if young Unionids of any species are present at a site. Secondary sampling efforts can focus on species of concern. The number of Unionid species at a given site in the Great Lakes basin varied widely. Most Unionid communities historically supported >12 species, depending on locality. Lake Huron probably never had more than 6-7 species, but Lake Erie and the connecting channels had 16-18, and the Unionid communities in inland waters in Michigan typically had about 16 species.

The northern riffleshell mussel, which occurred in Great Lakes connecting channels and perhaps in western Lake Erie, is listed by the U.S. government as "threatened" and action is being taken to change that listing to "endangered". That species is state-listed as "endangered". The Dreissenid mussel has probably exterminated northern riffleshell mussel populations in the connecting channels.

The species diversity and density of Unionids has severely declined in Lake Erie, the Detroit River, and Lake St. Clair since the arrival of Dreissenid mussels there in the mid-1980s. Species diversity of Unionids there has dropped from an average of 16 to less than 1. Many sites that historically supported Unionids now contain no live Unionids and no young (<5 years of age) have been found at these sites since about 1989.

***Unfinished Business***

< Although there may not be an endpoint for population, as well as reproductive output, can an endpoint be provided for soft tissue weight? Can any goal for population and reproductive output be stated?

***Relevancies***

Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): exotics
SOLEC Grouping(s): **open waters**, **nearshore waters**, coastal wetlands
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s):
Beneficial Use Impairment(s): 6: Degradation of benthos

***Last Revised***

March 8 , 2000

# Lake Trout (Indicator ID: 93)

***Measure***
Absolute abundance, relative abundance, yield, or biomass, and self-sustainability through natural reproduction of lake trout in coldwater habitats of the Great Lakes.

***Purpose***
To show the status and trends in lake trout populations, a major coldwater predator and subject of an international effort to rehabilitate populations to near historic levels of abundance.

***Ecosystem Objective***
The coldwater regions of the Great Lakes should be maintained as a balanced, stable, and productive ecosystem with self-sustaining lake trout populations as a major top predator.

***Endpoint***
Self-sustaining, naturally reproducing populations that support target yields to fisheries is the goal of the lake trout rehabilitation as established by the Fish Community Objectives drafted by the Great Lakes Fishery Commission. Target yields approximate historical levels of lake trout harvest or adjusted to accommodate stocked exotic predators such as Pacific salmon. These targets are 4 million pounds from Lake Superior, 2.5 million pounds from Lake Michigan, 2.0 million pounds from Lake Huron and 0.1 million pounds from Lake Erie. Lake Ontario has no specific yield objective but has a population objective of 0.5-1.0 million adult fish that produce 100,000 yearling recruits annually through natural reproduction. The lake trout is a highly valued species that is exploited by recreational and (where permitted) commercial fisheries, and harvest or yield reference values established for self-sustaining populations probably represent an attempt to fully utilize annual production; as a result, harvest or yield reference values for these populations can be taken as surrogates for production reference values.

***Features***
Self-sustainability of lake trout is measured in lakewide assessment programs carried out annually in each lake. The historical dominance of lake trout in oligotrophic waters in all of the Great Lakes provides a good basis for a basin-wide evaluation of ecosystem health. Maintaining or reestablishing historical levels of abundance, biomass, or production and reestablishing self-sustaining populations of lake trout throughout their native range in the basin will help ensure dominance in the ecosystem and the maintenance of a desirable aquatic community in oligotrophic, coldwater habitats. The desired trend is increasing dominance of the indicator species to historical levels in coldwater, oligotrophic habitats throughout the basin.

***Illustration***
For each lake, a graph with lake trout metrics including natural reproduction on the x-axis and year on the y-axis will be presented.

***Limitations***
The indicator is of greatest value in assessing ecosystem health in the oligotrophic, open-water portions of Lake Superior; it may be less useful in nearshore areas of the lake. Because the indicator includes only a single species, it may not reliably diagnose ecosystem health. Also, because lake trout abundance can be easily reduced by overfishing and sea lamprey predation, harvest restrictions designed to promote sustained use and enhanced sea lamprey control are required if the species is to be used as an indicator of ecosystem health. Annual interagency stock assessments measure changes in relative abundance, size and age structure, survival, and extent of natural reproduction but do not provide direct feedback to yield goals.

***Interpretation***
Interpretation is direct and simple. If natural reproduction is observed and contributing significantly to the target values, the system can be assumed to be healthy; if the values are not met then causative agents of impairment are implicated and need to be addressed.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota, fish
Related Issue(s): toxics, nutrients, exotics, habitat
SOLEC Grouping(s): open waters
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s): Ontario, Erie, Huron, Michigan, Superior, Erie
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations

***Last Revised***
August 2002

# Benthos Diversity and Abundance (Indicator ID: 104)

***Measure***
Species diversity and abundance over time and space in the aquatic benthic community.

***Purpose***
This indicator will assess trends in time and spatial distribution of species diversity and abundance in the aquatic benthic community, and it will be used to infer the relative health of the benthic community, including the relative abundance of non-native species.

***Ecosystem Objective***
This indicator addresses the general Fish Community Goals and Objectives to protect and enhance fish habitat, achieve no net loss of the productive capacity of habitat supporting fish communities, and restore damaged habitats. This indicator supports Annex 2 of the GLWQA.

***Endpoint***
Appropriate quantitative measures of species abundance and diversity should be established as reference values for a healthy, diverse benthic community.

***Features***
The aquatic benthic community has been used as one index to assess the relative health of the aquatic community in general. Benthic organisms are widespread and their abundances and species composition vary directly with the degree of nutrient enrichment and food supply. In addition, benthic species differ in their tolerances to polluted conditions. The desired trend is toward a diverse benthic community with inclusion of pollution-sensitive species.

***Illustration***
For each lake or sub basin, a graph showing the species composition and abundance of the representative benthic species community on the y-axis and years on the x-axis will be presented to illustrate the changes in species metrics over time. A map will be used to show the major, within lake, spatial-temporal differences.

***Limitations***
- Identifying benthic taxonomy is a highly specialized and time consuming activity that requires training and experience.
- Historical data are not housed in a data base.
- An endpoint for this indicator has not been established.

***Interpretation***
Abundant, pollution-tolerant benthic species indicate degraded habitats. Increasing species diversity and decreasing abundance of pollution-tolerant species indicate return to healthy habitats. Abundance and production of non-native species indicates a potentially unbalanced and degraded ecosystem.

***Comments***
This indicator measures the composition and production of the native and non-native benthic community over time and space. The relative abundance of non-native benthos such as zebra mussels, is indicative of a disrupted benthic community. Water depth has a strong effect on benthic community composition and should be standardized in any sampling design. Sampling design should also consider areas near sources of pollution as well as clean, offshore areas.

***Unfinished Business***
- May want to consider identifying specific species of interest to measure.
- Need to quantify "abundance", and "diversity".
- What will be the baseline to determine if species diversity is increasing or decreasing?

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): contaminants & pathogens, nutrients, habitat
SOLEC Grouping(s): open waters, nearshore waters
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s):
Beneficial Use Impairment(s): 6: Degradation of benthos

***Last Revised***
July 2, 2002

# Phytoplankton Populations (Indicator ID: 109)

***Measure***
Phytoplankton biomass (species and size composition) and size-fractionated primary productivity (Carbon-14 uptake or photosynthesis) as indicator of microbial food-web structure and function.

***Purpose***
This indicator will assess the species and size composition of phytoplankton populations in the Great Lakes, and it will be used to infer the impact of nutrient enrichment, contamination and invasive exotic predators on the Great Lakes ecosystem.

***Ecosystem Objective***
Mesotrophic to oligotrophic conditions are needed to maintain healthy food-web dynamics and habitat integrity of the Great Lakes ecosystem. Goals of phosphorus control are to maintain an oligotrophic state and relative algal biomass of Lakes Superior, Huron and Michigan, and to maintain algal biomass below that of a nuisance condition in Lakes Erie and Ontario (GLWQA Annex 3). This indicator also supports Annex 2 of the GLWQA.

***Endpoint***
An endpoint needs to be established, based on an international literature search of current and historical data of temperate ecosystems to determine a range of biomass concentrations, species and size structure, as well as fractionated primary productivity (Carbon-14 uptake) for various size fractions as being indicative of healthy and mesotrophic to oligotrophic trophic status.

***Features***
It is well known that the phytoplankton population and its productivity changes with anthropogenic pollution, both nutrients and contaminants. The ecosystem changes are reflected by the change of phytoplankton composition and productivity. For example, Lake Superior represents a pristine, healthy and ultra-oligotrophic ecosystem harboring a unique collection of phytoplankton species. Similarly, it is common knowledge that Lake Erie's phytoplankton composition, which was once eutrophic, has dramatically changed to meso-oligotrophic status due to phosphorous abatement and the invasion of zebra mussels. A great deal of data are available globally (temperate region) and in the Great Lakes about phytoplankton biomass, composition and primary productivity which will reflect the overall ecosystem health including grazing pressures of the exotic predators.

***Illustration***
A table with list of species or a diagram can be given as an illustration.

***Limitations***
Phytoplankton taxonomy (microscopic identification and enumeration) is a highly specialized and time consuming activity that requires intensive training and experience which is generally lacking in the Great Lakes. However, if properly done the phytoplankton analysis generates scientific, precise, and reliable species data that reflects the sensitivity of phytoplankton to anthropogenic stressors.

***Interpretation***

***Comments***
The study of lower trophic levels and their use as indicators have been largely ignored in the Great Lakes. There is an immediate need to evaluate the microbial loop - the base of the food chain ranging from bacteria, heterotrophic nanoflagellates, autotrophic picoplankton, ciliates to phytoplankton (nanoplankton and microplankton-netplankton).

This indicator was prepared using information from:
M. Munawar, I.F. Munawar, P. Ross & R. Dermott. 1992. Exploring aquatic ecosystem health: A multi-trophic and an ecosystemic approach. J. Aquat. Ecosyst. Health. 1:237-252

M. Munawar, I.F. Munawar, L.R. Culp and G. Dupuis. 1978. Relative importance of nannoplankton in Lake Superior phytoplankton biomass and community metabolism. J. Great Lakes Research. 4:462-480

Unfinished Business
< An endpoint needs to be established.
< The method of graphically displaying this indicator needs to be determined.
< Additional information is needed to interpret the data as well as a range of "good" or "poor" (e.g., an oligotrophic ecosystem that harbors phytoplankton populations that are diverse in species and size would indicate a healthy ecosystem.)

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): contaminants & pathogens, nutrients, exotics
SOLEC Grouping(s): **open waters**, **nearshore waters**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 3: Control of Phosphorus, 11: Surveillance and

monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 8: Absence of excess phosphorus
GLFC Objective(s):
Beneficial Use Impairment(s): 13: Degradation of phyto/zooplankton populations

***Last Revised***
March 8, 2000

# Phosphorus Concentrations and Loadings (Indicator ID: 111)

***Measure***
Total phosphorus levels (ug/L) in the springtime open waters, and annual total phosphorus loads to each lake.

***Purpose***
This indicator will assess the total phosphorus levels and loadings in the Great Lakes and it will be used to support the evaluation of trophic status and food web dynamics in the Great Lakes.

***Ecosystem Objective***
Goals of phosphorus control are to maintain an oligotrophic state and relative algal biomass of Lakes Superior, Huron and Michigan, to maintain algal biomass below that of a nuisance condition in Lakes Erie and Ontario, and to eliminate algal nuisance in bays and in other areas wherever they occur (GLWQA Annex 3). The IJC developed the following delisting guideline for eutrophication or undesirable algae: 'no persistent water quality problems (e.g., dissolved oxygen, depletion of bottom waters, nuisance algal blooms or accumulations, and decreased water clarity) attributed to cultural eutrophication.'

The indicator also supports Annexes 1, 2 and 13 of the GLWQA.

***Endpoint***
Maximum annual phosphorus loadings to the Great Lakes that would allow achievement of the stated goals (above) are: Lake Superior - 3400 tonnes, Lake Huron (main lake) - 2800 tonnes, Lake Michigan - 5600 tonnes, Lake Erie - 11,000 tonnes, Lake Ontario - 7000 tonnes (GLWQA, Annex 3). If these loading rates are maintained, the expected concentration of total phosphorus in the open waters of each lake are: Lake Superior - 5 ug/l, Lake Huron - 5 ug/l, Lake Michigan - 7 ug/l, Lake Erie Western Basin - 15 ug/l, Lake Erie Central Basin - 10 ug/l, Lake Erie Eastern Basin - 10 ug/l, Lake Ontario - 10 ug/l (IJC 1980).

***Features***
Analysis of phosphorus concentrations to the Great Lakes is ongoing and reliable, but insufficient monitoring of tributaries has been undertaken since 1993 to calculate reliable loading estimates. Current methodology used for analysis is adequate. This indicator provides information to infer the baseline potential productivity of each lake and linkages to future biological problems related to a potential return to excess nutrient loads. Also, the filtering effects of new colonizing species -- zebra and quagga mussels -- appear to exacerbate the effects of declining phosphorus loading (hence declining lake productivity). Measurements and reporting must reliably reflect spatio-temporal differences on scales needed to effectively address the ecosystem objective. Particular emphasis should be placed on open-lake data collected in the spring of the year, and comparison should be made with the GLWQA objectives. Biannual survey data are available for 1982 to present.

***Illustration***
For each lake, a graph will be presented showing total phosphorus concentrations and loadings on the y-axis and years on the x-axis. A map will be presented showing major, within-lake, spatio-temporal distributions of phosphorus concentrations.

***Limitations***
Tributary monitoring is currently (2000) insufficient to evaluate loadings of phosphorus.

A research effort should be undertaken to understand the effects of zebra mussels on phosphorus dynamics in the Great Lakes, and to then incorporate those effects into existing water quality models. The revised models should then be used to reanalyze the relationships between annual phosphorus loadings, the expected resultant phosphorus concentrations in the open waters, and the potential for nuisance growths of algae.

***Interpretation***
Desirable outcomes are the absence of blooms of undesirable algae and total phosphorus concentrations and loadings that do not exceed the target levels specified in the GLWQA. Remote sensing and satellite imagery can be used to identify algae blooms, which may then be correlated to phosphorus concentrations or increased loadings.

***Comments***
This indicator was prepared using information in:

Edsall, T., and M. Charleton. 1997. Nearshore waters of the Great Lakes. State of the Lakes Ecosystem Conference '96 Background Paper. ISBN 0-662-26031-7.

Charleton, M., and R. LeSage. 1999. Lake Erie in Transition: the 1990s. In State of Lake Erie (SOLE). M. Munawar, T. Edsall, and I. F. Munawar (eds.) Backhuys Publishers, Leiden, The Netherlands (In Press).

IJC. 1980. Phosphorus Management for the Great Lakes. Final report of the Phosphorus Management Strategies Task Force to the IJC Great Lakes Water Quality Board and Great Lakes Science Advisory Board.

***Unfinished Business***

***Relevancies***

Indicator Type: pressure
Environmental Compartment(s): water
Related Issue(s): nutrients
SOLEC Grouping(s): **open waters**, **nearshore waters**, coastal wetlands
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 3: Control of phosphorus, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 8: Absence of excess phosphorus
GLFC Objective(s): Erie
Beneficial Use Impairment(s): 8: Eutrophication or undesirable algae, 9: Restrictions on drinking water consumption or taste and odour problems, 11: Degradation of aesthetics, 13: Degradation of phyto/zooplankton populations

***Last Revised***

March 8, 2000

# Contaminants in Young-of-the-Year Spottail Shiners
## (Indicator ID: 114)

***Measure***
Concentration of PBT chemicals in young-of-the-year spottail shiners.

***Purpose***
This indicator will assess the levels of PBT chemicals in young-of-the-year spottail shiners, and it will be used to infer local areas of elevated contaminant levels and potential harm to fish-eating wildlife.

***Ecosystem Objective***
Forage fish concentrations of PBT chemicals should not pose risk to fish-eating wildlife. This indicator supports Annexes 1, 2 and 12 of the GLWQA.

***Endpoint***

***Features***
This indicator will be used to monitor long-term fluctuations in the concentration of measured contaminants and the risk they pose to fish-eating wildlife. Shiner collections have been ongoing for almost two decades and represent one of the best long-term data bases on chemicals in the Great Lakes. Because young-of-the-year spottail shiners are small and stay close to their natal area, their chemical concentrations provide information on local chemical inventories as well as the variability and distribution of the chemicals throughout the lakes. The shiners are captured from several spots on each Lake; therefore, the data can be used to illustrate both variability and average levels of PBT chemical exposure to fish-eating wildlife throughout the lakes

***Illustration***
Results of raw data will be used to construct simple bar graphs showing the fluctuation of contaminants over time and space. As decline of chemicals is an exponential decline, these graphs will be depicted on an logarithmic Y axis versus time.

***Limitations***
Trends of chemical contaminants in spottail shiners are confounded by other factors including: food chain effects, potential weather effects, analytical and sampling variability. These factors limit the usefulness of the shiner data as an indicator of short-term trends of PBTs in the Great Lakes. Larger, older forage fish may have higher PBT concentrations than young-of-the year spottail shiners, and therefore, shiner data may underestimate risk to fish-eating wildlife.

***Interpretation***

***Comments***
Concentrations of contaminants in young-of-the-year spottail shiners represent a good indicator of local concentrations of chemicals and potential risk to fish-eating wildlife.

***Unfinished Business***
< Need to provide the names of the PBT chemicals will be measured by this indicator.
< Need to provide a reference for the ecosystem objective.
< An endpoint, or frame of reference in which to interpret the data, needs to be defined.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): fish
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **nearshore waters**
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 23, 2000

# Contaminants in Colonial Nesting Waterbirds (Indicator ID: 115)

***Measure***
1) Annual concentrations of DDT complex, PCBs/PCDFs/PCDDs and other organic contaminants and Hg and other metals in Herring Gull eggs from 15 sites from throughout the Great Lakes (U.S. and Canada).
2) Periodic measurement of biological features of gulls and other colonial waterbirds known to be directly or indirectly impacted by contaminants and other stressors. These include (but are not limited to): clutch size, eggshell thickness, hatching and fledging success, size and trends in breeding population, various physiological biomarkers including vitamin A, immune and thyroid function, stress hormone levels, liver enzyme induction, PAH levels in bile and porphyrins and genetic and chromsomal abnormalities.

***Purpose***
This indicator will assess chemical concentration levels in a representative colonial waterbird, and it will be used to infer the impact of these contaminants on colonial waterbird physiology and population characteristics.

***Ecosystem Objective***
This indicator supports Annexes 1, 2 and 12 of the GLWQA.

***Endpoint***
Chemical levels and biological measures in colonial nesting waterbirds are not different from those from reference sites in Atlantic Canada or from the Prairies.

***Features***
Although there are Great Lakes wildlife species that are more sensitive to contaminants than Herring Gulls, and colonial nesting waterbird species in general, there is no other species which has the historical dataset that the Herring Gull does. As contaminant levels continue to decline (if they do), the usefulness of the Herring Gull as a biological indicator species may lessen (due to its reduced sensitivity to low levels of contamination) but its value as a chemical indicator will remain and probably increase - as levels become harder and harder to measure in other media. As well, it is an excellent accumulator. Adult Herring Gulls nest on all the Great Lakes and the connecting channels and remain on the Great Lakes year-round. Because their diet is usually made up primarily of fish, they are an excellent terrestrially nesting indicator of the aquatic community. Historical data on levels of chemical contamination in gull eggs are available, on an annual basis, for most sites in both the Canadian and U.S. Great Lakes dating back to the early 1970s. An immense database of chemical levels and biological measures from the Great Lakes, as well as many off-Lakes sites, is available from CWS. For Herring Gulls, many of the above biological measures are correlated with contaminant levels in their eggs. In other colonial waterbirds there are similar correlations between contaminant levels in eggs and various biological measures. Contaminant levels in eggs of other colonial waterbirds are usually correlated with those in Herring Gulls.

***Illustration***
1) Temporal trends, portrayed as annual contaminant levels over time, for 1974-present in most instances, are available for each site and each compound, for example, DDE, 1974-1997, for Toronto Harbour and could be displayed graphically. 2) Geographical patterns in contaminant levels, showing all sites relative to one another, are available for most years 1974-present and for most compounds, for example, PCBs, 1997, at 15 Great Lakes sites from Lake Superior to the St. Lawrence River (including U.S. sites) and could be displayed on both maps and graphs.

***Limitations***
Herring Gulls are highly tolerant of persistent contamination and may underestimate biological effects occurring in other less monitored, more sensitive species. Also, some adult Herring Gulls from the upper Lakes, especially Lake Superior, move to the lower Lakes, especially Lake Michigan, during harsh winters. This has the potential to confound the contaminant profile of a bird from the upper Lakes. Most of the gull's time is still spent on its home lake and this has not been noted as a serious limitation up to this point. Using contaminant accumulation by young, flightless gulls would eliminate this problem but their contaminant levels and effects would be less due to the much reduced contaminant exposure/intake.

***Interpretation***
Other tissues and species analyzed as necessary to confirm findings in Herring Gulls.

***Comments***
Contaminant concentrations in most colonial-nesting, fish-eating birds are at levels where gross ecological effects, such as eggshell thinning, reduced hatching and fledging success, and population declines, are no longer apparent. Greater reliance for detecting biological effects of contaminants is being put upon physiological and genetic biomarkers. These are not as well characterized, nor are they understood as easily by the public. Other complementary species include: Double-crested Cormorant (Phalacrocorax auritus), Common Tern (Sterna hirundo), Caspian Tern (Sterna caspia) and Black-crowned Night-Heron (Nycticorax nycticorax). The Herring Gull egg contaminants dataset is the longest running continuous contaminants dataset for wildlife in the world.

1) Chemical levels and trends: Contaminant levels in almost all Great Lakes colonial waterbirds are significantly and substantially reduced from what they were 25 years ago. However, now, in the 1990s, year to year differences in contaminant levels are quite small and without statistical analysis it is often difficult to tell if a compound has stabilized" and is undergoing only year to year, non-

significant, fluctuations or if it is still declining. Our analyses show that most contaminants at most sites are continuing to decline at a rate similar to what they have over the last decade or two. However, some compounds, at some sites, have stabilized. Geographical differences for a given compound among sites on the Great Lakes are not as dramatic as they once were. There is greater similarity in contaminant concentration among Great Lakes sites now than there was in the past. However, differences in contaminant levels between sites on and off the Great Lakes are still fairly evident.

2) It is difficult to show consistent differences in biological effects among colony sites within the Great Lakes. This is probably due to the great overall reduction in contaminant levels as well as the lessening in differences among Great Lakes sites. The comparisons which show the greatest differences for biological effects of contaminants are between sites on and off the Great Lakes.

***Unfinished Business***

< Need to an ecosystem objective that this indicator addresses and provide a reference.

***Relevancies***

Indicator Type: pressure
Environmental Compartment(s): biota
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **open waters**, **nearshore waters**
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s): Erie
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 5: Bird or animal deformities or reproductive problems

***Last Revised***

Feb. 23, 2000

# Zooplankton Populations (Indicator ID: 116)

***Measure***
Spatial and temporal trends in community composition; mean individual size; and biomass and production.

***Purpose***
This indicator will assess characteristics of the zooplankton community over time and space, and it will be used to infer changes over time in vertebrate or invertebrate predation, system productivity, energy transfer within the Great Lakes, or other food web dynamics.

***Ecosystem Objective***
Maintain the biological integrity of the Great Lakes and to support a healthy and diverse fishery as outlined by the Goals and Objectives of the LaMPs and Great Lakes Fishery Commission. This indicator supports Annex 2 of the GLWQA.

***Endpoint***
For mean individual size, Mills et al. (1987) suggest 0.8 mm as an optimal size when the water column is sampled with a 153-µm mesh net. Endpoints for community composition and biomass and productivity depend on the desired trophic state and type of fish community. Zooplankton as indicators of plankton and ecosystem community health are still in the early stages of development. Some information on the variability in zooplankton mean length is presented in Mills et al. (1987), and Johannsson et al. (1999b,c). Empirical relationships can be found in the literature relating zooplankton biomass and production to other state variables, such as total phosphorus, chlorophyll a concentration, primary production and zooplankton mean length (Makarewicz and Likens 1979 (if rotifers are measured), (McCauley et al. 1980), Hanson and Peters 1984, Yan 1985, McQueen et al. 1986, Johannsson et al. 1999a). End points for community structure are not clear now that new non-native zooplankton (*Bythotrephes* and *Cercopagus*) have entered the lakes.

***Features***
This indicator tracks trends in zooplankton populations, including community composition, mean individual size, and biomass and production, over time and space. Some data are available for Lake Ontario from 1967, 1970, 1972 on composition and abundance. Composition, density, biomass and production data are available for 1981-1995 from the Canadian Department of Fisheries and Oceans Lake Ontario Long-Term Biological Monitoring (Bioindex) Program (Johannsson et al. 1998). Mean individual size was not measured for the community during these years, but could be obtained from archived samples. Zooplankton work on Lake Erie has been reviewed by Johannsson et al. (1999c).

***Illustration***
Zooplankton mean length, ratio of calanoids to cladocerans + cyclopoids and biomass can be presented as line graphs if trend data are available. Shifts in composition might be better tracked using factor analysis followed by multi-dimensional scaling to show how the community structure moves in a two-dimensional space.

***Limitations***
At this point, it is not possible to rate mean individual size of zooplankton if they do not equal 0.8 mm. It is unclear how different energy flow is if the mean size is 0.6 mm or 1.0 mm, and if 0.6 mm is equivalent to 1.0 mm.

***Interpretation***
Some of the other measures which would help with the interpretation of the zooplankton data would include, total phosphorus, chlorophyll a, temperature, oxygen (in some regions), and, if possible, primary production and phytoplankton composition and biomass.

***Comments***
Composition: Changes in composition indicate changes in food-web dynamics due to changes in vertebrate or invertebrate predation, and changes in system productivity. Ratios such as calanoids to cladocerans + cyclopoids have been used to track changes in trophy. This particular ratio may NOT work in dreissenid systems (Johannsson et al. 1999c).

Mean Individual Size: The mean individual size of the zooplankton indicates the type and intensity of predation. When the ratio of piscivores to planktivores is approximately 0.2, the mean size of the zooplankton is near 0.8 mm. These conditions are characteristic of a balanced fish community (Mills et al. 1987). There is a high degree of variability about this relationship and further work needs to be done to strengthen this indicator. Total biomass and possibly production decrease with decreases in the mean size of the zooplankton (Johannsson et al. 1999b).

Biomass and Productivity: Biomass can be used to calculate production using size and temperature dependent P/B ratios for each of the major zooplankton groups. Production is a much better indicator of energy transfer within a system than abundance or biomass.

Of these measures, composition and mean size are the most important. However, these factors provide the information needed to calculate biomass and production.

***Relevancies***

Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): contaminants & pathogens, nutrients, exotics
SOLEC Grouping(s): open waters, nearshore waters
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s):
Beneficial Use Impairment(s): 13: Degradation of phyto/zooplankton populations

***Last Revised***
July, 2002

# Atmospheric Deposition of Toxic Chemicals (Indicator ID: 117)

***Measure***
Annual average loadings of toxic chemicals from the atmosphere to the Great Lakes, based on measured atmospheric concentrations of the chemicals, as well as wet and dry deposition rates.

***Purpose***
This indicator will estimate the annual average loadings of priority toxic chemicals from the atmosphere to the Great Lakes, and it will be used to infer potential impacts of toxic chemicals from atmospheric deposition on the Great Lakes aquatic ecosystem, as well as to infer the progress of various Great Lakes programs toward virtual elimination of toxics from the Great Lakes.

***Ecosystem Objective***
The GLWQA and the Binational Strategy both state the virtual elimination of toxic substances to Great Lakes as an objective. Additionally, GLWQA General Objective (d) states that the Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human, animal, or aquatic life. This indicator supports Annexes 2, 12, 15 and 17 of the GLWQA.

***Endpoint***
When atmospheric concentrations of toxic chemicals associated with existing water quality criteria are no longer measurable above naturally-occurring levels by current technology.

***Features***
This indicator will track whether concentrations of priority toxic chemicals are, as a group, decreasing, staying the same, or increasing in open waters over time. The chemicals of interest include, but are not limited to, PCBs, deildrin, chlordane, DDT and metabolites, hexachlorobenzene, toxaphene and mercury. Loadings will be calculated based on 1) measured atmospheric concentrations of the chemicals and 2) wet and dry deposition rates using techniques described in the "Chemicals of Concern" chapter of the Lake Superior Stage II LaMP. The indicator data will also demonstrate the magnitudes of the trends in the loadings of toxic chemicals from the air to the water. The magnitudes of the trends are expressed as a "half-fold time," or time to which the concentration of the chemical is decreased by a factor of two. The time which is most relevant to virtual elimination is the longest half-fold time of the measured chemicals.

***Illustration***

***Limitations***
There is concern that some of the features of the loadings calculations (see Comments field) are poorly known at present. The trends in the atmospheric concentrations of toxic chemicals, however, are much better known and a much better indicator of progress towards virtual elimination. Errors in these trends should be clearly stated and tested against the null hypothesis (things are not changing).

***Interpretation***
Progress will be determined based on whether trends of the toxic chemicals are positive (i.e., increasing pollutant concentrations) or negative (decreasing pollutant concentrations)and by the number of chemicals which reach the virtual elimination goal.

To understand the pollutant concentration trends related to atmospheric deposition, additional information is needed in interpreting pollutant load estimates derived using the suggested calculation (see Comments field). For example, information on the yearly variations in the rain rate (dry years versus wet years) is needed to understand the pollutant concentrations associated with wet deposition. Also, since it is known that the pollutant loads associated with atmospheric deposition have seasonality for some components, the data should be statistically deseasonalized to properly determine the trend.

***Comments***
Estimates of atmospheric deposition have been made since 1988 (Strachan and Eisenreich, 1988; Eisenreich and Strachan, 1992). More recently atmospheric deposition fluxes and loads have been measured by the Integrated Atmospheric Deposition Network (IADN) (Hoff et al., 1996; IADN Steering Committee, 1997). The indicator follows procedures set out in the IADN Quality Assurance Program Plan (1994). Several primary indicators of progress towards virtual elimination are found in the estimation of loading to the lakes, L, where L = W + D + G, below.

Wet deposition (W) is calculated as:

where $C_p$ (ng/l) is the volume-weighted mean precipitation concentration averaged over a year period, $R_p$ is the precipitation rate in m $y^{-1}$ (water equivalent for snow), and the factor of 1000 converts litres to cubic metres.

The magnitude of W and its change with time is an indicator of progress towards virtual elimination. It should be noted, however, that yearly variations in the rain rate (dry years versus wet years) will complicate the interpretation of the indicator. Therefore, the concentration of the chemical in precipitation should also be evaluated as an indicator.

Dry deposition of particles is calculated from:

where $v_d$ (m $y^{-1}$) is the dry deposition velocity of the species in question (a function of particle size and hygroscopic nature of the particles) and $C_{a,part}$ (ng $m^{-3}$) is the particulate phase concentration of the chemical in air. Since the dry deposition velocity of particles is not well known, it has been specified as 0.2 cm $s^{-1}$ in previous work (Strachan and Eisenreich, 1988; Hoff et al. 1996). Since the deposition velocity is not expected to be a determining factor in the long-term trend of dry deposition (particle sizes will not change much with time), the air concentration of chemicals on the particles will be a primary indicator which can be tracked for trends.

Gas exchange is computed from the knowledge of both the gas phase species concentration in air ($C_{a,gas}$, ng $m^{-3}$) and the concentration of the chemical in water ($C_w$, ng/l) through the formula:

where $k_{oL}$ (m $y^{-1}$) is the air-water mass transfer coefficient, H is the temperature dependent Henry's Law constant, R is the gas constant and T is the surface water skin temperature (Schwarzenbach et al., 1993). As expressed above if $G>0$ then the lakes are being loaded from the atmosphere and if $G<0$ then the lakes are a source of the chemical to the atmosphere. There is uncertainty (see below) in some of the chemical and physical properties which are part of the gas phase flux. A more precise indicator of trends in this flux are the air and water concentrations of the chemical themselves.

The rate of change of the loading, $L = W + D + G$, is $dL/dt$. Since it is known that the loads have seasonality for some components, in order to properly determine the trend, the data should be statistically deseasonalized (i.e, using a Rank-Kendall statistic, standard temperature correction, or equivalent).

Even after deasonalizing the trend data, there may be considerable error in the magnitude of the gas phase exchange. In order not to overstate the loading indicator precision, a secondary measure of the indicator will be the sign of the change in L, in the above equation. If the indicator is positive, the trends in the loadings are increasing and the objective is not being approached. If the indicator is negative, the loadings are decreasing and the objective is being approached. It is likely that if the sign of dL/dt is negative, the change in the atmospheric contributions to the tributary loadings is likely to be of the same sign.

A third component of the indicator is the relative rate of change of the loading with time. The more negative this indicator becomes the faster the goal of virtual elimination will be reached.

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Strachan, W.M.J. and S.J. Eisenreich. 1988. Mass Balancing of Toxic Chemicals in the Great Lakes: The Role of Atmospheric Deposition. Publ. International Joint Commission, Windsor, Canada, July, 113 p.

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***Unfinished Business***

< Need to provide a detailed description of how data will be displayed graphically. For example, will the illustration consist of various colored plottings on a map or a bar chart to convey the relative abundance?

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): air, water
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **open waters**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances, 15: Airborne toxic substances, 17: Research and development
IJC Desired Outcome(s): 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
March 8, 2000

# Toxic Chemical Concentrations in Offshore Waters (Indicator ID: 118)

***Measure***
The concentration of toxic chemicals in the offshore waters of the Great Lakes.

***Purpose***
This indicator will assess the concentration of priority toxic chemicals in offshore waters, and it will be used to infer the potential impacts of toxic chemicals on the Great Lakes aquatic ecosystem, as well as to infer the progress of various Great Lakes programs toward virtual elimination of toxics from the Great Lakes.

***Ecosystem Objective***
The GLWQA and the Binational Strategy both state the virtual elimination of toxic substances to Great Lakes as an objective. Additionally, GLWQA General Objective (d) states that the Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human, animal, or aquatic life. This indicator supports Annexes 1 and 12 of the GLWQA.

***Endpoint***
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.

***Features***
This indicator will track whether concentrations of the IJC priority toxic chemicals are, as a group, decreasing, staying the same, or increasing in open waters over time. The chemicals of interest include, but are not limited to, PCBs, deildrin, chlordane, DDT and metabolites, hexachlorobenzene, toxaphene and mercury. The indicator data will also demonstrate the magnitudes of the trends of the various chemicals. The magnitudes of the trends are expressed as a "half-fold time," or time to which the concentration of the chemical is decreased by a factor of two. The time which is most relevant to virtual elimination is the longest half-fold time of the measured chemicals. Monitoring for this indicator will occur during the two year periods between SOLEC. Every two years, water concentrations of zero discharge and lakewide remediation chemicals should be monitored throughout the offshore waters of Lake Superior, for comparison with an appropriate baseline. Sampling should be conducted during spring, isothermal conditions, as maximum concentrations have been reported during this time.

***Illustration***
Water concentrations of the zero discharge and lakewide remediation chemicals should be presented in a table which provides both the 95$^{th}$ percentile (see Interpretation field) and the appropriate baseline, for comparison. Spatial distribution maps, showing raw concentration data, should also be provided to indicate spatial gradients and to discern any problem areas.

***Limitations***
Although measurements exist for many priority chemicals in the Great Lakes system, these measurements are not all obtained on a time scale that would allow for significant reinterpretation every two years. As new information is available, and the indicator is updated, trends will become more discernable and progress toward virtual elimination can be assessed. Errors in these trends should be clearly stated and tested against the null hypothesis (i.e., things are not changing).

***Interpretation***
Pollutant concentrations will be considered positive only if 95-100% of the available data indicate concentration levels below the lake-specific baseline. Progress will be determined based on whether trends of the IJC priority toxic chemicals are positive (i.e., increasing pollutant concentrations) or negative (decreasing pollutant concentrations)and by the number of chemicals which reach the virtual elimination goal.

***Comments***

***Unfinished Business***
< Need to provide a detailed description of how data will be displayed graphically. For example, will the illustration consist of various colored plottings on a map or a bar chart to convey the relative abundance?

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **open waters**
GLWQA Annex(es): 1: Specific objectives, 11: Surveillance and monitoring, 12: Persistent toxic substances
IJC Desired Outcome(s): 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
March 8, 2000

# Concentration of Contaminants in Sediment Cores (Indicator ID: 119)

***Measure***
The concentrations of toxic chemicals in sediment cores at selected sites within the Great Lakes at ten year intervals.

***Purpose***
This indicator will assess the concentrations of toxic chemicals in sediments, and it will be used to infer potential harm to aquatic ecosystems by contaminated sediments, as well as to infer the progress of various Great Lakes programs toward virtual elimination of toxics from the Great Lakes.

***Ecosystem Objective***
The GLWQA and the Binational Strategy both state the virtual elimination of toxic substances to Great Lakes as an objective. Additionally, GLWQA General Objective (d) states that the Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human, animal, or aquatic life. And, GLWQA Annex 14 Objective asks to identify the nature and extent of sediment pollution of the Great Lakes System. This indicator also supports Annexes 2, 7 and 12 of the GLWQA.

***Endpoint***
When sediment concentrations of toxic chemicals associated with existing water quality criteria are no longer measurable above naturally-occurring levels by current technology.

***Features***
This indicator will track whether concentrations of the toxic chemicals are, as a group, decreasing, staying the same, or increasing in open waters over time. The chemicals of interest include, but are not limited to, PCBs, deildrin, chlordane, DDT and metabolites, hexachlorobenzene, toxaphene and mercury. The indicator data will also demonstrate the magnitudes of the trends of the various chemicals. The magnitudes of the trends are expressed as a "half-fold time," or time to which the concentration of the chemical is decreased by a factor of two. The time which is most relevant to virtual elimination is the longest half-fold time of the measured chemicals.

In the nearshore areas and harbours and bays, cores would be collected every 10 years from sites selected for index monitoring. Index sites should include areas where sediment sampling would provide added value to contaminant investigations, for example, sites previously monitored for contaminants in fish. Sites would also be chosen based on sediment type, expected sedimentation rates, and proximity to potential sources. Cores would be sectioned, dated and analyzed for the toxic chemicals.

Certain estuaries, bays, and harbours on the lakes, are designated as Areas of Concern because of past or on-going pollution problems. Sediment contamination in these areas, taken together, represent cumulative impacts to productive habitat areas. In addition, Areas of Concern can serve as contaminant source areas to the rest of the Lakes. Application of the sediment indicator at Areas of Concern is intended to integrate the information gathered by RAP monitoring efforts to give a lakewide picture for these important habitat areas.

***Illustration***
The sediment concentrations would be depicted using the standard tables and figures showing the change in concentration at different depths. Only the upper segment of the core would be compared to the yardstick or local standard. In addition, a set of maps showing locations and concentrations of sediments in the nearshore areas and a set of maps showing sediment chemical concentrations in the Areas of Concern would serve to illustrate the indicator.

***Limitations***
An update of this indicator with new data every two years for SOLEC may not be feasible because sediment cores may only be obtained every decade or so. However, the updates of the indicator when new information arise is applicable to past years (i.e., sediment cores will fill in the history for the previous decade). Errors in these trends should be clearly stated and tested against the null hypothesis (i.e., things are not changing).

***Interpretation***
Progress will be determined based on whether trends of the toxic chemicals are positive (i.e., increasing pollutant concentrations) or negative (decreasing pollutant concentrations) and by the number of chemicals which reach the virtual elimination goal.

***Comments***
Measurements exist for many priority chemicals in the sediments of the Great Lakes system.

The desired outcome of the indicator is that the trends are negative in sign and that the concentrations reach levels which are no longer measurable by current technology.

***Unfinished Business***

<	For the presentation of the indicator “standard tables and figures” should be defined or the text modified to be more descriptive (e.g., Sediment concentrations at each site, by depth, will be displayed on a bar graph. Current detection limits will be clearly marked).

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): sediments
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **open waters**, **nearshore waters**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 7: Dredging, 11: Surveillance and monitoring, 12: Persistent toxic substances, 14: Contaminated sediment
IJC Desired Outcome(s): 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s): 6: Degradation of benthos, 7: Restrictions on dredging activities

***Last Revised***
March 8, 2000

# Contaminants in Whole Fish (Indicator ID: 121)

***Measure***
Concentration of persistent, bioaccumulating, toxic (PBT) chemicals in Great Lakes whole lake trout and walleye (and major prey species).

***Purpose***
To assess trends in the concentration of PBT chemicals in the open waters of the Great Lakes using fish as biomonitors, as a measure of the success of remedial actions and to infer real or potential effects of contaminants on fish and fish-consuming wildlife.

***Ecosystem Objective***
Great Lakes waters should be free from materials will produce conditions that are toxic or harmful to animal or aquatic life (GLWQA General Objective). This indicator supports Annexes 1, 2, 11 and 12 of the GLWQA.

***Endpoint***
Reduction in concentration of PBT chemicals in whole fish to levels that do not pose a risk to the health of Great Lakes fish populations or to fish-eating wildlife populations.

***Features***
The temporal and geographic trends in the chemical contaminant levels in lake trout from Lakes Ontario, Huron, Michigan and Superior, and walleye from Lake Erie will be used as an indicator of exposure to PBT chemicals in the water and food web. Fish will be collected in the fall of the year, not less frequent than every other year. Using fish of similar size reduces the impact of size variation on contaminant trend data. Individual whole fish are analyzed to provide data on the spectrum of bioavailable contaminants present in Great Lakes aquatic ecosystems. Organochlorine contaminants to be measured include PCBs, DDT and metabolites, dieldrin, toxaphene, chlordanes, nonachlors, and other recently detected compounds that may be of concern. Trace metals chosen for monitoring will include Hg, Pb, Cu, Ni, Zn, Cd, Cr, As, and Se. Selection will depend on local environmental conditions. Data will be statistically analysed (by age or size cohort) to determine mean and variance for each species, chemical, lake and year.

***Illustration***
Bar graphs, line graphs and/or scatter plots may be used to show trends over time for each species (by age or size cohort), chemical and lake.

***Limitations***
Consistency is very important to conduct trend analyses. Over time, fish of similar size/age should be collected, contaminants monitored should be consistent, and specific analytical techniques used must be comparable to those used in the past. Caution is warranted if data from more than one jurisdiction or monitoring program are used to evaluate temporal or spatial trends. Data collected under different sample treatment or chemical analyses protocols may be incompatible in some cases. Contaminant concentrations in whole fish are routinely higher than in the edible portions. Therefore, the data may not be directly appropriate for assessing the need for fish consumption advisories to protect human health. The utility of these whole fish data are that they provide a more sensitive indicator of emerging contaminant issues such as the detection of recently identified contaminants or the increase in concentrations of a previously regulated contaminant.

***Interpretation***
Reductions in contaminant levels in whole fish will reflect environmental change, i.e. reductions in contaminant loading with subsequent reductions in the concentration of contaminants in the water or changes in the food web composition, and will pose less risk of harm to fish communities and fish-eating wildlife.

***Comments***

***Unfinished Business***
Should identify quantitative endpoints for each contaminant to be protective of aquatic life and fish-consuming wildlife.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): fish
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): open waters
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s): Ontario, Erie, Huron, Michigan, Superior
Beneficial Use Impairment(s): 3.Degradation of fish and wildlife populations

***Last Revised***
March 22, 2004

# Hexagenia (Indicator ID: 122)

***Measure***
Abundance, biomass, or annual production of burrowing mayfly (*Hexagenia* sp.) populations in historical, warm-cool water, mesotrophic habitats of the Great Lakes. Presence or absence of a *Hexagenia* mating flight (emergence) in late June early July in areas of historical abundance.

***Purpose***
This indicator will show the status and trends in *Hexagenia* populations, and will be used to infer the health of the *Hexagenia* populations and the Great Lakes ecosystem.

***Ecosystem Objective***
Historical mesotrophic habitats should be maintained as balanced, stable, and productive elements of the Great Lakes ecosystem with *Hexagenia* as the key benthic invertebrate organism in the food chain. (Paraphrased from **Final Report of the Ecosystem Objectives Subcommittee**, 1990, to the IJC Great Lakes Science Advisory Board.) In addition, this indicator supports Annex 2 of the GLWQA.

***Endpoint***
Appropriate quantitative measures of abundance, biomass, or production should be established as reference values for self-sustaining populations of *Hexagenia* in mesotrophic habitats in each lake.

***Features***
The historical dominance of *Hexagenia* in mesotrophic habitats in the Great Lakes provides a good basis for a basin-wide evaluation of ecosystem health. Maintaining or reestablishing historical levels of abundance, biomass, or production of *Hexagenia* throughout their native range in the basin will help ensure their dominance in the ecosystem and the maintenance of a desirable and balanced aquatic community in warm-cool water mesotrophic habitats. *Hexagenia* are a major integrator between detrital and higher levels in food web. *Hexagenia* are highly visible during emergence in June- July and the public can easily use the species as an indicator to judge ecosystem health in areas where it is now abundant or was historically abundant but now is absent. Historical data can be used to develop status and trend information on *Hexagenia* populations. Sediment cores from Lake Erie show major trends in abundance of *Hexagenia* extending back to about 1740 and other data are available to document more recent and present levels of abundance in Lake Erie and other parts of the basin.

***Illustration***
To be developed

***Limitations***
*Hexagenia* are extirpated at moderate levels of pollution, and more research is needed to develop data needed to show a graded response to pollution. Target reference values for the indicator are being developed for all major Great Lakes mesotrophic habitats.

***Interpretation***
The desired trend is increasing dominance to historical levels of the indicator species in mesotrophic habitats throughout the basin. If the target values are met, the system can be assumed to be healthy; if the values are not met there is health impairment. The presence of an annual *Hexagenia* mating flight (emergence) in late June-early July can also be used by the public and other non-technical observers as a specific indicator of good habitat quality, whereas the lack of a mating flight in areas where the species was historically abundant can be used as an indicator of degraded habitat. High *Hexagenia* abundance is strongly indicative of uncontaminated surficial sediments with adequate levels of dissolved oxygen in the overlying water columns. Probable causative agents of impairment for *Hexagenia* include excess nutrients and pollution of surficial sediments with metals and oil.

***Comments***
*Hexagenia* were abundant in major mesotrophic Great Lakes habitats including Green Bay (Lake Michigan), Saginaw Bay (Lake Huron), Lake St. Clair, western and central basins of Lake Erie, Bay of Quinte (Lake Ontario), and portions of the Great Lakes connecting channels. Eutrophication and pollution with persistent toxic contaminants virtually extinguished *Hexagenia* populations throughout much of this habitat by the 1950s. Controls on phosphorus loadings resulted in a major recovery of *Hexagenia* in western Lake Erie in the 1990s. Reduction in pollutant loadings to Saginaw Bay has resulted in limited recovery of *Hexagenia* in portions of the Bay. *Hexagenia* production in upper Great Lakes connecting channels shows a graded response to heavy metals and oil pollution of surficial sediments.

*Hexagenia* should be used as a benthic indicator in all mesotrophic habitats with percid communities and percid FCGOs. Contaminant levels in sediment that meet USEPA and OMOE guidelines for "clean dredged sediment" and IJC criterion for sediment not polluted by oil and hydrocarbons will not impair *Hexagenia* populations. There will be a graded response to concentrations of metals and oil in sediment exceeding these guidelines for clean sediment. Reductions in phosphorus levels in formerly eutrophic habitats are usually accompanied by recolonisation by *Hexagenia*, if surficial sediments are otherwise uncontaminated.

***Unfinished Business***

Has a quantitative endpoint for *Hexagenia* populations been developed? If not, then further development work is necessary for this indicator.

The method of graphically displaying this indicator needs to be determined. For example, will bar graphs or maps be used to depict trends in walleye and *Hexagenia* populations over time?

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota, fish
Related Issue(s): contaminants & pathogens, nutrients, exotics, habitat
SOLEC Grouping(s): **open waters**, **nearshore waters**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s): Ontario, Erie, Huron
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 6: Degradation of benthos

***Last Revised***
March 2002

# Benthic Amphipod (*Diporeia* spp.) (Indicator ID: 123)

***Measure***
Abundance or biomass, and self-sustainability of *Diporeia* in cold, deepwater habitats of the Great Lakes.

***Purpose***
To show the status and trends in *Diporeia* populations, and to infer the basic structure of coldwater benthic communities and the general health of the ecosystem.

***Ecosystem Objective***
The cold, deepwater regions of the Great Lakes should be maintained as a balanced, stable, and productive oligotrophic ecosystem with *Diporeia* as one of the key organisms in the food chain. Relates to Annex 1 of the GLWQA.

***Endpoint***
In Lake Superior, *Diporeia* should be maintained throughout the lake at abundances of >200/$m^2$ at depths <100m and >30/$m^2$ at depths >100m. In the open waters of the other lakes, *Diporeia* should be maintained at abundances of > 1,000/$m^2$ at depths 30-100m and >200/$m^2$ at depths > 100m. These are conservative density estimates for these depths. Density estimates at depths < 30 m in all the lakes can be highly variable and subject to local conditions. Thus, densities at these shallower depths may not be a good indicator of lake-wide trends.

***Features***
*Diporeia* abundances are measured in assessment programs carried out annually in each lake. Other, more regional assessments occur less frequently. The historical dominance of *Diporeia* in cold, deepwater habitats in all of the Great Lakes provides a good basis for a basin-wide evaluation of ecosystem health..

***Illustration***
For each lake, a figure with *Diporeia* metrics on the y-axis and year on the x-axis will be presented. For less frequent but more spatially-intense regional assessments, a figure giving metric contours or isopleths will be presented.

***Limitations***
The indicator is of greatest value in assessing ecosystem health in the cold, open-water portions of the Great Lakes. It may also be useful when assessing long term trends within a specific lake region in the nearshore (< 30 m), but its value is questionable if widely applied to nearshore areas over all the lakes.. Because this indicator consists of only one taxa, it may not reliably diagnose causes of degraded ecosystem health. A number of lakewide surveys and assessments of benthic invertebrate communities have been made over the past several decades in the Great Lakes and the current status of *Diporeia* populations is generally known, and an understanding of *the* changes related to the Dreissenid mussel invasion is emerging.

***Interpretation***
Target values are provided to evaluate abundances on a historic basis. Trends over time provide a means to assess indicator direction. On a more direct basis, if target values are met, the system can be assumed to be healthy; if the values are not met there is health impairment. Causative agents of impairment are not addressed by the indicator.

***Comments***
*Diporeia* is the dominant benthic macroinvertebrate in the cold, deepwater habitats of all the Great Lakes, comprising over 70% of benthic biomass in these regions. It feeds on material settled from the water column and, in turn, is fed upon by many species of fish. As such, it plays a key role in the food web of deepwater habitats. Among the fish species that are energetically linked to *Diporeia* is the lake trout. Young lake trout feed on *Diporeia* directly, while adult lake trout feed on sculpin, and sculpin feed heavily on *Diporeia*. Lake trout are a top predator in the deepwater habitat and abundances are another SOLEC Indicator. Therefore assessments of both *Diporeia* and lake trout provide an evaluation of lower and upper trophic levels in the cold, deepwater habitat.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota, fish
Related Issue(s): toxics, nutrients, exotics, habitat
SOLEC Grouping(s): open waters
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s): Ontario, Erie, Huron, Michigan, Superior
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 6: Degradation of benthos

***Last Revised***
July 2002

# External Anomaly Prevalence Index for Nearshore Fish

**(Indicator ID: 124)**

***Measure***
An index of external anomalies in nearshore fish that will include the prevalence of external raised lesions and the prevalence of barbel abnormalities for brown bullhead.

***Purpose***
This indicator will assess the combination of external anomalies in nearshore fish that will be used as an estimate of ecosystem health within the Great Lakes.

***Ecosystem Objective***
To restore and protect beneficial uses in Areas of Concern or in open lake waters, including beneficial use (iv) *Fish tumors or other deformities* (GLWQA, Annex 2). This indicator also supports Annex 12 of the GLWQA

***Endpoint***
When the incidence rate of external anomalies does not exceed rates at unimpacted reference sites (IJC Delisting criteria, see IJC 1996)

***Features***
Epizootics outbreaks or elevated frequencies of internal tumors (neoplasms, including cancer) have become more frequent in the past three decades. The neoplasms and have gained profile as indicators of beneficial use impairment of Great Lakes aquatic habitat and also as "early warnings" of potential impact on humans. While some tumors are genetically induced and others are virally induced, there is a substantial body of evidence from field and laboratory studies showing that chemical carcinogens cause neoplasia of the types seen in Great Lakes fishes. Recent research demonstrates that external anomalies might also be useful in assessing beneficial use impairment. The External Anomaly Prevalence index (EAPI) provides useful method of quantitatively comparing external anomalies. Historically, a decline in PAHs in river sediment in a Great Lakes tributary was accompanied with a decline in liver tumors in brown bullhead. Evidence also shows that external anomaly prevalence in fish from Great Lakes tributaries is positively associated with both chemical contaminants in sediment and with genetic damage. Restoration of Great Lakes aquatic habitats polluted with chemical carcinogens is now underway. The success of this restoration may be best demonstrated by using the EAP index for nearshore fish such as brown bullhead or white suckers. This indicator is similar to 4503, but applied to nearshore fish species rather than to coastal wetland species.

***Illustration***
For selected Areas of Concern, a graph will be presented showing the EAPI in brown bullhead over time.

***Limitations***
The indicator is most useful in defining habitats that are heavily polluted and largely occupied by pollution tolerant fishes. Joint U.S.-Canada studies of benthic fishes in a gradient of polluted to pristine Great Lakes habitats using standardized methodology would greatly enhance our knowledge of relation of contaminated harbor sediments and external anomalies and their usefulness as indicators of ecosystem health.

***Interpretation***
Internal tumors are generally believed to be a response to a degraded habitat and toxic exposure to carcinogens, but may also be due to immune suppression and exposure to viral agents. Prevalence of internal tumors should be cross-correlated with location to determine trends. Impairment determinations will be based on a comparison of rates of occurrence of internal tumors or related external anomalies at sites of interest with rates at unimpacted or least-impacted (reference) sites. Impairment is defined by:
1. An internal tumor prevalence of >5% occurs in mature native near-shore species of benthic fishes (e.g., brown bullhead, black bullhead, white sucker, and several species of redhorse).
Tumors are histopathologically verified neoplasms of intestinal, bile duct, or liver cells only.
2. A prevalence of raised growth on lips >10%, or of overall external raised growth on body and lips >15% in any of the mature benthic species listed in 1 above.
3. A prevalence of barbel abnormalities (missing or deformed barbels) of >20% occurs in mature brown or black bullhead.

***Comments***
This indicator was prepared using information from: IJC. 1996. Indicators to evaluate progress under the Great Lakes Water Quality Agreement. Indicators for Evaluation Task Force. ISBN 1-895058-85-3.

***Unfinished Business***
Canadian and US investigators need to combine available pathology data on Great Lakes near-shore benthic species into a single data base. A collaborative study using standardized methodology over a series of locations representing a contamination gradient would further allow the index to be fine tuned and correlated with other aspects of environmental health at Great Lakes Areas of Concern.

***Relevancies***
Indicator Type: state
Environmental Compartment(s): fish

Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): open waters, nearshore waters
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances IJC Desired Outcome(s): 6: Biological community integrity and diversity, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s): Beneficial Use Impairment(s): 4: Fish tumors and other deformities

***Last Revised***
August 5, 2002

# Status of Lake Sturgeon in the Great Lakes (Indicator ID: 125)

***Measure***
Population numbers of lake sturgeon in the Great Lakes and their connecting waterways and Tributaries.

***Purpose***
Presence of lake sturgeon in abundance in the Great Lakes will indicate a healthy ecosystem. When the Great Lakes were still in pristine conditions (prior to European settlement) lake sturgeon were extremely abundant in the lakes. If the condition of the lakes were improved to the point where lake sturgeon numbers were able to increase, it would indicate a healthy improving ecosystem.

***Ecosystem Objective***
Lake sturgeon is identified by all the Great Lakes in their Fish Community Objectives. Lake Superior has a lake sturgeon management plan, many of the Great Lakes States have lake sturgeon recovery/rehabilitation plans which call for increasing numbers of lake sturgeon beyond current levels. Because lake sturgeon are a native species to the Great Lakes efforts should be put forth to restore their numbers.

***Endpoint***
Lake sturgeon populations increase to the point that they can be removed from state threatened or endangered lists.

***Features of the Indicator***
Efforts are underway to determine the number of active spawning sites for lake sturgeon in the Great Lakes. In addition, work is currently being carried out to genetically determine the status of lake sturgeon in the Great Lakes.

***Illustration***
Graphs for each lake will be displayed depicting the spawning locations and the genetic variability of lake sturgeon collected from that lake.

***Limitations***
This is a relatively costly indicator that requires coordination between federal, state, tribal and provincial agencies. The indicator is linked to the overall health of the Great Lakes ecosystem.

***Interpretation***
Variations in spawning periodicity of lake sturgeon and the effect that river flow rates have on spawning could affect annual results and complicate interpretation of long-term trends.

***Comments***
Increasing passage for lake sturgeon at hydroelectric facilities is needed to allow fish access to historic spawning sites. In addition to this, creation of artificial spawning sites might aid the recovery process.

***Unfinished Business***
More information is needed on the current status of lake sturgeon populations. Standardized protocols and continued sampling of existing populations. The largest source of unknown information is related to juvenile lake sturgeon (age 0-2). Considerable research needs to be conducted to determine the habitat preferences and location of this age group of lake sturgeon.

***Relevancies***
Indicator Type:
Environmental Compartment(s):
Related Issue(s):
SOLEC Grouping(s):
GLWQA Annex(es):
IJC Desired Outcome(s):
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
July 16, 2002

# Commercial/Industrial Eco-Efficiency Measures

**(Indicator ID: 3514)**

***Measure***
Proportion of the 25 largest employers in the Great Lakes basin that track and report on eco-efficiency measures (net sales, quantity of goods produced, energy consumption, material consumption, water consumption, greenhouse gas emissions, ozone depleting substances). Data will also be collected on eco-efficiency strategies implemented related to each of the following success factors of eco-efficiency (as developed by the World Business Council on Sustainable Development): material intensity of goods and services, energy intensity of goods and services, toxic dispersion, material recyclability, and sustainable use of renewable resources (material durability).

***Purpose***
To assess the commercial/industrial sector response to pressures imposed on the ecosystem as a result of production processes and service delivery.

***Ecosystem Objective***
To foster healthy, sustainable economic productivity, without compromising environmental and societal health. The first Antwerp Workshop on Eco-efficiency (November, 1993) stated that eco-efficiency is 'reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with the earth's estimated carrying capacity'. Reaching this target is consistent with economic, social and environmental sustainability objectives within the Great Lakes basin.

***Endpoint***
100% of the 25 largest employers report publicly on eco-efficiency measures and 100% of the 25 largest employers in the basin have implemented specific eco-efficiency strategies to:

1) reduce the material intensity of goods and services,
2) reduce the energy intensity of goods and services,
3) reduce toxic dispersion,
4) enhance material recyclability; and,
5) maximize sustainable use of renewable resources.

***Features***
Eco-efficiency is founded in the sustainable development principle of integration of economic growth and environmental improvement. Activities associated with eco-efficiency not only reduce stress on the ecosystem, but also emphasize value creation for a stronger economy; the vision of eco-efficiency is to 'produce more from less'. This indicator has the benefit of capturing a wide range of activities that make goods and services production more sustainable. It has the additional feature of being applicable to all economic sectors. By tracking commercial and industrial eco-efficiency activities, it is possible to assess the level to which corporate behavior supports a sustainable Great Lakes ecosystem.

***Illustration***
This indicator will be displayed as a table of the proportion of the 25 largest employers in the basin that measure eco-efficiency and have adopted eco-efficiency strategies.

***Limitations***
There is no single data source for eco-efficiency activities within the basin and, therefore, it is necessary to limit the number of organizations surveyed. The 25 largest employers were selected as industry leaders and proxy for assessing commercial/industrial eco-efficiency measures. This indicator should not be considered a comprehensive evaluation of all the activities of the commercial/industrial sector, particularly small-scale organizations. Typically, eco-efficiency activities are more widely applied by larger organizations and require longer time scales before they are widely adopted by smaller-scale operations.

***Interpretation***
This indicator can be used to monitor progress toward more responsible goods and services production and a stronger, more sustainable Great Lakes economy.

***Comments***
The World Business Council for Sustainable Development and the World Resources Institute produce extensive resources related to eco-efficiency. Trade organizations are also a good data source. Employer lists are available from local chambers of commerce and InfoUSA, Omaha, Nebraska.

***Relevancies***
Indicator type: response
Environmental Compartment: cross-cutting
Related issues: waste generation, energy use, water use, vehicle use
SOLEC Groupings: societal responsibility – commercial industrial
GLWQA Annex(es): 3: Phosphorus, 6: Shipping/Pollution, 8: Facilities Discharges, 10: Hazardous Polluting Substances, 12: Persistent toxic substances, 14: Contaminated sediments, 15: Airborne toxic substances, 11: Monitoring

IJC Desired Outcome(s): All
GLFC Objectives:
Beneficial Use Impairment(s): All

***Last Revised***
July 15, 2002

# Household Stormwater Recycling (Indicator ID: 3516)

***Measure***
Number of households participating in municipal stormwater recycling programs such as rain barrel, green roof and downspout disconnect programs. A complementary measure is the number of household stormwater recycling programs provided by local government.

***Purpose***
To assess the level of public awareness and concern for the environmental consequences of stormwater runoff.

***Ecosystem Objective***
To reduce the pressures induced on the ecosystem as a result of stormwater surges and urban runoff to rivers and lakes within the ecosystem.

***Endpoint***
Thirty percent (or greater) of households participating in stormwater recycling programs in all municipalities within the Great Lakes ecosystem.

***Features***
Stormwater runoff has a significant impact on the water quality of streams, rivers and lakes in the Great Lakes ecosystem. Ecosystem consequences of stormwater run off include increased erosion and flooding, and higher concentrations of contaminants and bacteria. The impact of stormwater in urban areas served by combined sewers is especially significant, due to the effects of combined sewer overflows. This indicator presents trends in community participation in municipal stormwater recycling programs, which reduce the pressure that stormwater runoff has on the ecosystem. Households alone cannot resolve the issues that arise from stormwater runoff; however, this indictor recognizes the significant role that the community plays in stormwater management. By monitoring municipal programs, information is also obtained about the extent of municipal stormwater recycling programs in the basin.

***Illustration***
This indicator will be displayed as a graphic of base-year participation in household stormwater recycling programs to current participation rates. Comparison tables of participation rates and number of municipal stormwater recycling programs amongst urban centers in the Great Lakes region may also be included.

***Limitations***
By focusing on municipal programs, this indicator will not measure stormwater recycling efforts conducted outside municipal programs. While information is widely available, there is no aggregated data source for household stormwater recycling. This indicator is most relevant to households of single-family homes, since many households in multi-family buildings would have limited ability to recycle stormwater.

***Interpretation***
As the number of stormwater recycling programs increase and more households participate, the ecosystem stress caused by stormwater will decrease. Increasing participation rates indicate a wider public awareness and support for reducing stormwater impacts on the Great Lakes ecosystem.

***Comments***
Descriptions of municipal stormwater management programs are widely available on municipal websites. Expansion of this indicator could also examine greywater recycling efforts, though data in this area are very limited.

***Unfinished Business***

***Relevancies***
Indicator type: response
Environmental Compartment: water
Related issues: water quality, human health, contaminants, water use, land use
SOLEC Groupings: societal response – household/community
GLWQA Annex(es): 2: LaMPs/RAPs/BUIs, 12: Persistent toxic substances, 13: Non-point sources, 17: Res. & Devel.
IJC Desired Outcome(s): 1: Fishability, 2: Swimmability, 3: Drinkability, 4: Healthy Humans, 6: Biological Integrity and Diversity, 7: Virt. Elim. PTS
GLFC Objectives:
Beneficial Use Impairment(s): 1: F&W Consumption, 9: Drinking Water, 10: Beach Closings, 11: Aesthetics

***Last Revised***
July 17, 2002

# Drinking Water Quality (Indicator ID: 4175)

***Measure***
The number and proportion of drinking water systems that fail to meet water quality regulations and take measurements of the Safe Drinking Water Act, Maximum Contaminant Levels, Contaminant Candidate List, and contaminants monitored under state regulations and guidelines by type of water supply.

***Purpose***
To assess the chemical and microbial contaminant levels in drinking water, and to evaluate the potential for human exposure to drinking water contaminants and the efficacy of policies and technologies to ensure safe drinking water.

***Ecosystem Objective***
Treated drinking water supplies should be safe to drink. This indicator supports Annexes 1, 2, 12 and 16 of the GLWQA.

***Endpoint***
Densities of disease-causing organisms or concentrations of hazardous or toxic chemicals or radioactive substances should not exceed human health objectives, standards, or guidelines.

***Features***
This indicator would reveal trends in contaminant levels in raw, treated and distributed water in various locations throughout the basin. Through existing water monitoring programs, which analyse raw, treated and distributed waters, results can be compared against established water quality objectives. This evaluation applies to water supply systems that draw water from either surface water or groundwater sources. Data on temporal trends, such as seasonal differences or changes over time, in chemical or microbial contaminant concentrations for specific locations could be identified.

***Illustration***
For selected locations in the Great Lakes basin, simple bar or line graphs would display the average concentration of contaminants in raw, treated and distributed water. The data could also be displayed in a GIS format that would allow for a variety of endpoint analyses to be displayed as an overlay on maps of the entire Great Lakes basin or more local areas.

***Limitations***
Most contaminants in drinking water rarely exceed guidelines and many are below their analytical detection limit. Since the absolute concentration of some contaminants may not be determinable, it is difficult to show fluctuations in their concentration levels.

***Interpretation***
Existing monitoring programs at drinking water treatment plants analyze for chemical and microbial contaminants in raw, treated and distributed waters. Results can be compared against established water quality guidelines and objectives. The data could be supplemented with additional information showing relationships between contaminant levels and human health risks; for example, the association between long-term exposure to chlorination disinfection by-products in drinking water and the increased risk of bladder and colon cancers.

***Comments***

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water
Related Issue(s): contaminants & pathogens, nutrients
SOLEC Grouping(s): open waters, nearshore waters, **human health**
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances, 16: Pollution from contaminated groundwater
IJC Desired Outcome(s): 3: Drinkability, 4: Healthy human populations
GLFC Objective(s):
Beneficial Use Impairment(s): 9: Restrictions on drinking water consumption or taste and odor problems

***Last Revised***
Apr. 14, 2004

# Biologic Markers of Human Exposure to Persistent Chemicals
## (Indicator ID: 4177)

***Measure***
Serum concentration level (95$^{th}$ percentile) for polychlorinated biphenyls (PCB), dioxins, and furans.

***Purpose***
To assess the serum concentration level (95$^{th}$ percentile) for polychlorinated biphenyls (PCB), dioxins, furans in human tissues, and to infer the efficacy of policies and technology to reduce these persistent bioaccumulating toxic chemicals in the Great Lakes ecosystem.

***Ecosystem Objective***
This indicator supports Annexes 1, 12 and 17 of the GLWQA.

***Endpoint***
Continued reduction of PBT chemical concentrations in human tissue. Where serum concentrations of PBT chemicals are detected, they should be maintained below health guidance levels.

***Features***
This indicator will monitor the serum concentration of PCBs, dioxins, and furans in human tissues (both general and at-risk populations) to establish geographic patterns and trends over time, providing an estimate of both past and current chemical exposures.

***Illustration***
Data will be displayed as bar graphs showing PBT chemical serum concentrations over time to highlight trends and in GIS format to illustrate geographic patterns in body burden levels.

***Limitations***
This indicator requires extensive sampling of human populations, as well as standardized tissue collection and chemical analysis methods for use by participating laboratories. A detailed history of the sample population, including diet, lifestyle, and occupation, is necessary to characterize the history of exposure.

***Interpretation***
The long persistence of PBT chemicals in the body would indicate that there is a relatively long time period between reductions in exposure and subsequent reductions in tissue levels. However, trends that demonstrate a decrease in the concentration of PBT chemicals in human tissue, to levels below health guidance levels, would be a positive indication that the human health risks posed by exposure to environmental contaminants are being reduced. Tissue levels above health guidance values are a concern for human health.

***Comments***
The body burdens of some PBT chemicals in at-risk populations around the Great Lakes and St. Lawrence basins can be 2 to 4 times greater than the general population.

Ref. Johnson et al., 1998. Public Health Implications of Persistent Toxic Substances in the Great Lakes and St. Lawrence Basins. J. Great Lakes Res. 24(2):698-722.

Health Canada, 1998. Health-Related Indicators for the Great Lakes Basin Population: Numbers 1 to 20. Minister of Public Works and Government Services Canada.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): humans
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **human health**
GLWQA Annex(es): 1: Specific objectives, 11: Surveillance and monitoring, 12: Persistent toxic substances, 17: Research and development
IJC Desired Outcome(s): 4: Healthy human populations, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
February 27, 2004

# Geographic Patterns and Trends in Disease Incidence
## (Indicator ID: 4179)

***Measure***
Disease incidence rate (rate = number of new cases of specific disease/ size of population) for those diseases that have a demonstrated environmental link, such as cancers and birth defects, in the Great Lakes basin.

***Purpose***
To assess geographic and temporal patterns in disease incidences in the Great Lakes basin population, and to identify areas where further investigation of the exposure and effects of environmental pollutants on human health is needed.

***Ecosystem Objective***
This indicator relates to Annex 17 of the GLWQA.

***Endpoint***
Disease incidence rates should decrease over time. Environmental pollutants should be minimized as health risk factors.

***Features***
This indicator provides geographical and temporal patterns of disease incidence, such as cancer and birth defects, throughout the Great Lakes basin. Although cause and effect relationships cannot be established from this indicator, it is useful for identifying areas that may require investigation.

***Illustration***
This indicator is represented by maps of the Great Lakes basin illustrating the distribution of disease incidences, such as cancers and birth defects, in Ontario. In addition, a graph will show trends in the incidences of diseases over time.

***Limitations***
The accuracy of this indicator depends on the availability and quality of hospital records and continuing improvements of registry databases. Cause and effect relationships between environmental conditions and disease incidence rates cannot be established from this indicator. The explanation of disease incidence rates, such as cancer and birth defects, in any area requires more extensive epidemiological research to assess the relative importance of various factors, including diet, lifestyle, occupation, and exposure to environmental contaminants.

***Interpretation***
Although cause and effect relationships between environmental contaminants and disease cannot be established from this indicator, it is useful for identifying areas which require investigation. Additional evaluation will be required to refine the analysis to specific cancers and birth defects that are most likely to be related to environmentally related. This indicator may also allow for the development of new hypotheses regarding the role of environmental exposure in the etiology of human disease.

***Comments***
This indicator could be expanded in the future to include biomonitors of exposure, biomarkers of pre-disease conditions, endocrine disruption, and low birth weight.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): humans
Related Issue(s):
SOLEC Grouping(s): **human health**
GLWQA Annex(es): 17: Research and development
IJC Desired Outcome(s): 4: Healthy human populations
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 24, 2000

# Beach Advisories, Postings and Closures (Indicator ID: 4200)

***Measure***
**Assess the number of health-related swimming advisory and beach closure and posting days for freshwater recreational areas (beaches) in the Great Lakes Basin. A health-related advisory, closure day or posting day is one that is based upon elevated levels of E. coli, or other indicator organisms, as reported by county or municipal health departments in the Great Lakes Basin.**

***Purpose***
**To infer potential harm from pathogens to human health through body contact with nearshore recreational waters.**

***Ecosystem Objective***
**Waters should be safe for recreational use. Waters used for recreational activities involving body contact should be substantially free from pathogens, including bacteria, parasites, and viruses, that may harm human health. This indicator supports Annexes 1, 2 and 13 of the GLWQA.**

***Endpoint***
**90% of Great Lakes beaches of high priority (or high use) to the county or province should meet bacteria standards 95% of the swimming season.**

***Features***
In order to be considered safe for use, recreational water quality must be substantially free from microbial contamination. Recreational waters may become contaminated with animal and human feces from sources and conditions such as combined sewer overflows that occur in certain areas after heavy rains, storm water run-off, and malfunctioning septic systems. This indicator will track the number of health-related swimming advisories and beach closure and posting days at freshwater recreational areas and across geographic locations throughout the basin. Analysis of data may show seasonal and local trends in nearshore recreational waters. The trends provided by this indicator may aid in beach management and in the prediction of episodes of poor water quality.

***Illustration***
For each site selected throughout the basin, a graph will be presented showing the proportion of Great Lakes beaches that have closures based on contaminant counts above acceptable standards over several years. Statistical analysis will be used to examine the temporal and spatial trends in water quality in recreational beach areas. Data will be presented as a graph or as a map showing the number of beach closings over time.

***Limitations***
Variability in the data from year to year may result from the process of monitoring and variations in reporting, and may not be solely attributable to actual increases or decreases in levels of microbial contaminants. In addition, variability of weather from year to year may also affect the variability in bacterial counts. Viruses and parasites, although a concern in recreational waters, are difficult to isolate and quantify at present, and feasible measurement techniques have yet to be developed. Although considered a reliable indicator of potential harm to human health, the presence of *E. coli* and enterococci may not necessarily be related to fecal contamination. Comparisons of the frequency of beach closings will be limited due to use of different water quality criteria and standards, between different municipalities as well as between Canada and the United States. This difference in reporting structure and criteria poses challenges when attempting to establish a basin wide trend.

***Interpretation***
This indicator will rely on national, state/provincial advisory, closure or posting data as a benchmark. Trends that demonstrate an increase in advisory, closure or posting days related to health events over time, and above the appropriate standard, will be considered negative, or bad, trends. Trends that demonstrate a decrease in closure and posting days related to health events over time, and below the appropriate standard, will be considered positive, or good, trends.

***Comments***
Analysis of data shows seasonal and local trends in recreational water. Episodes of poor recreational water quality have been associated with specific events (such as rainfall), and forecasting for episodes of poor water quality is being used.

This indicator was modified from #4081, *E. coli and Fecal Coliform Levels in Nearshore Recreational Waters*.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water, biota
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): nearshore waters, **human health**
***GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources***
IJC Desired Outcome(s): 2: Swimmability, 4: Healthy human populations
GLFC Objective(s):

Beneficial Use Impairment(s): 10: Recreational water impairment

***Last Revised***
**June 17, 2004.**

# Contaminants in Sport Fish (Indicator ID: 4201)

***Measure***
Levels of mercury, dioxin, and PCBs targeted by the GLWQA in edible fish tissue.

***Purpose***
To assess the level of mercury, dioxin, and PCBs in Great Lakes sport and commercial fish, and to infer the potential harm to human health through consumption of contaminated fish.

***Ecosystem Objective***
Fish in the Great Lakes ecosystem should be safe to eat; consumption should not be limited by contaminants of human origin. This indicator supports Annexes 1, 2 and 12 of the GLWQA.

***Endpoint***
Reduction in the levels of mercury, dioxin, and PCBs in sport and commercial fish tissue to levels that do not pose a risk to populations consuming Great Lakes fish. The elimination of fish advisories in the Great Lakes may be considered to be an appropriate endpoint.

***Features***
The temporal and geographic trends in the chemical contaminant levels in fish species consumed by human populations in the Great Lakes basin will be used as an indicator of exposure to mercury, dioxin, and PCBs. Levels of contaminants in fish should be determined from a 5 fish composite made up of boneless, skin-on fillets of dorsal muscle flesh removed from the fish. This would provide not only the most consistent test results, but is also the most edible portion of the fish. Choosing appropriate indicator species is crucial and should be based on fish consumption patterns and availability of data. Additional chemicals can be considered as new information arises. The indicator will allow regulatory agencies to make suggestions regarding remedial planning as well as issuing advisories to the public on safe consumption limits.

***Illustration***
Results of raw data will be used to construct simple bar graphs showing the fluctuation of contaminants over time and space.

***Limitations***
Data for use in developing indicators exist, however, there are differences in surveillance techniques for fish consumption and differences in tissue sampling methods between jurisdictions.

***Interpretation***
Reductions in contaminant levels in fish tissue will reflect an improvement in environmental quality and the potential for reduced exposure to contaminants from consumption of Great Lakes fish.

***Comments***

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): fish
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): open waters, nearshore waters, **human health**
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances
IJC Desired Outcome(s): 1: Fishability, 4: Healthy human populations, 6: Biological community integrity and diversity, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s): Ontario, Erie, Huron, Michigan, Superior
Beneficial Use Impairment(s): 1: Restrictions on fish and wildlife consumption

***Last Revised***
Feb. 26, 2004

# Air Quality (Indicator ID: 4202)

***Measure***
Tons of criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide ($NO_2$), ozone ($O_3$), $PM_{10}$, sulphur dioxide ($SO_2$) released into ambient air annually and annual high levels of criteria pollutants.

***Purpose***
To monitor the air quality in the Great Lakes ecosystem, and to infer the potential impact of air quality on human health in the Great Lakes basin.

***Ecosystem Objective***
Air should be safe to breathe. Air quality in the Great Lakes ecosystem should be protected in areas where it is relatively good, and improved in areas where it is degraded. This is consistent with ecosystem objectives statements being adopted by certain lakewide management plans, including Lake Superior, (Ecosystem Principles and Objectives, Indicators and Targets for Lake Superior, Lake Superior Binational Program, 1995), in fulfilment of Annex 2 of the Great Lakes Water Quality Agreement. This indicator also supports Annexes 1, 13 and 15.

***Endpoint***
Canadian and U.S. air quality standards.

***Features***
The Great Lakes basin experiences high levels of certain air pollutants due to both local sources and long range transport. Studies conducted in the Great Lakes region have provided strong evidence linking ground-level ozone and sulphates to increased rates of hospital admissions for cardiorespiratory disease and to increased death rates. Pollutants that can be used to assess overall air quality include $SO_2$, CO, $O_3$, $NO_2$, $PM_{10}$ and Pb. Other air pollutants and toxics such as benzene, formaldehyde, and ethylene dichloride, can also be used to assess air quality and can be added as new information becomes available. This indicator can use information from existing air monitoring databases.

***Illustration***
Using a GIS mapping display, trends in pollutant levels over several years for each pollutant in a particular region or over the entire Great Lakes basin data could be presented. Data could also be displayed as the annual high levels of criteria pollutants and measure the tons of those pollutants released into the ambient air.

***Limitations***
Although indoor air is a major contributor to exposure to air toxics, there is no practical way to consistently monitor indoor air quality. Therefore, this component to the estimate of total exposure to airborne contaminants will not be included in this indicator.

***Interpretation***
Interpretation of the indicator would be made by identifying trends in the levels of air contaminants over time in comparison to guideline levels.

***Comments***
A significant association is found between atmospheric ozone and sulphate levels and the number of daily hospital admissions for respiratory conditions. Five percent of daily respiratory admissions in the months of May to August can be attributed to ozone, and an additional 1% to sulphates. This finding is consistent among all age groups. The largest impact appears to be on children under 2 years of age, in whom 15% of respiratory hospital admissions are attributed to ozone and sulphate together, while the elderly are least affected (4%). There does not appear to be a level of ozone below which no adverse respiratory health effects are observed.

For both respiratory and cardiac illnesses, the average daily hospitalization rates increase with increasing levels of sulphates. A 13 $ug/m^3$ increase in sulphates recorded on the previous day is associated with a 3.7% increase in respiratory admissions and a 2.8% increase in cardiac admissions. Admissions for cardiac diseases increases 2.5% for those under 65 years and 3.5% for those 65 years and older.

Some air pollution emissions can be prevented through better pollution prevention or by changing the demand for certain products and services that contribute to air pollution. Therefore, this indicator can additionally measure progress on sustainable development by determining the degree to which resources are wasted as pollution, thereby representing inefficiency in human economic activity.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): air
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **human health**
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources, 15: Airborne toxic substances
IJC Desired Outcome(s): 4: Healthy human populations

GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 27, 2004

# Coastal Wetland Invertebrate Community Health

**(Indicator ID: 4501)**

***Measure***
An Index of Biotic Integrity (IBI) was developed. The IBI utilizes relative abundance of sensitive taxa (e.g., mayflies, caddisflies, dragon and damselflies), richness of specific taxa, and other measures that could distinguish between reference and impacted systems.

***Purpose***
To directly measure specific components of invertebrate community composition and use these as a surrogate for the chemical, physical and biological integrity and range of degradation of Great Lakes coastal wetlands.

***Ecosystem Objective***
To measure and evaluate, both spatially and temporally, the chemical, physical, and biological integrity of Great Lakes coastal wetlands (GLWQA Annexes 2, 11 and 13; IJC Desired Outcomes 6 and 9) to restore and maintain the functional and structural role that these systems play in Great Lakes ecology.

***Endpoint***
The endpoint for this indicator was established by using reference systems located by Lake, ecoregion, wetland type and vegetation type. The protocols for the IBI were designed to remove natural variability due to water levels and fetch.

***Features***
To restore/maintain the overall biological integrity of Great Lakes coastal wetlands, various ecological components need to be adequately represented. The invertebrate IBI not only provides information on overall wetland integrity, but also the invertebrate community specifically . The IBI was developed from a composite of specific parameters, termed "metrics" These metrics describe aspects of the invertebrate community directly.. The IBI provides a rigorous approach that quantifies the condition of the invertebrate community of the Great Lakes coastal wetlands. These data are based on data from relatively undisturbed wetlands representative of Great Lakes ecosystems. Metric scores are based on how similar they are to the reference condition, or the best case scenario for this day and age. The IBI also provides a narrative characterization that provides a measure of the environmental condition and is calibrated for regional use. The cost of monitoring for this indicator may be reduced because monitoring may be conducted in conjunction with monitoring for other indicators.

***Illustration***
For representative coastal wetlands, the IBI would be displayed on a map of each Lake or the basin. In addition, the invertebrate IBI score can be plotted based on a given shoreline distance to reflect patterns in Lake quality. Color-coded symbols could be used to reflect site scores for each representative Great Lakes coastal wetland. As sufficient IBI data becomes available, graphs showing trends over time would be included. A narrative explanation and analysis would also be critical to reporting on this indicator so that an understanding of driving characteristics could be gained.

***Limitations***
The invertebrate IBI was developed for coastal wetlands that are directly connected to the Great Lakes. Another system is currently being developed for those wetlands that are only connected hydrologically via groundwater. Until the IBI is developed and tested for adequacy, the metrics to be used in for those that are connected via surface water will be monitored with the intent that the IBI can be calculated in the future using previously collected monitoring data.

***Interpretation***
This indicator would be evaluated as part of an overall analysis of biological communities of Great Lakes coastal wetlands.

***Comments***
***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): habitat
SOLEC Grouping(s): coastal wetlands
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations

***Last Revised***
May 25, 2004

# Coastal Wetland Fish Community Health (Indicator ID: 4502)

***Measure***
A preliminary Index of Biotic Integrity (IBI) was developed based on measures of richness and abundance, percent exotic species, functional feeding groups, and other species-level parameters.

***Purpose***
To assess the fish community composition , and to infer suitability of habitat and water quality for Great Lakes coastal wetland fish communities.

***Ecosystem Objective***
Restore and maintain the diversity of the fish community of Great Lakes coastal wetlands while indicating overall ecosystem health. (GLWQA Annexes 2 and 13)

***Endpoint***
An endpoint for this indicator was established based on fish communities of reference systems. Data were evaluated for patterns by lake, ecoregion, wetland type, and vegetation zone.

***Features***
The IBI provides a rigorous approach to quantify the biological condition of fish communities within the Great Lakes. It is based on reference conditions and is developed from a composite of specific measures used to describe fish community, structure, function, individual health, and abundance. Specific parameters, termed "metrics," are scored based on how similar they are to the reference condition. The IBI will also provide a narrative characterization that provides a measure of the environmental condition and will be calibrated for regional use.

***Illustration***
For representative coastal wetlands, the IBI would be displayed on a map of each Lake or the basin. In addition, the IBI score can be plotted based on a given shoreline distance to reflect patterns in Lake quality. Color-coded symbols could be used to reflect site scores for each representative Great Lake coastal wetland. As sufficient IBI data becomes available, graphs showing trends over time would be included. A narrative explanation and analysis would also be critical to reporting on this indicator.

***Limitations***
Until the IBI is thoroughly tested, the metrics used in developing the IBI will be monitored with the intent that the IBI can be calculated in the future using previously collected monitoring data.

***Interpretation***
This indicator will be evaluated as part of an overall analysis of biological communities of Great Lakes coastal wetlands and nearshore aquatic systems.

***Last Revised***
June 21, 2004

# Coastal Wetland Amphibian Diversity and Abundance

## (Indicator ID: 4504)

***Measure***
Species composition and relative occurrence of calling frogs and toads, based on evening surveys using protocols developed for the Marsh Monitoring Program (MMP) or modification of the MMP protocol.

***Purpose***
To directly measure species composition and occurrence of frogs and toads, and to infer condition of coastal and inland wetland habitat as it relates to factors that influence the biological condition of this ecologically and culturally important component of wetland biotic communities.

***Ecosystem Objective***
To restore and maintain diversity and self-sustaining populations of Great Lakes coastal and inland wetland amphibian communities. Breeding populations of amphibian species across their historical range should be sufficient to ensure population maintenance of each species and overall species diversity. (GLWQA Annex 13).

***Endpoint***
Endpoints should be established based on current data available from pristine or near pristine wetland habitats that occur in the Great Lakes basin, and such endpoints should be supported by information gathered from a literature search of available current and historical data. Data regarding amphibian diversity and occurrence would be evaluated for patterns by lake, wetland type, and ecoregion, and then calibrated against ecosystem objectives, and against monitoring objectives based on professional judgement of those with field monitoring expertise.

***Features***
To restore/maintain the overall biological integrity of Great Lakes coastal and inland wetlands, various ecological components need to be addressed. This indicator tracks trends in Great Lakes coastal and inland wetland amphibian diversity and occurrence over time, and efforts will be made to develop indices of biotic integrity (IBIs) using data for this indicator to measure relative biotic condition of coastal wetland habitats.

***Illustration***
For representative coastal and inland wetlands in each of the lake basins, species richness and measures of occurrence are graphically displayed. As annual data accumulate, graphs showing trends in occurrence through time are presented. As development of IBIs progresses, information available for using this indicator to biomonitor condition of coastal wetland habitats could be displayed. A narrative explanation of these results will be critical to reporting on this indicator.

***Limitations***
This indicator focuses on anurans (frogs and toads) because they are readily censused aurally by volunteer observers. Other amphibians, such as salamanders, are not censused at all by these monitoring protocols. However, monitoring results for those species surveyed may provide an indication of habitat suitability for other amphibians that are dependent on coastal wetlands. The relationships among calling codes recorded during surveys, anuran chorus size, and local population size and dynamics requires further study. This validation work is necessary for extrapolations of call code survey data to population size estimates.

***Interpretation***
Amphibian populations naturally fluctuate through time; therefore, this indicator would be evaluated as part of an overall analysis of biological communities of Great Lakes coastal wetlands. Many amphibian species are associated with wetlands for only a portion of their life cycle. Periodically, more rigorous studies may be needed at some sites to relate annual occurrence indices and their temporal trends to environmental factors. Adequate upland areas adjacent to coastal wetlands are important to amphibians, and so measures of suitable, adjacent upland areas also need to be considered when assessing anuran population trends. Interpretation of this indicator will be most effective if coupled with patterns observed in other indicators (e.g., Indicator #4501, Invertebrate Community Health; Indicator #4507, Wetland-Dependent Bird Diversity and Abundance; Indicator #4510, Wetland Area by Type). Many anuran species use aquatic and terrestrial habitats during their life cycle. Temporal trends in occurrence of local anuran populations can be influenced by factors external to breeding wetlands, such as surrounding upland habitat condition or local land uses. These are important considerations for efforts to develop a wetland amphibian IBI for monitoring coastal wetland biotic condition.

***Comments***
Properly trained volunteer and professional participants currently conduct monitoring for this indicator, and all data are subject to a stringent quality assurance program. Additional coastal wetlands are monitored as volunteer participants become available. Available data on historical and current presence/abundance should be collected to supplement monitoring data. Anuran monitoring programs and/or protocols other than the MMP exist, however they do not specifically focus on coastal wetlands.

Protocol testing and evaluation of this indicator has been applied to a selected set of representative wetlands for certain coastal reaches of the Great Lakes through the Great Lakes Coastal Wetland Consortium and Great Lakes Environmental Indicators projects.

Any amphibian deformities observed should be noted and shared with the appropriate jurisdictional representatives responsible for monitoring effects of environmental contamination on wildlife.

***Unfinished Business***
Work is currently underway to use data collected for this indicator to seek viable metrics for developing and index of biotic integrity for rapidly monitoring condition of discrete Great Lakes coastal wetland sites. In calculating annual indices of wetland dependent anuran species occurrence, there is a need to estimate and account for variation resulting from detection probabilities that are virtually always lower than 100 percent. Habitat associations of wetland dependent anurans and landscape level factors that influence anuran occupancy and population dynamics are important questions that require further investigation.

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota
SOLEC Grouping(s): coastal wetlands
GLWQA Annex(es): 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s) 3: Degraded fish and wildlife populations, 14: Loss of fish and wildlife habitat

***Last Revised***
July 15, 2004

# Contaminants in Snapping Turtle Eggs (Indicator ID: 4506)

***Measure***
Concentrations of organochlorine chemicals and mercury in snapping turtle eggs.

***Purpose***
To assess the accumulation of organochlorine chemicals and mercury in snapping turtle eggs, and to infer the extent of organochlorine chemicals and mercury in food webs of Great Lakes coastal wetlands.

***Ecosystem Objective***
Snapping turtle populations in Great Lakes coastal wetlands and populations observed at contaminated sites should not exhibit significant differences in concentrations of organochlorine chemicals and mercury compared to a clean inland reference site, such as Algonquin Provincial Park, Ontario. Subsequently, this lack of difference in contaminant concentrations should ensure normal hatching success and low abnormality rates (GLWQA Annexes 1, 12 and 13).

***Endpoint***
Chemical levels, biological and reproductive measures (exact measures to be confirmed) in Snapping Turtles are not different from those turtles from reference sites away from the Great Lakes, e.g. inland sites from Ontario, Atlantic Canada or the Prairies.

***Features***
Snapping turtles are long-lived, top predators that bioaccumulate contaminants. Their sedentary nature means that their contaminant burdens reflect local sources of contaminants, although not necessarily a specific industry. The embryonic, physiological, and sexual development of snapping turtles appear to be sensitive to organochlorine chemicals. Given these characteristics, the snapping turtle is useful in monitoring trends in contaminants levels within specific wetlands. Variations in diet among snapping turtle populations can influence the degree of contamination in the population. In areas where fish are the primary source of food, snapping turtles are more likely to bioaccumulate greater concentrations of persistant contaminants.

***Illustration***
Mean concentration of organochlorine chemicals and mercury at the uncontaminated reference site (e.g., Algonquin Provincial Park) superimposed over concentrations from representative sites from the Lakes and connecting channels. This would be presented as a bar graph showing sites and concentrations, along with the mean concentration for the reference site as a comparison.

***Limitations***
This indicator requires labor-intensive sampling to collect eggs (2 weeks in June) and expensive analyses (as with any species requiring such chemical analyses). The monitoring for this indicator, as with any biotic indicator, focuses only on bio-accumulative chemicals, and therefore does not illustrate trends in non-bioaccumulative contaminants that may be present in Great Lakes coastal wetlands.

***Interpretation***
Contamination levels observed in snapping turtles at reference sites, and other sites throughout the Great Lakes, would provide the context needed to interpret this indicator.

***Comments***
This indicator would apply to a selected set of representative wetlands for each of the coastal reaches of the Great Lakes. The SOLEC '98 Biodiversity Investment Areas paper on Coastal Wetland Ecosystems identifies the ecoreaches from which representative wetlands will be selected.

The concentrations provided as endpoints for this indicator serve as tentative concentrations which should not be exceeded to ensure that the hatching success and hatchling deformity rates do not significantly exceed those at the examined inland, non-contaminated reference sites.

The mean wet weight concentration in snapping turtle eggs provided as endpoints are concentrations found in eggs from Big Creek Marsh, Lake Erie which showed no significant difference in hatching rates and deformity rates as compared to Lake Sasajewun, Algonquin Provincial Park, an inland lake in Ontario.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): biota
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): coastal wetlands
GLWQA Annex(es): 1: Specific objectives, 11: Surveillance and monitoring, 12: Persistent toxic substances, 13: Pollution from non-point sources
IJC Desired Outcome(s): 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):

Beneficial Use Impairment(s):

***Last Revised***
July 19, 2004

# Wetland-Dependent Bird Diversity and Abundance

## (Indicator ID: 4507)

***Measure***
Species composition and relative abundance of wetland-dependent birds, based on evening surveys using protocol developed for Marsh Monitoring Program (MMP) or modification of the MMP protocol.

***Purpose***
To assess wetland-dependent bird species composition and relative abundance, and to infer condition of coastal and inland wetland habitat as it relates to factors that influence the biological condition of this ecologically and culturally important component of wetland biotic communities.

***Ecosystem Objective***
To restore and maintain diversity and self-sustaining populations of Great Lakes coastal and inland wetland bird communities. Breeding populations of bird species across their historical range should be sufficient to ensure population maintenance of each species and overall species diversity (GLWQA Annex 2).

***Endpoint***
Endpoints should be established based on current data available from pristine or near pristine wetland habitats that occur in the Great Lakes basin, and such endpoints should be supported by information gathered from a literature search of available current and historical data. Data regarding wetland-dependent bird diversity and abundance would be evaluated for patterns by lake, wetland type, and ecoregion, and then calibrated against ecosystem objectives, and against monitoring objectives based on professional judgement of those with field monitoring expertise.

***Features***
To restore/maintain the overall biological integrity of Great Lakes coastal and inland wetlands, various ecological components need to be addressed. This indicator tracks trends in Great Lakes coastal and inland wetland-dependent bird diversity and relative abundance over time, and efforts will be made to develop indices of biotic integrity (IBIs) using data for this indicator to measure relative biotic condition of coastal wetland habitats.

***Illustration***
For representative coastal and inland wetlands in each of the lake basins, species richness and measures of relative abundance are graphically displayed. As annual data accumulate, graphs showing trends in relative abundance through time are presented. As development of IBIs progresses, information available for using this indicator to biomonitor condition of coastal wetland habitats could be displayed. A narrative explanation of these results will be critical to reporting on this indicator.

***Limitations***
A rigorously tested index of the relations between wetland-dependent bird community composition and factors that affect biotic condition of wetland habitats (i.e., IBIs) is a preferable approach to community-based indicators, but wetland-dependent bird IBIs have not yet been developed for Great Lakes coastal wetlands. However, work is currently underway to develop a wetland-bird IBI for monitoring coastal wetland habitat condition. The IBI should be able to take advantage of the information on species occurrence and relative abundance currently collected through the MMP.

***Interpretation***
Both regional and local bird populations naturally fluctuate over time; therefore, several years of monitoring data are required to detect all but the most dramatic trends. Interpretation of this indicator will be most effective if coupled with patterns observed in other indicators (e.g., Indicator #4501, Invertebrate Community Health; Indicator #4504, Amphibian Diversity and Occurrence; Indicator #4510, Wetland Area by Type). Wetland birds are highly mobile and most are dependent on wetlands for only part of their life cycle. Temporal trends in local bird populations can be influenced by factors external to breeding wetlands, those at wintering grounds, during migration, or non-wetland areas at breeding grounds. For this reason, intensive work is required to identify site- and region-specific impacts to bird breeding productivity and survivorship. These intensive studies are particularly important for informing efforts to develop a wetland-dependent bird IBI for monitoring coastal wetland biotic condition.

***Comments***
Properly trained volunteer and professional survey participants currently conduct monitoring for this indicator, and all data are subject to a stringent quality assurance program. This indicator applies most directly to the selected representative wetland sites, but could complement other existing wetland monitoring efforts in both coastal and inland sites in the Great Lakes basin. Wetland birds are important culturally and ecologically. Monitoring wetland-dependent bird species of conservation concern (e.g., Black Tern, Least Bittern, King Rail) should receive special attention during protocol development. Additional coastal and inland wetlands are monitored as volunteer participants become available. Available data on historical and current presence/abundance should be collected to supplement monitoring data. Monitoring programs and/or protocols other than the MMP exist, however they do not specifically focus on coastal wetlands.

***Unfinished Business***
Work is currently underway to use data collected for this indicator to seek viable metrics for developing an IBI for rapidly monitoring condition of discrete Great Lakes coastal wetland sites. In calculating annual indices of wetland dependent bird species relative

abundance, there is a need to estimate and account for variation resulting from detection probabilities that are virtually always lower than 100 percent.

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota
SOLEC Grouping(s): coastal wetlands
GLWQA Annex(s): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 14: Loss of fish and wildlife habitat

***Last Revised***
July 15, 2004

# Coastal Wetland Area Extent by Type (Indicator ID: 4510)

***Measure***
Areal extent of coastal wetlands by hydrogeomorphic type as a range (e.g., dry year/low water level area versus wet year/ high water level area).

***Purpose***
To assess the periodic changes in area (particularly losses) of coastal wetland types, taking into account natural lake level variations.

***Ecosystem Objective***
Maintain total areal extent of Great Lakes coastal wetlands, ensuring adequate representation of coastal wetland types across their historical range. (GLWQA Annexes 2 and 13)

***Endpoint***
No net loss of coastal wetland area due to human actions and, in the future, a gain to coastal wetlands due to restoration activities, recognizing that a reference year needs to be selected and accurate inventory integrated into the analysis.

***Features***
The total wetland area should be reported by lake basin and hydrogeomorphic type. The baseline status should be considered within a historical perspective. The monitoring must be conducted on a regular and ongoing basis over an entire Great Lakes water level cycle for meaningful baseline data.

***Illustration***
For each wetland type, tabular summaries and graphics could show the areal extent of hydrogeomorphic wetland types by lake basin as they change relative to water level and over time.

***Limitations***
Although not inexpensive, remote sensing, with statistically significant ground-truthing, would be the most cost-effective method to comprehensively monitor this indicator throughout the Great Lakes basin. The costs would be partially offset if other SOLEC indicators are also concurrently monitored using remote sensing. Additionally, integrating SOLEC needs with those of existing and proposed regional initiatives (i.e. Great Lakes Observing System and National Ecological Observation Network) would also offset costs and greatly increase scientific benefits.

The extent of each coastal wetland type varies with Great Lakes water level fluctuations. Monitoring must be repeated throughout the Great Lakes water level fluctuation cycle. No one is currently doing this on a regular basis. Conducting the monitoring and detecting human-induced change in an area may not be feasible in the two-year time frame of SOLEC. Scientifically meaningful monitoring of coastal wetlands needs to be long-term and regular.

Wetland area change caused by human actions may be difficult to measure because (a) natural water level fluctuation can have a dramatic effect on area by type and (b) a historic "original size" by type for each water level regime is difficult to establish. But again, remote sensing techniques can provide meaningful data and establish trends and linkages with human activities if linked to ground-truthing.

***Interpretation***
This indicator needs to be evaluated in terms of both wetland quality and extent. While some wetlands may decrease in both area and quality due to the lack of water level fluctuation, as on Lake Ontario, the area of other wetlands could remain within the range determined by natural water level fluctuations, but be degraded by other factors, such as sedimentation, excessive nutrients, invasive species or land use pressures. When interpreting the data, the other coastal wetland indicators that evaluate wetland quality need to be considered. Measurement should be based upon total area of inventoried coastal wetlands where known. Where areal extent is not known, efforts should be focused on collecting that baseline data. Total change can be roughly determined on a lake basin basis and for scientifically-based sampling, priority sites should be established where regular ground-truthing facilitates a statistical analysis.

***Comments***
The wetland area measured would include the data from indicator #4511, Gain in Restored Wetland Area by Type.

***Unfinished Business***
- A cost efficient method for data acquisition and monitoring using remote sources must be implemented
- Complementary data sets that can be concurrently gathered should be defined and integrated into the collection process

***Relevancies***
Indicator Type: state
Environmental Compartment(s): water, land
Related Issue(s): habitat
SOLEC Grouping(s): **coastal wetlands**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised*** June 28, 2004

# Coastal Wetland Restored Area by Type (Indicator ID: 4511)

***Measure***
Gain in restored wetland area by type.

***Purpose***
To assess the amount of restored wetland area, and to infer the success of conservation and rehabilitation efforts.

***Ecosystem Objective***
Sufficient gain in restored wetland area to ensure adequate representation of coastal wetlands by type across their historical range. (GLWQA Annexes 2 and 13)

***Endpoint***
The endpoint for this indicator needs to be defined and could be as simple as defining a certain amount of Great Lakes areas that should be classified as wetland. There should be enough gain in wetland area to offset any losses to ensure no net loss; however, opportunities for wetland gain may be limited by lack of available sites. Also, the endpoint should consider wetland quality including zones of vegetation and desired species.

***Features***
This indicator measures additional restored wetland area, not enhancement of existing wetland area. When evaluating this indicator, wetland quality, not just total restored area needs to be considered. High quality examples of each wetland type, based on geomorphology and climatic setting, should be used to define the expected zones of vegetation, sediment characteristics, and plant species in restored wetland. Also, wildlife use, based on baseline high quality wetlands, could be used to evaluate the success of the wetland restoration. Other coastal wetland indicators should be used to help interpret wetland quality.

***Illustration***
A graph displaying the amount of gained/restored wetland area by type over time.

***Limitations***
The gain in restored wetland area does not necessarily reflect the quality of the wetland. Also, lack of available sites for restoration would be a limitation.

Data quality may vary because data will be submitted from a number of agencies. Also, because of multi-agency partnerships in most restoration projects, it is crucial to ensure that restored areas are counted only once when agencies submit data from the same project.

Wetland area change caused by human actions may be difficult to measure because (a) natural water level fluctuation can have a dramatic effect on area by type and (b) a historic 'original size' by type for each water level regime is difficult to establish.

***Interpretation***
By looking at both indicator #4510, Wetland Area by Type, and the gain in restored area within a particular water level regime, it will be possible to determine whether the no net loss goal is being met, or being surpassed with additional gains. Further investigation or incorporation of historical data could be important for Lakes Erie and Ontario and the St. Lawrence River. For many of the wetland types characterizing the Great Lakes shoreline, baseline data for high quality examples exist for both the typical zonation, relation to water depth, and typical plant species of each zone. Baseline data for Lakes Erie and Ontario and the St. Lawrence River are less reliable because of the high level of wetland degradation. In Lake Ontario and the St. Lawrence River, water level control/manipulation has altered the species composition in even the least disturbed wetlands.

***Comments***
Gain in wetland area will be determined using data reported by agencies that track wetlands restoration, and confirmed by remote sensing. This will allow gain, not just enhancement of existing wetland, to be tracked. Agencies will need to provide documentation about the location of restoration projects and track restoration (i.e. true gain in area) versus enhancement (i.e. modifications to existing area).

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): water, land
Related Issue(s): habitat, stewardship
SOLEC Grouping(s): **coastal wetlands**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 23, 2000

# Sediment Flowing into Coastal Wetlands (Indicator ID: 4516)

***Measure***
Suspended Sediment Unit Area Yield (tonnes/km$^2$ of upstream watershed) for a representative set of existing monitoring sites just upstream of coastal wetlands.

***Purpose***
To assess the severity of sediment yields flowing into coastal wetlands and potential impact on wetland health.

***Ecosystem Objective***
To maintain and restore healthy coastal wetlands which are highly dependent on appropriate sediment loads. (GLWQA Annexes 1, 2 and 13)

***Endpoint***
Wetlands require some sediment to maintain barriers and elevation against scour etc., so the reference value is not zero. A desired endpoint can be set from unit area yields to representative wetlands without sedimentation problems.

***Features***
Sediment yield is critical to habitat health and is one of the major wetland stressors. Sites throughout the basin can be chosen to represent stream inflow to individual wetlands and it is possible that there is enough existing monitoring to represent the basin-wide situation. The data are already collected, analyzed, and maintained comparably in both countries. There is fairly high variability among the data because stream sediment yields are directly related to flow, which varies depending on precipitation events. Sediment yields are also dependent upon agricultural land management practices and land use. This indicator links to other wetland stressor indicators that have similar causes, including 4560, Nitrate and Total Phosphorus into Coastal Wetlands, and indicator 4519, Number of Extreme Storms. Sediment affects the wetland State/Response indicators including those associated with area by type, invasive plants and wildlife.

***Illustration***
This indicator could be displayed graphically as tonnes of sediment per km$^2$ of coastal wetland watersheds (y axis) versus time (x axis). The desired reference point or endpoint could be indicated on the y axis and across the graph.

***Limitations***
The indicator is developed from flow measurements using stream-specific and regularly updated relationships of flow and sediments.

***Interpretation***
Interpretation will be based on the magnitude of the difference of the monitoring stream sediment yields from the reference yield. The reference yield will be scored as 10. The greater the difference in the monitored yield, the lower the score. Additional information that could help interpret reasons for stream sediment yield include: weather, conservation practices data, and upstream reservoirs. Data for percentage of silt and clay are also available and can help interpret associated contaminants and whether material is likely to settle out or not.

***Comments***
This is a clearly understood indicator to which both development and agriculture industries can relate. Excess sediment is of concern not only for its physical smothering, in-filling and light obstruction properties but also for other harmful contaminants it can carry.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water, sediments
Related Issue(s): habitat
SOLEC Grouping(s): **coastal wetlands**, nearshore terrestrial
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 23, 2000

# Climate Change: Ice Duration on the Great Lakes

**(Indicator ID: 4858)**

***Measure***
Maximum percentage of Great Lakes area covered by ice each year.

***Purpose***
To assess the temperature and accompanying physical changes to each lake over time, and to infer potential impact of climate change on wetlands.

***Ecosystem Objective***
GLWQA General Objective: "These waters should be free from materials and heat directly or indirectly entering the water as result of human activity that . . . produce conditions that are toxic or harmful to human, animal or aquatic life." Change in water temperature (potentially due to global warming) will affect ice extent on the Lakes and, in turn, affect coastal wetlands. Awareness of occurrence will encourage human response to reduce the stressor towards minimizing biological disruption.

***Endpoint***
An endpoint will need to be established, based on a literature search of historical data to determine the average number of days per year that ice historically (prior to 1980) formed on each lake.

***Features***
Ice cover reflects temperature, wind, and heat stored in a lake, therefore, this is a good indicator of climate effects. This data is already collected annually for each lake by NOAA using satellite imagery. There is a natural variability in MAXIMUM ice extent accounted for in the interpretation.

This indicator may show similar trends to other indicators of climate change (ie. 4519, Number of Extreme Storms, 4857, First Emergence of Water Lily Blossoms in Coastal Wetlands, and 4861, Water Level Fluctuations). It is indirectly linked to any other indicator that track trends in wetland area/habitat change.

***Illustration***
A graph displaying the maximum percentage of ice cover on the y axis and years on the x axis. The historical median and extremes will be indicated.

***Limitations***
The data that have already been collected by NOAA are specific to each lake rather than coastal wetlands.

***Interpretation***
Even though it is unclear if storms alter ice extent, storms can break up ice and alter their formation, therefore, information regarding storms and their severity is needed to properly interpret this indicator.

To interpret this indicator, data for maximum percentage ice cover need to be gathered each year. From the period of record for maximum percentage of ice cover, the pre-1980 high and low extremes will be determined. The historic range will be divided into 3 equally occurring ranges of maximum per cent ice cover: below average, average, and above average (i.e., maximum per cent ice cover exceeded 0 to 33.3%, 33.3% to 66.7%, 66.7% to 100% of the pre-1980 years of record). The indicator will score high if the annual maximum percentage values for the previous 10 years are within the maximum and minimum historical extremes and they are distributed fairly evenly among the 3 historical ranges. Low scores will be obtained if any annual maximum percentage cover value lies beyond the high or low extremes or if the annual values are becoming highly skewed away from a fairly even distribution among the 3 ranges.

***Comments***
This is a very understandable feature. Lake ice indicates coastal wetland ice and itself affects wetlands (e.g., winter storm severity).

The endpoint is reached when the previous 10 years' values of maximum per cent ice cover are distributed evenly within the pre-1980 historic range of maximum per cent ice cover.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water
Related Issue(s): climate change
SOLEC Grouping(s): open waters, nearshore waters, coastal wetlands, **unbounded**
GLWQA Annex(es):
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 24, 2000

# Phosphorus and Nitrogen Levels (Indicator ID: 4860)

***Measure***
Concentration of nitrate and of total phosphorus just upstream from, or in, a set of Great Lakes coastal wetlands.

***Purpose***
To assess the amount of nitrate and total phosphorus flowing into Great Lakes coastal wetlands, and to infer the human influence on nutrient levels in the wetlands.

***Ecosystem Objective***
Maintenance and restoration of more natural levels of nutrients to maximize: species and community diversity, wetland integrity and wetland values. (GLWQA Annexes 3 and 13)

***Endpoint***
In the growing season, at least one instance of < 0.5 mg/l nitrate and < 0.03 mg/l total phosphorus.

***Features***
This indicator will assess the concentrations of nitrate and total phosphorus found in and entering Great Lakes coastal wetlands. These are the major nutrients affecting coastal wetlands. Data for this indicator will be collected from the following locations: 1) existing closest stream monitoring sites within 5 km upstream of a coastal wetland (within 10 km upstream if on the Canadian Shield); 2) existing monitoring for Long Range Transport of Air Pollutants (LRTAP) at stations nearest the coastal wetland sites with stream monitoring stations; and 3) proposed in situ monitoring of a representative set of coastal wetlands. Past trends can be constructed using historical stream data, which exists for many years.

The indicator will be updated on an annual basis, as new data are available. Stream sampling data are often collected on the order of 1 sample per month. Concentrations may vary with seasons and events but choice of presence/absence type indicator during the growing season greatly reduces variability. This indicator links to other coastal wetland indicators that assess wildlife affected by eutrophication or reduced habitat diversity (e.g., 4501, Coastal Wetland Invertebrate Community Health; 4502, Coastal Wetland Fish Community Health; 4504, Amphibian Diversity and Abundance in Coastal Wetlands), as well as indicator 4510, Coastal Wetland Area by Type, and indicator 4513, Presence, Abundance and Expansion of Invasive Plants. The in situ sampling piggy-backed on wetland visits proposed for other indicators and will have relatively low associated lab costs.

***Illustration***
This indicator will be presented using a graph with y axis as % of sites with at least one instance of both <0.5 mg/l nitrate and <0.03 mg/l total phosphorus from May to July, and x axis as time in years. Percentage reaching the endpoint can also be recorded for each of the set of upstream samples (with airborne contribution (LRTAP) concentrations added) and the set of in situ samples in case their trends differ.

***Limitations***
Low incremental cost assumes (1) no major downsizing of the stream water quality monitoring network, and (2) on-site wetland visits by biologists monitoring other indicators. Total phosphorus has an official standard; nitrate does not. Variation within each wetland will require a general protocol for such factors as storm event avoidance and grab sample location.

***Interpretation***
The higher percentage of sampled wetlands and streams reaching the endpoint (at least one instance of both < 0.5 mg/l nitrate and <0.03 mg/l total phosphorus from May through to July), the better. A ranking system of 0 to 10 can be used to interpret this indicator, with 0 for no stations reaching the endpoint and 10 for all (100%) stations reaching the endpoint.

Analysis of this indicator must consider recent data from monitoring stations dropped since the previous year's monitoring. For example, if dropped stations were all high water quality, then their omission, rather than just pollution levels, affects the trend in percentage reaching the endpoint.

***Comments***
In nutrient over-enriched wetlands, a few species out-compete many others reducing biological and social values. One instance of low concentration indicates the site is capable of non-excessive nutrient levels and allows the indicator to avoid (1) the confusion imposed by the high variability in concentration which often occurs among monthly samples, and (2) the need for many more samples to fully assess nutrient level regimes.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water
Related Issue(s): nutrients
SOLEC Grouping(s): **coastal wetlands**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 3: Control of phosphorus, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 8: Absence of excess phosphorus
GLFC Objective(s):
Beneficial Use Impairment(s): 8: Eutrophication or undesirable algae

***Last Revised***
Feb. 23, 2000

# Effect of Water Level Fluctuations (Indicator ID: 4861)

***Measure***
For each lake: 1) Mean lake level; 2) Lake-wide annual range in monthly averages; 3) Lake-wide seasonal peak (days after January 1); 4) Lake-wide seasonal minimum (days after September 1); and 5) Elevation Difference between Upper and Lower Emergent Vegetation Extent based on Water Level model (Painter and Keddy, 1992).

***Purpose***
To assess the lake level trends that may significantly affect components of wetland and nearshore terrestrial ecosystems, and to infer the effect of water level regulation on emergent wetland extent.

***Ecosystem Objective***
To maintain and restore healthy coastal wetlands whose existence and integrity depend on naturally fluctuating water levels (GLWQA Annexes 2 and 17).

***Endpoint***
The endpoint for this indicator is based on four historic ranges (i.e., data exceeded 0-25%, 25-50%, 50-75%, and 75-100% of the years examined) for each measure per lake. All years of historical data from 1918 to 1959 for Lake Ontario, and from 1918 to 1980 for all other lakes, will be used to set the historic ranges. The endpoint is reached if in the previous 20 years, distribution of data is fairly evenly distributed among the four historic ranges. The endpoint for water level regulation effects is the elevation difference between upper and lower emergent vegetation extent, calculated by application of the Painter and Keddy model to water levels in Lakes Ontario and Superior under a "no regulation" scenario.

***Features***
Lake levels have a major influence on undiked coastal wetlands and are basic to any analysis of wetland change trends. This indicator uses existing annual summaries of lake and basin-wide water level fluctuations based on daily data. Natural variability will occur in each measure, but will be accounted for in the interpretation method. Yearly data can vary and should be reviewed whenever data for other wetland indicators are collected. Interpretation into the score of 10 (see Interpretation), however, will show far less variability and may be required only every second or third SOLEC cycle. This indicator links to indicator #4510 Coastal Wetland Area by Type, and all wildlife indicators. The data for this indicator are already collected, standardized, easily available and analyzed.

***Illustration***
One graph per lake of "Correspondence of Previous 20 Years of Water Levels With Historical Distribution" on the y-axis with the x-axis as time in years. Lakes Ontario and Superior will also have a graph of "Effect of Regulation on Extent of Emergent Vegetation Elevation", which will be the difference between pre- and post-regulation modeled values each year. Lakes Michigan and Huron will be illustrated on one graph.

***Limitations***
Some analysis is required to set historical reference ranges and to calculate emergent vegetation elevation difference. The indicator shows changes from historic distribution of levels but cannot distinguish if changes are due to natural climatic variability or human-induced climate change. The emergent elevations are based on a model using lake level data but not direct field measurements of vegetation extent.

***Interpretation***
If previous 20 years of data are distributed evenly across the historical range for a measure (i.e., within historical high and low values AND distributed reasonably evenly among the 4 historical ranges), the trend can be interpreted as "good." If a year is beyond high or low historical value OR distribution is becoming highly skewed from a fairly even distribution among the 4 historical ranges, the trend can be interpreted as "bad."

A ranking system of 0 to 10 can be used to determine the trend of the overall indicator (i.e., an aggregate of all five measures). Each of 5 parameters for each lake will receive a score of 0, 1, or 2, depending on how well the previous 20 years of data fit the historical ranges. The total of the scores for the 5 parameters identified under Measure above provides a lake score (maximum of 10). An average of the 4 lakes scores could provide a basin-wide score. The four lakes are Superior, Michigan/Huron, Erie and Ontario. The y axis of the "Effect of Regulation" graphs will be scaled so larger effects score lower; no effect scores 10.

Lake St. Clair is omitted from the basin-wide score since ice jams in the Detroit and St. Clair Rivers can greatly affect ranges and extreme levels. For the same reason St. Clair indicators are restricted to the average level and elevation differences.

***Comments***
Water levels are important to the public. The importance to wetland integrity, however, of natural level fluctuations is less widely appreciated and use of modelled elevations of emergents, historical ranges and one index for all parameters and lakes may be difficult for public understanding.

Painter, S. and P. Keddy. 1992. Conceptual Emergent Marsh Response to Water Level Regulation. National Water Research Institute, Environment Canada, Burlington Ontario.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water
Related Issue(s): habitat, climate change
SOLEC Grouping(s): **coastal wetlands**, **nearshore terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 17: Research and development
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 23, 2000

# Coastal Wetland Plant Community Health (Indicator ID: 4862)

### *Measure*
Presence, abundance, and diversity of aquatic macrophytes within Great Lakes coastal wetlands. The prevalence of native plants in a wetland is considered an indicator of low levels of human manipulation and increased sediment loading. In contrast, the presence, abundance, and expansion of invasive plants (both native and non-native), such as flowering rush, great hairy willow-herb, common frogbit, yellow iris, purple loosestrife, Eurasian water milfoil, curly pondweed, cattail, reed canary grass, and common reed (*Phragmites australis*), is considered a response to wetland manipulation and increased sediment loading.

### *Purpose*
To assess the level of native vegetative diversity and cover for use as a surrogate measure of quality of coastal wetlands which are impacted by coastal manipulation or input of sediments.

### *Ecosystem Objective*
Coastal wetlands throughout the Great Lakes basin should be dominated by native vegetation, with low numbers of invasive plant species that have low levels of coverage. (GLWQA Annexes 2 and 13).

### *Endpoint*
The characteristic size and plant diversity of coastal wetlands vary by wetland type, lake, and latitude, due to differences in geomorphic and climatic conditions; in this document these differences will be described broadly as “regional wetland types”. The number and coverage of invasive plant species also varies by region wetland type and must be identified through sampling.

### *Features*
Two considerations in assessing the condition of coastal wetlands are quantity and quality. The aerial extent of a wetland is based on a combination of physically limiting factors and management history. Evaluation of degradation of a wetland is based on loss of wetland plants from a portion of the habitat that originally supported wetland. The same wetland can be degraded or modified by the replacement of native plant species by invasive plant species, or by the reduction of native species diversity (without introduction of exotic or invasive native species). Similarly, wetland restoration may be evaluated based on the diversity and extend of native plant species. This indicator will track the quality of coastal wetlands by assessing the native diversity of wetland vegetation over time.

### *Illustration*
Graphs will display the number of native species over time. Plant diversity can be further refined by using Floristic Quality Indices, which provide additional information concerning the conservativeness of the plants found in the wetland and the wetland affinity. Diversity and integrity of a wetland is often not uniform across the entire wetland, with wetland quality sometimes differing between plant community zones; the most common zones in coastal wetlands being wet meadow zone and emergent zone, with submergent zone sometimes present. Presence and coverage of invasive (native and non-native) plant species are some of the easiest to measure indicators of wetland degradation. For many of the most aggressive invasives, it is possible to map the extent within a wetland using aerial photography or satellite imagery. On a broader scale regional extent of invasive plant ranges can be mapped to track expansion over time.

### *Limitations*
The characteristic presence and abundance of native plants has not been adequately documented across the Great Lakes basin, but most regional wetland types can be adequately described on the basis of existing studies. The changes in species composition and dominance related to Great Lakes water-level fluctuations has not been adequately determined for many regional wetland types. This is an important task, as natural water-level fluctuations can introduce changes in wetland vegetation that could falsely be attributed to either increased wetland degradation or improved management. A further need for wetland plants is laboratory studies to identify species responses to different types of degradation, including turbidity, sedimentation, heavy metal and organic chemical introduction, pH change, erosion, exotic plant competition, and increased herbivory by exotic fauna.

### *Interpretation*
A ranking could be developed based on a combined score of 1) the diversity of native plants, 2) the conservatism (FQA) of all plants or native plants only, 3) the plant zones present within the wetland, 4) the number of invasive plant species, and 5) the coverage value of invasive plant species.

### *Comments*
This indicator would apply to a selected set of representative wetlands for each of the coastal reaches of the Great Lakes, as identified in the SOLEC ’98 Biodiversity Investment Areas paper on Coastal Wetland Ecosystems, or for each regional wetland type.

### *Unfinished Business*
The evaluation of the response of wetland plant diversity and coverage to water-level fluctuation remains as an obstacle to development of indicator values, as does identification of the response of individual wetland plants to different types of wetland degradation.

### *Relevancies*

Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): plant diversity, exotics, habitat
SOLEC Grouping(s): coastal wetlands, nearshore terrestrial
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
July 20, 2004

# Land Cover Adjacent to Coastal Wetlands (Indicator ID: 4863)

***Measure***
Presence, wetland-proximity, and/or spatial extent of land cover type(s) nearby coastal wetlands

***Purpose***
Assess the presence, location, and/or spatial extent of land cover in close proximity to coastal wetlands. Infer the condition of coastal wetlands as a function of adjacent land cover.

***Ecosystem Objective***
Restore and maintain the ecological (i.e., hydrologic and biogeochemical) functions of Great Lakes coastal wetlands. Presence, wetland-proximity, and/or spatial extent of land cover should be such that the hydrologic and biogeochemical functions of wetlands continue.

***Endpoint***
Ecological endpoints may be inferred by using field sample data and by a literature search of current and historical relationships between land cover adjacent to coastal wetlands. Field sampling data and *a priori* knowledge of such endpoints and the mechanisms of such endpoints could be used to calibrate this indicator at broad scales, and contribute to the understanding of such relationships at fine scales. Ecological endpoints may include presence/absence or assemblage structure of species; vegetational characteristics/structure; or characteristics/constituents of soil and water within the wetland.

***Features***
This indicator offers information on the presence, location, and predominance of land cover adjacent to wetlands, and may provide information about how such land cover types affect the ecological characteristics and functions of coastal wetlands, as demonstrated by the use of remote-sensing data and/or field observations. This indicator can be tracked over time if necessary.

***Illustration***
The coastal area of a desired portion of the Great Lakes could be mapped for the presence, wetland-proximity, and/or spatial extent of land cover adjacent to coastal wetlands using remote-sensing based geographic information, and analyzed in relationship to field measures of wetland functions. A limited number of coastal wetland sites could be mapped with regard to this indicator, using field surveys, sketches, and global positioning systems to record transitions between wetland and adjacent land cover types.

***Limitations***
To conduct such measures at a broad scale, the relationships between wetland-adjacent land cover and the functions of coastal wetlands need to be verified. This measure will need to be validated fully with thorough field sampling data and sufficient *a priori* knowledge of such endpoints and the mechanisms of impact. The development of indicators (e.g., a regression model using adjacent vegetation characteristics and wetland hydroperiod) is an important goal, and requires uniform measurement of field parameters across a vast geographic region to determine accurate information to calibrate such models.

***Interpretation***
”Land cover” types may be used to infer “land use” types, but such uses should be considered under “Human Impact Measures” (See SOLEC indicator TBD). Land cover types adjacent to coastal wetlands can be more thoroughly explored and explained if they are linked to the ecological functions of a wetland (e.g., vegetation density, as it relates to uptake/accumulation/leaching of nutrient runoff, as it relates to nutrient loading into wetlands, as it relates to wetland water quality). For this reason, interpretation of this indicator is correlated with many other SOLEC indicators and their patterns across the Great Lakes. Land cover change has great potential for complicating the development of wetland-adjacent land cover parameters as indicators of wetland function. Thus, multiple-season, multiple-year analyses of wetland-adjacent land cover are required to develop a robust indicator. The classification system for land cover types should be linked to the ecological endpoint of interest. This interpretation may vary as a result of the specificity of land cover type. For example, general-agriculture land cover types (e.g., “row crop agriculture”) may be most appropriate, if considering general nutrient inputs from sheet flow into adjacent wetlands. Alternatively, crop-type land cover information may be most appropriate if considering pesticide inputs from sheet flow into adjacent wetlands.

***Comments***
A thorough field-sampling protocol and properly validated geographic information and other remote-sensing-based data could lead to successful development of wetland-adjacent land cover as indicators of coastal wetland function and ecological vulnerability. This indicator could be applied to selected wetland sites, but would be most effective if used at a regional or basin-wide scale.

***Unfinished Business***

***Relevancies***
Indicator Type:
Environmental Compartment(s):
SOLEC Grouping(s): **coastal wetlands**
GLWQA Annex(es):

IJC Desired Outcome(s):
GLFC Objective(s):

***Last Revised*** August 12, 2004

# Human Impact Measures (Indicator ID: 4864)

***Measure***
Presence, wetland-proximity, and/or spatial extent of factors that are a direct or indirect result of human behaviors in or nearby coastal wetlands

***Purpose***
Assess the presence, location, and/or spatial extent of factors that are a direct or indirect result of human behaviors. Infer the condition of coastal wetlands as a function of these human impact measures.

***Ecosystem Objective***
Restore and maintain the ecological (i.e., hydrologic and biogeochemical) functions of Great Lakes coastal wetlands. Presence, wetland-proximity, and/or spatial extent of human impact measures should be such that the hydrologic and biogeochemical functions of wetlands continue.

***Endpoint***
Ecological endpoints may be inferred by using field sample data and by a literature search of current and historical relationships between human activities in the vicinity of coastal wetlands. Field sampling data and *a priori* knowledge of such endpoints and the mechanisms of such endpoints could be used to calibrate this indicator at broad scales, and contribute to the understanding of such relationships at fine scales. Ecological endpoints may include presence/absence or assemblage structure of species; vegetational characteristics/structure; or characteristics/constituents of soil and water within the wetland.

***Features***
This indicator will offer information on the presence, location, and predominance of land cover as it relates to human habitation and activities, and may provide information about how such land cover types and activities affect the ecological characteristics and functions of coastal wetlands, as demonstrated by the use of both current and historic remote-sensing data. Field-based collection of human impacts can also be accomplished by: surveys; sketches (using global positioning systems); personal interviews; and record analyses at local, county, or state offices.

***Illustration***
The coastal area of a desired portion of the Great Lakes could be mapped for the presence, wetland-proximity, and/or spatial extent of human impact 'indicators' using remote-sensing based geographic information, and analyzed in relationship to field measures of wetland functions. Human impacts may include (but are not limited to) agricultural, mining, recreational, and urbanization activities.

***Limitations***
To conduct such measures at a broad scale, the relationships between human activities and wetland functions of coastal wetlands need to be verified. This measure will need to be validated fully with thorough field sampling data and sufficient *a priori* knowledge of such endpoints and the mechanisms of impact. The development of indicators (e.g., a regression model using impervious surface parameters and wetland hydroperiod) is an important goal, and requires uniform measurement of field parameters across a vast geographic region to determine accurate information to calibrate such models.

***Interpretation***
Human impacts can be interpreted more easily, in the context of wetland impacts, if they are defined as either as direct (e.g., road density) or indirect (e.g., human population density) impacts. This conceptual distinction between human impact types allows for a more thorough exploration of the potential mechanistic relationships with ecological functions of affected coastal wetlands (e.g., road density, as it relates to impervious surface, as it relates to runoff into wetlands, as it relates to wetland hydroperiod). Human impact measures may be correlated with other SOLEC indicators (e.g., Land Cover Adjacent to Wetlands) and their patterns across the Great Lakes. Because human activities are temporally variable and are non-linear in their spatial and temporal patterns, this indicator is complex. Thus, multiple-scale, multiple-season, multiple-year analyses of human impact measures are required to develop a robust indicator.

***Comments***
A thorough field-sampling protocol and a properly validated geographic information and other remote-sensing-based data could lead to successful development of human impact measures as indicators of coastal wetland function and ecological vulnerability. This indicator could be applied to selected wetland sites, but would be most effective if used at a regional or basin-wide scale.

***Unfinished Business***

***Relevancies***
Indicator Type:
Environmental Compartment(s):
SOLEC Grouping(s): **coastal wetlands**
GLWQA Annex(es):

IJC Desired Outcome(s):
GLFC Objective(s):

***Last Revised*** August 12, 2004

# Urban Density (Indicator ID: 7000)

***Measure***
Human population per square kilometre of existing and proposed development areas. Total area is adjusted to exclude parks and other designated greenspace.

***Purpose***
To assess the human population density in the Great Lakes basin, and to infer the degree of inefficient land use and urban sprawl for communities in the Great Lakes ecosystem.

***Ecosystem Objective***
Socio-economic viability and sustainable development are generally accepted goals for society.

***Endpoint***
The most efficient and ecologically sustainable conditions will occur when large urban centres are intensively developed with a high population density. The contrary exists for sparsely populated rural areas — the lower the population density the less stress is imposed on the ecosystem. As a corollary, new growth is best accommodated by adding to the high density area rather than the lower density rural areas.

***Features***
Urban density is a relative measure of efficiency. In general, and other things being equal, higher density land use is less energy and resource consuming and thus is more efficient from an ecosystem perspective. For example, transportation in higher density areas is less resource demanding since distances are shorter and public transportation is often more available and inexpensive. Consequently, air pollution should be lower in more densely populated areas. In addition, since inefficient land use for urban development implies loss of land use for natural and other purposes there are significant biodiversity dimensions to inefficient land use. In general, the less land used for development, the greater the opportunities that exist for natural biodiversity goals to be met. Urban densities have been declining over time as urban development has become much more sprawling with the vast majority of new development occurring on former agricultural or natural lands. This has resulted in greater reliance for urban residents on the automobile as virtually the only method of public transit for these widespread and low density new communities has become impractical. Information for this indicator needs to be collected perhaps every 5 or 10 years as changes in density take place relatively slowly.

***Illustration***
This indicator will be displayed by a numerical ratio of population to land area (population per square kilometre).

***Limitations***
This indicator is useful in comparing municipalities to each other, but would need to be aggregated into an index in order to be represented as a basin wide measure. Identifying park space may be complicated and difficult in some cases because the information most likely exists only at the local level and would require a survey to collect.

***Interpretation***
The indicator is a simple representation of urban efficiency since higher density communities typically are lower in cost and less intrusive on the rest of the ecosystem. Thus, the higher the ratio of population per square kilometre of land the better in achieving overall urban efficiency and a less stressed ecosystem.

***Comments***
The indicator is also a good proxy for commercial and industrial sprawl since development patterns for this sector typically parallels that of residential development. The socio-economic paper of SOLEC '94 indicated the relative urban densities between the City of Toronto, Ontario and Chicago, Illinois. The SOLEC '96 Land Use paper also discussed at length the efficiency aspects of higher density through the report.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): land
Related Issue(s):
SOLEC Grouping(s): **land use**
GLWQA Annex(es):
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 24, 2000

# Land Cover – Land Conversion (Indicator ID: 7002)

***Measure***
Percent change in land use type, including agriculture, urban development, and forest, marsh or other natural cover.

***Purpose***
To assess the changes in land use within the Great Lakes basin, and to infer the potential impact of land conversion on Great Lakes ecosystem health.

***Ecosystem Objective***
Sustainable development is a generally accepted land use goal for Canadians and Americans. This indicator supports Annex 13 of the GLWQA.

***Endpoint***
Zero change would be sustainable but probably unrealistic, while reversion of other uses to the natural ecosystem would be desirable.

***Features***
High rates of land conversion place stress on the natural ecosystem and are typically associated with inefficient land use, such as urban sprawl. Population growth is a driver for more development which displaces both agricultural and natural lands. Other things being constant, high conversion rates are associated with rapid rates of urban sprawl which is economically inefficient and displaces natural land that serves other biological purposes in the ecosystem or agriculture which in turn may convert land from natural uses. The conventional pattern of land conversion has been for urban growth to displace agricultural lands which, in turn, expand into remaining lands. Urban development also expands into natural lands.

***Illustration***
The indicator allows easy and visual interpretation of land use changes and trends. Land conversion is an evolutionary process and this indicator will be displayed as a graphical representation of land use by category in the basin.

***Limitations***
This indicator provides a measurement of the conversion of the land use type, but not of the change in quality of the land use. For example, conversion of a highly intensive, chemical-intensive agriculture area to an urban area, particularly one that is well-planned and utilizes environmental and resource conservation management plans, may result in less stress to the ecosystem. Also, urban development on excavated, landfill or other contaminated sites may also be positive changes.

***Interpretation***
Generally, land that converts from natural to agricultural and from natural and agricultural uses to developed uses is undesirable. Conversion back to natural uses would be desirable.

***Comments***
SOLEC '96 represented the rate of land converted from agriculture to developed urban uses. Clearly, loss of agricultural land in the basin places pressure on other lands such as forests and wetlands to be placed into agricultural uses. Satellite imagery might be useful in detailing the changes over time of the urban frontier actually developed and this indicator.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): land
Related Issue(s):
SOLEC Grouping(s): **land use**
GLWQA Annex(es): 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 24, 2000

# Brownfield Redevelopment (Indicator ID: 7006)

***Measure***
Total acreage of redeveloped brownfields.

***Purpose***
To assess the acreage of redeveloped brownfields, and to evaluate over time the rate at which society rehabilitates and reuse former developed land sites that have been degraded by poor use.

***Ecosystem Objective***
Sustainable development is a generally accepted goal for North American society.

***Endpoint***
Elimination of all brownfield sites.

***Features***
"Brownfields" are abandoned, idled, or under-used industrial and commercial facilities where expansion, redevelopment, or reuse is complicated by real or perceived environmental contamination. Some of the sites contain underground storage tanks; others have contaminated soils from industrial waste or manufacturing byproducts. Still others may possess no contamination at all, but the fear of contamination nonetheless scares prospective buyers and lenders away. This creates an incentive for development to occur in pristine, undeveloped areas.

The indicator would describe trends in brownfields redevelopment and urban renewal, including areas that technically can not be described as brownfields. The indicator is a measure of the rate at which society is employing former contaminated (typically industrial) sites to new and more environmentally compatible uses. Brownfields reuse offers an opportunity to reduce pressure on the ecosystem by slowing the rate of land conversion and typically increasing urban densities. An inventory of contaminated sites is maintained by most provincial and state and federal governments, although a broader definition would require municipal involvement. The goal is to redeploy all of these lands as soon as possible.

***Illustration***
The total number of identified acres of outstanding brownfield sites throughout the basin by state/province and lake basin. Bar graphs could be used to demonstrate changes over time.

***Limitations***
The identification of brownfield sites is limited by the availability of information on vacant and redeveloped sites. Data for this indicator may not reveal an accurate trend in brownfield redevelopment, particularly if redevelopment on brownfield sites results in another use that causes further land contamination.

***Interpretation***
Reducing the number of acres/square kilometres of brownfield sites can be seen as a positive development in the basin. Increasing brownfield inventories not only indicate challenges of dealing with contaminated sites but also opportunities for redevelopment.

***Comments***
Numerous examples are available including one site in Detroit that has been converted to a public park. Others are typically reduced as urban housing or clean industrial use.

The achievement of the end point will depend on the opportunities available for new land uses as an alternative to land conversion.

***Unfinished Business***

***Relevancies***
Indicator Type: human activity
Environmental Compartment(s): land
Related Issue(s): stewardship
SOLEC Grouping(s): **land use**
GLWQA Annex(es):
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 24, 2000

# Sustainable Agricultural Practices (Indicator ID: 7028)

***Measure***
Number of Environmental and Conservation farm plans in place.

***Purpose***
To assess the number of Environmental and Conservation farm plans, and to infer environmentally friendly practices in place, such as integrated pest management to reduce the unnecessary use of pesticides, zero tillage and other soil preservation practices to reduce energy consumption, and prevention of ground and surface water contamination.

***Ecosystem Objective***
This indicator supports Annexes 2, 3, 12 and 13 of the GLWQA.

***Endpoint***
Sustainable agriculture through non-polluting, energy efficient technology and best management practices for efficient and high quality food production.

***Features***
Given the key role of agriculture in the Great Lakes ecosystem, it is important to track changes in agricultural practices that can lead to better ecological integrity in the basin. The indicator identifies the degree to which agriculture is becoming more sustainable and has less potential to adversely impact the Great Lakes ecosystem. Integrated pest management and zero till soil management are typically part of an environmental farm management plan. It is expected that more farmers will embrace environmental planning over time.

***Illustration***
The total number of farm environmental plans (or ecological plans) that are in place as a percentage of the total number of farms in the basin.

***Limitations***
Plans vary from jurisdiction to jurisdiction and thus may lack consistency in terms of completeness of agricultural sustainable practices. In addition there is no standard way of knowing the state of implementation of these plans.

***Interpretation***
Having an environmental management plan in place provides an incentive for farmers to commit to environmentally sound land use practices. The more plans in place the better. In future there may be a way to grade plans by impacts on the ecosystem. The first year in which this information is collected will serve as the base line year.

***Comments***

***Unfinished Business***
- This indicator requires much further development and refinement. Specific consideration will be given to assessing the use of conservation tillage, buffer strips and herbicide application.

***Relevancies***
Indicator Type: human activity
Environmental Compartment(s): land
Related Issue(s): stewardship
SOLEC Grouping(s): **land use**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 3: Control of phosphorus, 11: Surveillance and monitoring, 12: Persistent toxic substances, 13: Pollution from non-point sources
IJC Desired Outcome(s): 8: Absence of excess phosphorus, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 8: Eutrophication or undesirable algae, 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 24, 2000

# Economic Prosperity (Indicator ID: 7043)

***Measure***
Unemployment rates within the Great Lakes basin.

***Purpose***
To assess the unemployment rates within the Great Lakes basin, and, when used in association with other Societal indicators, to infer the capacity for society in the Great Lakes region to make decisions that will benefit the Great Lakes ecosystem.

***Ecosystem Objective***
Human economic prosperity is a goal of all governments. Full employment is a goal for all economies and humans are part of the ecosystem.

***Endpoint***
Achieving the lowest economically sustainable unemployment levels possible. Levels of unemployment under 5% in western societies are considered full employment.

***Features***
The indicator demonstrates the economic ability of humans to avoid abusive behaviour of the rest of the ecosystem. In a global context, wealthier nations (US and Canada, Europe) are more likely to also have better environmental management regimes because they can better afford them and can afford to avoid many of the highly exploitive choices with respect to the environment. Data on employment rates are collected regularly and frequently throughout the basin. The unemployment rate is a better indicator than gross domestic production per capita for this purpose since it focuses on human ability to meet their own needs through income provision and not necessarily through undesirable environmentally activities. For example, the oil spill from the Exxon Valdez increased gross domestic production, although it had a minimal effect on employment rates.

***Illustration***
The indicator will be best represented by a chart showing trends over years.

***Limitations***
The collection and presentation of the indicator information is not limited. It was noted in the World Commission on Environment and Development report "Our Common Future" that although economic well being is associated with higher levels of resource consumption and environmental degradation, higher levels of economic development afford the ability to better manage the ecosystem and can constrain unsustainable resource exploitation.

***Interpretation***
This indicator is useful in defining the extent to which society is meeting only human need and should be presented in the context of the other ecosystem indicators. Decreasing trends in unemployment may not correlate to improvements in the condition of the Great Lakes ecosystem. For example, higher employment levels may lead to greater spending, which may cause environmentally undesirable consequences, such as new sprawl development.

***Comments***
Since unemployment is determined from those actually seeking work, this is a good indicator of the degree to which society's pursuit of economic prosperity is being met.

Currently unemployment rates in the U.S. are at almost historic lows. Although distribution of income may not be ideal, there is a sense that the human component of the ecosystem is better off than it was prior to this period. Arguments for excessive ecosystem exploitation can be countered as not being necessary.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s):

Related Issue(s):
SOLEC Grouping(s): **societal**
GLWQA Annex(es):
IJC Desired Outcome(s): 5: Economic viability
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
October 20, 1999

# Ground Surface Hardening (Indicator ID: 7054)

***Measure***
Percentage of land that is covered by buildings, roads, parking lots and other hardened surfaces.

***Purpose***
To indicate the degree to which development is affecting natural water drainage and percolation processes and thus causing erosion, and other effects through high water levels during storm events and reducing natural ground water regeneration processes.

***Ecosystem Objective***
Sustainable Development

***Endpoint***
Imperviousness mitigated through land management engineering (storm ponding, swells, etc.)

***Features***
This indicator is realted to land conversion indicator for new development. It is also is expected to be indirectly proportional to the amount of high density development taking place, although low density sprawl that includes shopping malls etc. may be similar to high density imperviousness

***Illustration***
New urban development without storm retention ponding or other conservation management systems in place.

***Limitations***
As noted above this indicator may appear be in conflict with other efficiency indicators, such as urban density. However, used as a basin-wide measure it is a valuable indicator of groundwater recharge. It is also not clear that runoff will not receive percolation after being diverted away from impervious surfaces or that it poses significant ecosystem implications in itself - it may be just a measure of development that has more significant effects.

***Interpretation***
The interpretation is that hardening of surfaces is generally undesirable.

***Comments***
Data for this indicator should be fairly easy to achieve by estimating the rough proportions of built up areas that are harder from the softer ground cover portions by examination of aerial or satellite photos.

***Unfinished Business***

***Relevancies***

***Last Revised***

# Water Withdrawal (Indicator ID: 7056)

***Measure***
Water use per capita in the Great Lakes basin.

***Purpose***
To assess the amount of water used in the Great Lakes basin per capita, and to infer the amount of wastewater generated and the demand for resources to pump and treat water.

***Ecosystem Objective***
Sustainable development is societal goal for the Great Lakes basin.

***Endpoint***
Resource conservation means reducing the amount of water that is used and the amount of wastewater that results from that water use. Current North American water use rates are in excess of 300 litres per day - reducing that by 50% is desirable and consistent with some European countries.

***Features***
The indicator provides a quantitative measure of the rate at which natural resources are being used. For example, high levels of water use results in considerable wastewater pollution, that results in degraded water quality, as well as increased demand for energy to pump and treat water. The indicator is a gross measure of water supplied through water supply facilities in a jurisdiction divided by the total number of people in the jurisdiction.

***Illustration***
The indicator will be displayed as the water use per capita in litres/capita within jurisdictions in the basin and the basin as a whole. The indicator is a measure of both residential and industrial/commercial water use.

***Limitations***
Data are readily abundant although it needs to be gathered in a consistent format. Ground water sources from private wells are excluded.

***Interpretation***
Water use symbolizes societal regard to resource use. North Americans, including those in the Great Lakes region, have very high rates of per capita water use compared with other developed nations, and reductions would result in reduced stress on the ecosystem. Water use is high and growing in places such as Toronto, in spite of efforts over the years to encourage water efficiency and conservation.

***Comments***
Canada and the United States are among the highest water using nations, per capita on the Earth.

***Unfinished Business***

- Need to add a discussion related to understanding the trends presented by the indicator. For example, will a baseline of "ideal" or "sustainable" water consumption rates need to be developed to determine if data collected on an annual basis (or another regular interval) reveals positive or negative trends in the amount of water consumed.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water, humans
Related Issue(s): stewardship
SOLEC Grouping(s): land use, **societal**
GLWQA Annex(es):
IJC Desired Outcome(s):
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 16, 2000

# Energy Consumption (Indicator ID: 7057)

***Measure***
Energy use in kilowatt hours per capita.

***Purpose***
To assess the amount of energy consumed in the Great Lakes basin per capita, and to infer the demand for resource use, the creation of waste and pollution, and stress on the ecosystem.

***Ecosystem Objective***
Sustainable development is a generally accepted goal in the Great Lakes basin. This indicator supports Annex 15 of the GLWQA.

***Endpoint***
Resource conservation minimizing the unnecessary use of resources is an endpoint for ecosystem integrity and sustainable development.

***Features***
The indicator is useful on a state/province/country basin basis. The trend for energy use has been increasing over time, which this indicator will depict as it tracks annual energy use.

***Illustration***
The indicator will be shown as a measure of kilowatt hours electrical energy used per capita.

***Limitations***
While the data are readily abundant for electrical energy, it will be more difficult to assess other energy sources such as hydrocarbon used in transportation, wood burned in fireplaces, natural gas and furnace fuels. This will require considerable effort.

***Interpretation***
Energy is a key aspect of ecosystem sustainability. The second law of thermodynamics is a starting point to understanding the way in which energy plays a key role in long term sustainability. Reducing the use of energy of all kinds will reduce 'entropy' and ensure a more sustainable future. Although electrical energy is a good proxy for total energy use, a complete accounting of all energy used is desirable. Although all forms of energy should be considered for conservation, electrical energy is used as a proxy.

***Comments***
Canada and the United States are among the highest energy consuming nations on Earth.

The indicator provides a quantitative measure of the rate at which non-renewable natural resources are being used up and that renewables are being consumed.

Electrical energy generation is among the largest source of smog related pollutants. In addition, it also generates a major share of all greenhouse gases that are responsible for global climate change.

***Unfinished Business***
< Need to develop a more quantitative endpoint.
< Need to determine how this indicator will be presented - as a graph, on a map, etc?
< Need to develop a baseline or reference value to be used in assessing whether energy use is increasing or decreasing over time.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): air, humans
Related Issue(s): climate change, stewardship
SOLEC Grouping(s): land use, **societal**
GLWQA Annex(es): 15: Airborne toxic substances
IJC Desired Outcome(s):
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 16, 2000

# Solid Waste Generation (Indicator ID: 7060)

***Measure***
Amount of solid waste generated per capita (tons and cubic metres).

***Purpose***
To assess the amount of solid waste generated per capita in the Great Lakes basin, and to infer inefficiencies in human economic activity (i.e., wasted resources) and the potential adverse impacts to human and ecosystem health.

***Ecosystem Objective***
Sustainable development is a generally accepted goal for Great Lakes basin society. This indicator supports Annex 12 of the GLWQA.

***Endpoint***
The reduction of waste to levels achieved in some European and Asian nations.

***Features***
Solid waste is generated and deposited on land or is incinerated and the residue remains on the land while other contaminants are redistributed by air and water sources. Solid waste represents a significant portion of all human land activities that generate waste and pollution and is stressful to the ecosystem. The indicator represents waste that goes to hazardous and non-hazardous landfills, as well as incinerators. Annual rates of waste generation will be presented by this indicator and bi-annual reporting will be useful.

***Illustration***
The indicator will be displayed as tons (tonnes) and cubic metres per capita in jurisdictions and for the basin over time. The indicator will be for all solid wastes over time.

***Limitations***
Although data are available for all jurisdictions, this indicator will require data coordination and integration. Variability in waste stream composition will result in the need for different types of measurement, such as weight versus volume, and may produce conflicting indications of progress. Regardless of the manner of disposal, the measure should consider the total volume of disposed solid waste. Therefore, important land contamination issues, such as acres of land fill space, will not be dealt with in this indicator.

***Interpretation***
Solid waste provides a measure of the inefficiency of human land based activities and the degree to which resources are wasted by the creation of waste. Reducing volumes of solid waste are indicative of a more efficient industrial ecology and a more conserving society. Reduced waste volumes are also indicative of a reduction in contamination of land through landfilling and incineration and thus reduced stress on the ecosystem.

***Comments***
Canada and the U.S. are among the highest waste producers on Earth. Reuse and recycling are opportunities to reduce solid waste levels.

Solid waste stored in sanitary landfills is a major source of methane, a very important greenhouse gas responsible for global climate change. Incineration of mixed solid waste has been shown to be a significant source of mercury and dioxins.

***Unfinished Business***
< Need to determine a specific endpoint.
< Need to determine a baseline value to use for assessing positive or negative trends in the amount of solid waste generated.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): air, land, humans
Related Issue(s): contaminants & pathogens, climate change, stewardship
SOLEC Grouping(s): **societal**
GLWQA Annex(es): 12: Persistent toxic substances
IJC Desired Outcome(s): 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 16, 2000

# Nutrient Management Plans (Indicator ID: 7061)

***Measure***
Number of Nutrient Management Plans (NMP) in place. Percentage of Municipalities with Nutrient Management By-law's containing standards for intensive livestock operations.

***Purpose***
To determine the number of Nutrient Management plans and to infer environmentally friendly practices in place, to prevent ground and surface water contamination.

***Ecosystem Objective***
This indicator supports Annexes 2, 3, 11,12 and 13 of the GLWQA.

***Endpoint***
Sustainable agriculture through non-polluting, energy efficient technology and best management practices for efficient and high quality food production.

***Features***
Given the key role of agriculture in the Great Lakes ecosystem, it is important to track changes in agricultural practices that can lead to protection of water quality as well as the sustainable future of agriculture and rural development and better ecological integrity in the basin. The indicator identifies the degree to which agriculture is becoming more sustainable and has less potential to adversely impact the Great Lakes ecosystem. Nutrient management is managing the amount, form, placement and timing of applications of nutrients for crop uptake and is typically part of an environmental farm management plan. It is expected that more farmers will embrace environmental planning over time. The Ontario Environmental Farm Plans (EFP) identifies the need for best nutrient management practices. Over the past 5 years significant progress has been made by Ontario farmers, municipalities and governments and their agencies to implement nutrient management planning. Ontario farmers and consultants are attending workshops to assist with the development of nutrient management plans. Each farmer in their EFP may list environmental actions such as these that they intend to take as a result of completing their EFP. These actions however are currently not tracked by any government agency. The EFP was intended to be an education awareness evaluation tool and not to be used to track environmental actions taken. As part of Ontario's Clean Water Strategy, the recently passed Nutrient Management Act (June 2002) will provide for province-wide standards to address the effects of agricultural practices on the environment, especially as they related to land-applied materials containing nutrients. An anticipated requirement of this act will be the tracking of land applied nutrients by farms and municipalities alike. Two U.S. programs dealing with agriculture nutrient management are the Comprehensive Nutrient Management Plans (CNMP) developed by USDA and the proposed Permit Nutrient Plans (PNP) under the Environmental Protection Agency's (EPA) National Pollution Discharge Elimination System permit requirements. State's in the U.S. also have additional nutrient management programs.

***Illustration***
For the U.S. portion of the basin the graphic will show the total number of nutrient management plans that are developed expressed as a percentage of the total number of farms in the basin. In Canada the graphic will show the percentage of municipalities with nutrient management by-law's containing standards for intensive livestock operations.

***Limitations***
Presently on the Canadian side (Ontario) Nutrient Management Plans (NMP) are done on a voluntary basis and where municipal by-laws require them to be completed. Due to the fact that NMP's are voluntarily done every plan developed/put into place is not tracked. There are similarities and differences between nutrient management by-laws that reflect local concerns yet highlight the need for standardisation. Such standardisation is proposed in Ontario in the form of province-wide legislation regarding the management of nutrients. In the United States basin the CNMP's are currently tracked on an annual basis due to the rapid changes in farming operations. This does not allow for an estimate of the total number of CNMP's. EPA will be tracking PNP as part of the State's NPDES program.

***Interpretation***
Having a completed a NMP provides assurance farmers are considering the environmental implications of their management decisions. The more plans in place the better. In the future there may be a way to grade plans by impacts on the ecosystem. The first year in which this information is collected will serve as the base line year.

***Comments***
In 1998 Ontario provincial staff of the Ministry of Agriculture, Food and Rural Affairs (OMAFRA) assisted with the development of a model by-law for municipalities to use. The intent of the model by-law is to promote consistency in by-law development across the province. In many instances these by-laws require that OMAFRA, consultants, or professionals certified by OMAFRA complete third-party review of NMP submitted to support a building permit application. At this time OMAFRA also developed Nutrient Management Plan software (NMAN). This allowed for the consistent preparation of nutrient management plans and conformed to the Ministry's 1998 Nutrient Management Planning Strategy. Some municipalities enforce each nutrient management by-law by inspections performed by employees of the municipality or others under authority of the municipality. Presently in Ontario provincial legislation A Proposed Nutrient Management Act (Bill 81) is before the legislature. If proclaimed, provincial regulations under it would supersede municipal bylaws and make Nutrient Management Plans a legal requirement for all farms. This proposed legislation stipulates the establishment of a computerised NMP registry that would act as a tracking method for nutrient management plans. In 1997 the

USDA's Natural Resources Conservation Service formed a team to revise its Nutrient Management Policy. The final policy was issued in the Federal Register in 1999. In December 2000, USDA published its Comprehensive Nutrient Management Planning Technical Guidance (CNMP Guidance) to identify management activities and conservation practices that will minimize the adverse impacts of animal feeding operations on water quality. The CNMP Guidance is a technical guidance document only; it does not establish regulatory requirements for local, tribal, State, or Federal programs. PNPs are complementary to and leverage the technical expertise of USDA with its CNMP Guidance. EPA is proposing that CAFOs, covered by the effluent guideline, develop and implement a PNP.

***Relevancies***
Indicator Type: human activity
Environmental Compartment(s): land
Related Issue(s): stewardship
SOLEC Grouping(s): land use
GLWQA Annex (es): 2: Remedial Action Plans and Lakewide Management Plans, 3: Control of phosphorus, 11: Surveillance and monitoring, 12: Persistent toxic substances, 13: Pollution from non-point sources
IJC Desired Outcome(s): 8: Absence of excess phosphorus, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 8: Eutrophication or undesirable algae, 14: Loss of fish and wildlife habitat

***Last Revised***
Aug 17, 2002

# Integrated Pest Management (Indicator ID: 7062)

***Measure***
The acres of USDA recorded Pest Management Plans developed and applied in the U. S. Great Lakes basin. Report the numbers of farmer attending and Certified under the Ontario Pesticide Education Program Grower Pesticide Safety Course. Evaluate Training Session Questionnaire Surveys administered to farmers by the University of Guelph (Ridgetown College) who have attended the Ontario Pesticide Education Program Grower Pesticide Safety Course. USDA tracks the amount of pesticides used by weight by farmers within the Great Lakes Basin to indicate reductions of use by farmers through pesticide user surveys as an indicator of the adoption of more sustainable agricultural practices.

***Background***
Research has found that reliance on pesticides in agriculture is overwhelming and that it would be impossible to abandon their use in the short term. Most consumers want to be able to purchase inexpensive yet wholesome food. Currently, other than organic production, there is no replacement system readily available at a reasonable price for consumers, and at a lesser cost to farmers that can be brought to market without pesticides.

***Purpose***
To assess the adoption and uptake of Integrated Pest Management practices by farmers and to infer environmentally friendly practices in place, to prevent ground and surface water contamination.

***Ecosystem Objective***
This indicator supports Article, V1 (e (I, viii) – Programs and other Measures (Pollution for Agriculture), Annexes 1,2, 3, 11,12 and 13 of the GLWQA.

***Endpoint***
Sustainable agriculture through non-polluting, energy efficient technology and best management practices for efficient and high quality food production.

***Features***
Given the key role of agriculture in the Great Lakes ecosystem, it is important to track changes in agricultural practices that affect bio diversity, lead to protection of soil, water quality as well as the sustainable future of agriculture and rural development and better ecological integrity in the basin. To produce effective results this indicator relies on optimum combinations of chemical, biological and cultural methods (such as crop rotation, tillage, weeding techniques, intensive monitoring and insect mating disruption. The indicator identifies the degree to which agriculture is becoming more sustainable and has less potential to adversely impact the Great Lakes ecosystem.

***Illustration***
The number/acres of Integrated Pest Management plans being practiced on cropland in the basin compared to the acres needed. This could be an illustrated on a percentage or acre basis. The growth or decline of crop protection chemicals on a long term trend basis.

***Limitations***
USDA only records the IPM plan data on an annual basis currently. It is assumed that these plans, which are voluntary, will be continue to be carried out. A violation of farm chemical *SOLEC 2002 - Proposed Changes to the Great Lakes Indicator suite (Draft for Discussion, October 2002)* 46 use would be a violation of state and federal laws. USDA does track the amount of chemicals applied but with rapid chemical and technology changes it would be difficult to develop accurate trends.

***Interpretation***
Having complete records of IMP's developed and/or chemicals used would provide a better indication of operator's acceptance of environmentally sustainable practices. This data will serve as a baseline for future trends.

***Comments***
Chemicals, technology and legislation are continually changing so the indicator will need to be updated and revised as needed.

***Relevancies***
Indicator Type: human activity
Environmental Compartment(s): land
Related Issue(s): stewardship
SOLEC Grouping(s): land use
GLWQA Annex (es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances, 13: Pollution from non-point sources
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Aug 17, 2002

# Vehicle Use (Indicator ID: 7064)

***Measure***
Amount of vehicle miles traveled. Number of licensed vehicles in the Great Lakes basin. Amount of fuel consumed.

***Purpose***
To assess the amount and trends in vehicle use in the Great Lakes basin and to infer the societal response to the ecosystem stressed caused by vehicle use.

***Ecosystem Objective***
This indicator supports Annex 15 of the Great Lakes Water Qualilty Agreement. An alternative objective is to reduce stress on the environmental integrity of the Great Lakes region caused by vehicle use.

***Endpoint***
Declining trends in automobile dependence and vehicle emissions.

***Features***
Automobiles are the primary contributor to the level of greenhouse gases in the atmosphere. Emissions from vehicle use also contribute contaminants to air and water systems. Automobile oriented development degrades the liveability of urban environments. This indicator assesses the societal response to the well-known consequences of automobile use by measuring trends in vehicle use. This indicator is reported by measuring vehicle miles travelled, amount of fuel consumed, and car ownership numbers. Vehicle use measures provide data that is not available from modal split measures including possible trends in trip distance (a proxy for sprawl development) and trends in number of trips taken.

***Illustration***
A chart showing vehicle miles travelled in the basin or amount of fuel consumed over time will best represent this indicator. Graphic representation of this indicator also involves a ratio of vehicle miles travelled to number of licensed vehicles to infer individual automobile use trends.

***Limitations***
This indicator is limited by details such as different sized cars and trucks will emit different levels of emissions. Daily vehicle miles travelled rates may not take into account a lower number of weekend trips. This measure does not separate miles travelled by trip type, such as commercial goods movement, travel to work and home based trips.

***Interpretation***
This indicator can be used as a reference, indicating an improvement in the state of the ecosystem, as well as a community's commitment towards ecosystem health. Results for this indicator should be interpreted in conjunction with urban development patterns in the basin and indicators in the Urban Issues suite of indicators. Those collected can also be used to compare areas within the Great Lakes region.

***Comments***
This indicator should be measured in conjunction with trends in mass transportation (#7012), which is an alternative to vehicle use. Focusing on automobile use and the current transportation trends will lead to the establishment of higher levels of air quality and in turn improved human health. Data for this indicator is produced by census agencies and local transportation planning departments.

***Relevancies***
Indicator type: response
Environmental Compartment: crosscutting – air, land, and water
Related issues: mass transit, air quality, urban sprawl, smog
SOLEC Groupings: societal responsibility – household/community
GLWQA Annex(es): 10: Hazardous Pollutants, 13: Non-point sources, 15: Airborne Toxic
Substances, 17: Research & Development
IJC Desired Outcome(s): 4: Healthy humans, 5: Economic Viability, 6: Biological Integrity and Diversity, 9: Physical Environmental Integrity
GLFC Objectives:
Beneficial Use Impairment(s): 3: F & W Populations, 9: Drinking water, 14: F&W Habitat

# Natural Groundwater Quality and Human-Induced Changes
## (Indicator ID: 7100)

***Measure***
Groundwater quality as determined by the natural chemistry of the bedrock or overburden, and the concentrations of anthropogenic contaminants such as pesticides, nitrates, pathogens and urban pollutants. Measured parameters would include atrazine levels, nitrate/nitrite levels, total coliform and Escherichia coli levels, taste & odour, TOC/DOC, as well as other parameters of concern.

***Purpose***
This indicator will assess the quality of groundwater for drinking water and agricultural purposes, and for ecosystem function. The consumption of groundwater that is degraded in quality may lead to both animal and human health effects. This indicator may also reveal areas where contamination is occurring, and where programs for remediation and prevention of non-point contamination should be focused.

***Ecosystem Objective***
The quality of groundwater will remain at, or approach, natural conditions.

***Endpoint***
Monitoring of groundwater quantity and quality in the most stressed of the sub-divisions does not detect the deterioration of these conditions.

***Features***
Significant variability of natural groundwater chemistry occurs throughout the basin, however, little variability should occur within hydrogeologic units. Changes in groundwater quality due to anthropogenic activity will indicate the quality of groundwater for human consumption. This indicator should work in conjunction with the Drinking Water Quality Indicator #4175, which measures concentrations of chemical substances such as metals (e.g., lead, mercury) and other inorganic compounds, pesticides, radionuclides, and drinking water disinfection by-products (e.g., trihalomethanes) as well as microbial parameters such as bacteria, viruses and parasites in raw, treated and distributed drinking water.

***Illustration***
Maps showing the natural base chemistry of the U.S. states and province of Ontario could be produced. Additional maps could show the locations of contaminated wells, either in total or for specific types of contamination or areas that are vulnerable to contamination. Water quality data from groundwater monitoring wells adjacent to stormwater retention basins would also be useful, especially in permeable overburden or karst areas.

***Limitations***
Programs to sample both the natural and contaminated quality of groundwater are already present in all eight states and Ontario; however, they are not currently comparable on all levels. Collaboration between federal, state, and provincial agencies could produce a sampling protocol that would make all programs comparable. Several national programs exist in the U.S. that are implemented in all eight states, but sampling sites are too few to be adequate.

Also, groundwater quality sampling of ambient wells unaffected by human activities is necessary to evaluate the natural chemistry. In some areas ambient sampling has not been done, and if contamination has occurred, natural chemistry may not be evaluated effectively.

***Interpretation***
Information relating water use rates may be required to evaluate whether the contamination of groundwater supplies will affect human health. Groundwater in areas of low to non-existent consumption may remain contaminated with little harm to humans. Still, the sensitivity of aquatic ecosystems to groundwater contamination should not be overlooked, as the effects will increase significantly in areas where groundwater discharge is a large component of stream flow.

***Comments***
None.

***Relevancies***
Indicator Type: State
Environmental Compartment(s): water, land
Related Issue(s): drinking water, land-use, fish habitat
SOLEC Groupings: Terrestrial, Land Use
GLWQA Annexes: 1,11,13,16

***Last Revised***
Mar 25 2004

# Groundwater and Land: Use and Intensity (Indicator ID: 7101)

***Measure***
Water use and intensity and land use and intensity.

***Purpose***
This indicator measures land use and water use and intensity within political sub-divisions (or watershed boundaries) and is used to infer the potential impacts of these practices on the quantity and quality of the groundwater resource. Specifically referring to water use, the indicator also measures supply versus demand issues by assessing the reconstruction of water wells and the construction of new wells.

***Ecosystem Objective***
Groundwater quantity and quality remain at, or near, natural conditions.

***Endpoint***
Monitoring of groundwater quantity and quality in the most stressed of the sub-divisions does not detect the deterioration of these conditions.

***Features***
Land use is a measure of the primary use of the land (e.g., percentage of an area occupied by livestock feedlot operations) and land use intensity is the intensity of this use (e.g., head of feedlot cattle per hectare). Water use is a measure of the primary use of all constructed water wells (e.g., the percentage of all wells that are constructed for livestock watering) and water use intensity of withdrawals from these wells (e.g., the equivalent annual depth of water use for livestock watering). The intra-annual variability of water use intensity is also significant. For example, municipal water use is modestly variable during the year while the use of water for livestock is more temperature dependent and the use of water for irrigation is episodic. The reference watershed sub-divisions should be sufficiently large to ensure the availability of data and sufficiently small to ensure that contrasts in the potential impacts are not masked by averaging. Water use that is consumptive (e.g., irrigation) can result in diminished base flows and impacts downstream water supplies and aquatic habitat. Water use that is not consumptive can result in the degradation of water quality (e.g. water used for municipal drinking water). Supply versus demand issues are expressed in the reconstruction of water wells; for example, in the deepening of existing wells or replacement of existing wells with larger capacity wells. Patterns in this practice may indicate a diminished supply due to climatic factors or adjacent land or water use, an increased demand at the well and variations in the quality of the supply or the quality requirements of the demand. All of these causes may be evidence of changes in the sustainability of the groundwater resource. In some cases and jurisdictions, it may not be possible to directly determine water use and intensity. Under these conditions, it may be necessary to infer water use and intensity from land use and related information.

***Illustration***
Water use and intensity, and changes in these practices over time, and supply versus demand issues will be mapped by sub-division. Similarly, land use and intensity, and changes in these practices over time will be mapped by sub-division.

***Limitations***
Methodologies for the determination of land use and intensity using remotely sensed and census data are presently under development and testing. Changes in these parameters can be determined with no greater frequency than that of the collection of the required data and it is unlikely that extensive historical information can be derived. Water use can be measured using data such as water well construction records and permits to take water. These data may be adequate to measure both current and historical practices and therefore changes over time. However, not all uses and users of water are captured in these data sets.

The sustainability of prevailing water use and land use and intensity relative to the groundwater resource is not currently known with certainty in all settings. For example, water well construction information does not include the reason for the reconstruction of a well, which therefore must be determined from other supporting data.

Also, surface water withdrawals may adversely impact groundwater quantity, if surface water contributes to groundwater recharge.

***Interpretation***
Statistical methods are used to detect changes in water use and land use and intensity over time and to identify patterns in supply versus demand.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): water, land
Related Issue(s): land use, agriculture, forestry, and drinking water
SOLEC Grouping(s): groundwater, land use

***Comments***
Land use and water use and intensity, and the characteristics of the groundwater resource are interrelated. Water use within an area is dependent on the distribution of land uses within the same area. Likewise, the intensity of water use is dependent on land use and intensity. Land uses associated with high water use intensities, or with more stringent water quality requirements, are likely to be restricted in areas where the natural quantity or quality of the groundwater resource are limited.

***Last Revised***
Mar 25, 2004

# Base Flow Due to Groundwater Discharge New Indicator
## (Indicator ID: 7102)

***Measure***
Base flow normalized by catchment drainage area, known as base flow yield. This is a common method in which the absolute base flow amount can be determined and normalizing against area allows for a site to site comparison.

***Purpose***
This indicator measures the contribution of base flow due to groundwater discharge to total stream flow by sub-watershed and is used to detect the impacts of anthropogenic factors on the quantity of the groundwater resource.

***Ecosystem Objective***
The capacity of groundwater discharge to maintain in-stream conditions and aquatic habitat at, or near, potential is not compromised by anthropogenic factors. Groundwater inputs influence most critical summer stream habitat characteristics, such as depth, hydraulics, temperature, and chemistry and the distributions of many aquatic organisms, in particular fishes, are linked to base flow levels.

***Endpoint***
Deviations in the base flow characteristics of sub-watersheds are not attributable to anthropogenic factors.

***Features***
Base flow is the more slowly varying component of total stream flow and is often attributed to groundwater discharge to wetlands, lakes, and rivers. Base flow represents the lowest stream flows and some of the most extreme stream habitat conditions, such as low oxygen and high, fluctuating temperatures. Many organisms may be sensitive to, and limited by, these extremes. Base flow is determined from total stream flow data using mathematical algorithms. Unlike point measurements of groundwater levels, base flow is an integrated measure of cumulative groundwater conditions and impacts upstream of the stream flow gauge. Various anthropogenic factors can impact the base flow characteristics of a sub-watershed. For example, increasing extents of paved and other impermeable surfaces due to urban development can reduce recharge and therefore decrease base flow. In contrast, conveyance losses, defined as the quantity of water that is lost in transit, in municipal water and wastewater systems, can increase base flow. Anthropogenic factors in rural settings such as tile drainage and changes in vegetation coverage can impact base flow. The withdrawal of groundwater by pumping or through the drainage of quarries and other excavations can also impact base flow. Natural factors such as climate variability modify both average rates of base flow and the annual distribution of flow.

***Illustration***
**Base flow is calculated and summarized using consistent and standard methods. Base flow indices are mapped by sub-watershed and plotted as time series. Temporal trends, where discernable, are mapped by sub-watershed.**

***Limitations***
Stream flow monitoring of the full land mass is neither technologically nor economically feasible. Methods of determining base flow from total stream flow data are not standardized and the use of differing methods may produce inconsistent results. Differing summary statistics of base flow may also yield inconsistent results. Base flow is a delayed measure of changes in net infiltration (i.e., recharge due to precipitation less water withdrawal by pumping) and, in some settings, changes in this net rate due to anthropogenic factors may not be evident for extended periods of time. Water management practices such as flow regulation replicate base flow characteristics and disable the calculations of natural base flow in sub-watersheds where these practices are significant. Wastewater discharge similarly disables the calculation of natural base flow in sub-watersheds where this discharge is significant.

***Interpretation***
Statistical methods are used to detect changes in indices of base flow with respect to time. These methods are also used to differentiate natural (e.g. climatic) factors from anthropogenic factors as the cause of these changes.

***Relevancies***
Indicator Type: State
Environmental Compartment(s): water, land, biota
Related Issue(s): groundwater dependant ecosystems, climate change, land use
SOLEC Grouping(s): groundwater

***Last Revised***
Mar. 25, 2004

# Groundwater Dependant Animal and Plant Communities (including amphibians) (Indicator ID: 7103)

***Measure***
Numbers and diversity of native invertebrates, fish, wildlife and plant communities dependent on groundwater discharges in tributaries and near shore areas of the Great Lakes. An additional focus on the presence of native cool water adapted frogs (mink frog and pickerel frog) and four salamander species (spring salamander, red salamander, two-lined salamander, four-toed salamander) from the lungless family Plethodontidae that have long-lived larval periods adapted to perennial flowing cool-cold groundwater springs and headwater streams.

The following fishes are associated with cool, groundwater-fed streams and would serve as indicators: slimy sculpin, mottled sculpin, and several species of trout (brook trout, brown trout, rainbow (steelhead) trout). Increased abundance of blacknose dace and other fishes tolerant of warmer conditions relative to that of trout suggests a system that is less influenced by groundwater. Differences across sites (or at a site over time) in the relative proportions of these fishes versus warm- and cool-water fishes may be indicative of groundwater inputs (or changes in such over time). Such data will likely be noisy due to natural population variation. Collection of water temperature data (i.e. hourly measurements during the summer) should also be used for the streams of interest. This will provide an inexpensive and direct measure, of the groundwater contribution to rivers, since most stream fishes have distinct thermal optima.

In order to compare and contrast across the Basin, the co-existence of all species dependant on groundwater must be considered. One could use a species as a surrogate for another where only one species exists. An example would be salamanders and brook trout.

The following outlines a number of groundwater dependent plant communities that would serve as indicators:

| **Community Name** | ***Representative Species*** |
|---|---|
| Northern Poor Fen | SLENDER SEDGE - Carex lasiocarpa<br>FEW-SEEDED SEDGE - Carex oligosperma<br>MOSSES - Sphagnum spp. & Polytrichum spp. |
| Bog Birch-Leatherleaf Poor Fen | LEATHERLEAF - Chamaedaphne calyculata<br>SWAMP BIRCH (a.k.a. Bog Birch) - Betula pumila<br>SLENDER SEDGE - Carex lasiocarpa |
| Bog Birch - Willow Rich Boreal Fen | SWAMP BIRCH (a.k.a. Bog Birch) - Betula pumila<br>WILLOW – Salix spp. |
| Boreal Calcareous Seepage Fen | SLENDER SEDGE - Carex lasiocarpa<br>TUFTED CLUB-RUSH - Scirpus cespitosus<br>HORNED BEAKRUSH - Rhynchospora capillacea<br>BOG ROSEMARY - Andromeda polifolia var. glaucophylla |
| Boreal Sedge Rich Fen | BUXBAUM'S SEDGE - Carex buxbaumii<br>SLENDER SEDGE - Carex lasiocarpa<br>TUFTED CLUB-RUSH - Scirpus cespitosus |
| Northern Poor Patterned Fen | BOG ROSEMARY - Andromeda polifolia var. glaucophylla<br>LEATHERLEAF - Chamaedaphne calyculata<br>SWAMP BIRCH (a.k.a. Bog Birch) - Betula pumila<br>FEW-SEEDED SEDGE - Carex oligosperma |
| Dogwood - Willow - Poison Sumac<br>Shrub Fen | SILKY DOGWOOD - Cornus amomum<br>WILLOW – Salix spp.<br>POISON SUMAC - Toxicodendron vernix<br>LANCE-LEAVED BUCKTHORN - Rhamnus lanceolata |
| Willow - Mixed Rich Shrub Fen | SILKY DOGWOOD - Cornus amomum<br>BLACK CHOKEBERRY - Aronia melanocarpa<br>NANNYBERRY – Viburnum lentago |
| Patterned Rich Fen | SHRUBBY CINQUEFOIL - Pentaphylloides floribunda<br>DIOECIOUS SEDGE - Carex sterilis<br>BIG BLUESTEM - Andropogon gerardii |
| Northeastern Cinquefoil - Sedge Fen | SHRUBBY CINQUEFOIL - Pentaphylloides floribunda |

| | |
|---|---|
| | INLAND SEDGE - Carex interior<br>YELLOW SEDGE - Carex flava<br>NORTHERN PITCHER-PLANT - Sarracenia purpurea |
| Sweet Gale Shrub Fen | SWEET BAYBERRY - Myrica gale |
| Leatherleaf-Sweetgale Shore Fen | LEATHERLEAF - Chamaedaphne calyculata<br>SWEET BAYBERRY - Myrica gale<br>SLENDER SEDGE - Carex lasiocarpa |

***Purpose***
This indicator will assess locations of groundwater intrusions, support measuring of the contribution of groundwater to stream and near shore flows, and contribute to evaluation of trophic status, food web dynamics, and location of groundwater-fed habitats and the groundwater-dependent fish, wildlife and plant communities at risk in the Great Lakes basin. By inference, this indicator will also describe certain chemical and physical parameters of groundwater, including changes in patterns of seasonal flows.

***Ecosystem Objective***
The purpose of the GLWQA is to 'restore and maintain the chemical, physical and biological integrity of the Great Lakes'. Loss of quality and quantity of groundwater in the Great Lakes basin threatens sustained use, and may cause deterioration of drinking water quality for animals and humans and productive capacity of fauna and flora dependent on groundwater resources. This indicator supports Annexes 1, 2, 10, 12, 16 of the GLWQA and Fish Community Goals and Objectives by Great Lakes Fishery Commission.

The "river continuum concept" proposes that the trophic dynamics and integrity of larger streams is based on biological, chemical and hydrological processes that occur in the smaller headwater streams that feed them. Cold groundwater is the primary source of flowing water found in most perennial flowing streams that have a healthy population of cold water adapted fish. However, not all headwater streams in a watershed are fed by groundwater, many become intermittent or ephemeral in summer months. The identification of cold groundwater-fed headwater streams would provide useful information for the development of watershed management plans that seek to protect groundwater sources, and the integrity of the downstream cold water ecosystems.

The newly emerging ecological concept of the "landscape" identifies two operational units, the "patch" and the "corridor", which are imbedded within a background "matrix" of physical-biological structure. Cold spring-fed habitats that emerge at the surface are called rheocrenes, limnocrenes and heliocrenes and are unique types of groundwater dominated landscape patches and corridors.

***Endpoint***
Pre-selected reference species or species composition occurring at a test site. Biomass/production of the selected species/composition is within normal range (means plus 2 SD) of same parameter measured at selected reference sites.

***Features***
The diversity would be reported by indices and/or by biomass and/or presence/absence of selected species or compositions e.g. brook trout, mottled and slimy sculpins, brook lamprey, selected aquatic insects (e.g., mayflies, stoneflies, caddis flies), cedar groves, watercress. In looking at amphibians in particular, the presence of frogs will be determined based on either visual observations of adults, collections of tadpoles, or vocal calls. For salamander, efforts will focus on field documentation of salamander "reproductive potential" such as larvae, egg clutches, or a good mix of juveniles and adults. Specific frog and salamander species found in the Great Lakes basin that can be used as bio-indicators of cold groundwater-fed headwater include: two frog species (mind frog and pickerel frog), and four salamander species (four-toed salamander, spring salamander, red salamander, and two-lined salamander).

Where groundwater emerges to the land surface from a cold water table aquifer, a "spring" type aquatic habitat is formed. There are three general types of cold water-spring habitats:

(1) those that form a well-defined channel (rheocrene);
(2) those that form small pools or basins (limnocrene); and
(3) those that form a vegetated marsh, or swamp (heliocrene).

Cold water springs are unique freshwater ecosystems because their physical and chemical environments are relatively "stable" (low daily variance), although seasonal amplitude is present. The defining characteristics of spring-fed habitats are: (1) water is constantly present, and (2) the thermal environment is relatively cooler in summer months, and warmer in winter, compared to other aquatic habitats across the landscape that are not hydraulically connected to groundwater discharge. Loss of cold spring-fed groundwater habitats can threaten those species with stenothermic (narrow) temperature adaptations.

Two frog species (mind frog and pickerel frog), and the four-toed salamander, are associated with limnocrene and heliocrene types of cold water spring-fed wetland habitats in the Great Lakes basin. The three other salamander species (spring salamander, red salamander, two-lined salamander) are found in very small primary headwater streams that are the origin of larger cold water streams with native fish species (ie. trout and sculpin type streams). Salamander species move higher into the headwater stream network than fish, forming what can be viewed as a 'salamander region' within the headwater streams of nature. The presence of salamander species with long-lived larval periods (2-5 years) can be used to provide a rapid assessment that cold groundwater flow is present. All four of the proposed salamander bio-indicators have extended larval periods, lasting from 2 to 4 years in duration.

***Illustration***
For selected watersheds and sub-watersheds, and selected years, changes in species diversity, relative abundance, biomasses, and distribution would be graphed and/or mapped as surrogate for changes in groundwater quantity, quality and special distribution.

***Limitation***
Selection of other species to complete the description of aquatic communities in coldwater and to assess cool water environments may be necessary. Invertebrate species need to be selected basin-wide. For the amphibian portion of this indicator, use of this indicator depends on experience collecting frogs and stream salamanders, especially larvae. Thus it will be recommended that a combination of qualitative (visual search, vocal calls) and quantitative (leaf bags for salamander larvae, funnel traps for frog tadpoles) sampling methods be used to assess each habitat.

***Interpretation***
More data analyses after modeling of different monitoring networks e.g. well water and fish distributions, plus research, are essential to using existing databases, and making monitoring programs efficient.
However, it may be possible to overlap field information gained from biological sampling with GIS based mapping of geologic features such as depth to bedrock to predict the potential location of groundwater-fed headwater streams.
Combining the bio-indicators (amphibians, cold water fish, plants such as mosses, diatoms, benthic macroinvertebrates, crayfish, etc.) will allow for the identification of cool-cold water groundwater-fed habitat types. In addition, the various biological taxa could be combined to form an "Index of Ecological Integrity" of cold water habitats with groundwater intrusions for the Great Lakes.

***Relevancies***
Indicator Type: State
Environmental Compartment(s): water, land, biota
Related Issue(s): habitat, drinking water, land-use, fish habitat
SOLEC Grouping: groundwater
GLWQA Annexes: 1, 2, 10, 11, 12, 16, 13
IJC Desired Outcome(s): 6:Biological integrity and diversity; 9:Physical environment integrity groundwater
Beneficial Use Impairments: Restrictions on drinking water consumption; loss of fish and wildlife habitat

***Last Revised***
Mar. 25, 2004

# Habitat Fragmentation (Indicator ID: 8114)

***Measure***
The pattern of natural habitat remaining within ecoregions/subsections, as measured by 1) area to perimeter ratio; 2) habitat patch size; and 3) percent intact cover.

***Purpose***
To assess the amount and distribution of natural habitat remaining within Great Lakes ecoregions, and to infer the effect of human land uses such as housing, agriculture, flood control, and recreation on habitat needed to support fish and wildlife species.

***Ecosystem Objective***
Each LaMP is likely to contain objectives that address maximizing the amount of land cover adjacent to the lake. This indicator supports Annex 2 of the GLWQA.

***Endpoint***
The Framework on Guiding Habitat Rehabilitation in Great Lakes Areas of Concern (Environment Canada et al, 1998) suggests specific marsh and forest patch sizes that are required to support various species. For example, 200 hectares of forest patch is required for successful interior forest bird breeding. A total area with more than 70% intact cover is needed for birds.

***Features***
This indicator will present trends in remaining natural habitat within ecoregions/subsections over time. Sufficient parcels of natural habitat are necessary to support wildlife activities such as breeding and migration. For example, lack of interior forest habitat adversely impacts the reproduction of breeding birds. Loss of natural habitat also adversely impacts migrating birds that need to touch down to refuel on their treks north and south. For some threatened species, there is insufficient habitat to sustain populations.

***Illustration***
Using GIS, habitat patch size and percent intact cover can be graphically displayed on a map. Calculations to determine area to perimeter ratio could be done on a GIS using a specially designed algorithm. Although illustrating area to perimeter ratio is more difficult, it would be possible to highlight all patches with a desirable ratio on a GIS map once calculations are complete.

***Limitations***
Although "intact cover" most likely means natural vegetation, primarily forest, there is a need to define this term. The relationship, for example, between the three endpoints — percent intact cover, patch size and perimeter to area ratio — and bird breeding is better understood than the relationship between the endpoints and bird migration. A better understanding of how these endpoints affect bird migration is necessary.

***Interpretation***
Additional research is needed to understand how much habitat is required in a particular ecoregion for different species and for different functions.

***Comments***
As suggested, the amount of habitat required for breeding birds is known, but less is known about the amount of natural vegetation required for migrating birds. The requirements for other species will be just as challenging. Information for this indicator can be collected using remote sensing products.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): land
Related Issue(s): habitat
SOLEC Grouping(s): **land use**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***

# Area, Quality, and Protection of Lakeshore Communities
## (Indicator ID: 8129)

***Measure***
Area, quality, and protected status of twelve special lakeshore communities occurring within 1 kilometre (km) of shoreline. The twelve special lakeshore communities are sand beaches, sand dunes, bedrock and cobble beaches, unconsolidated shore bluffs, coastal gneissic rocklands, limestone cliffs and talus slopes, lakeplain prairies, sand barrens, arctic-alpine disjunct communities, Atlantic coastal plain disjunct communities, shoreline alvars, and islands.

***Purpose***
To assess the changes in area and quality of the twelve lakeshore communities, and to infer the success of management activities associated with the protection of some of the most ecologically significant habitats in the Great Lakes terrestrial nearshore.

***Ecosystem Objective***
This indicator supports Annex 2 of the GLWQA.

***Endpoint***
No net loss in area or quality of the twelve lakeshore communities.

***Features***
The twelve lakeshore communities presented in this indicator are identified in "Land by the Lakes," a paper from SOLEC '96, as some of the most ecologically significant habitats in the terrestrial nearshore. This indicator will map the location and extent of these lakeshore communities from existing studies (where available), Biological Conservation Databases, remote sensing and aerial photos, and land use planning data. The quality of the lakeshore communities will be ranked using criteria such as size, condition, and landscape context. In addition to location and quality, this indicator will identify the protection status related to each identified lakeshore community (e.g., public conservation ownership, private conservation ownership, protective land use policies), as well as the severity of threats to the quality of each community, such as the presence of invasive exotic species.

***Illustration***
Colour mapping could show the distribution of each lakeshore community, ranked by quality or degree of protection for each lake, ecoregion, or the basin. Bar charts could highlight changes over time for each community, or compare the current area to estimates of the original area. A preliminary analysis of sand dune complexes across the Great Lakes basin by The Nature Conservancy's Great Lakes Program provides an example of how the results could be portrayed. In addition to charts showing the percentage of protective ownership, this model illustrates the severity of different types of stresses affecting this community.

***Limitations***
Data collection may be difficult for many reasons. Collection of detailed data on a regular basis may be difficult due to the large area and the number of different jurisdictions to be examined. Identification of lakeshore communities using aerial photography may prove easy for some communities and more difficult for others. Lastly, information on location and quality for some lakeshore communities is incomplete, therefore, this indicator will require some expense to establish a reliable baseline.

***Interpretation***
A baseline of the area of each of the twelve lakeshore communities will be established for comparison with periodic monitoring every 3-5 years to identify changes. As more information becomes available, this indicator could provide a more detailed analysis of changes in area and habitat quality within each of the communities, as well as a better understanding of the threats to these communities. Quality rankings for each occurrence of a lakeshore community can be based on techniques developed by state/provincial Heritage Programs, which establishes classes for size, assesses condition based on disturbance and the presence/absence of sensitive species, and rates the degree of connection and buffering provided by the surrounding landscape context.

***Comments***
This indicator provides easily understood information on the ongoing loss of the best of Great Lakes shoreline communities. The information conveyed by this indicator will help to focus attention and management efforts on the communities undergoing the greatest rate of change.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): land, biota
Related Issue(s): habitat, stewardship
SOLEC Grouping(s): **nearshore terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 23, 2000

# Extent of Hardened Shoreline (Indicator ID: 8131)

***Measure***
Kilometres of shoreline that have been hardened through construction of sheet piling, rip rap and other erosion control shore protection structures. (Does not include artificial coastal structures such as jetties, groynes, breakwalls, piers, etc.)

***Purpose***
To assess the amount of shoreline habitat altered by the construction of shore protection, and to infer the potential harm to aquatic life in the nearshore as a result of conditions (i.e., shoreline erosion) created by habitat alteration.

***Ecosystem Objective***
Shoreline conditions should be healthy to support aquatic and terrestrial plant and animal life, including the rarest species. This indicator supports Annex 2 of the GLWQA.

***Endpoint***
No net increase in the amount of hardened shoreline along any of the Great Lakes or connecting channels.

***Features***
There is limited historical data available on this indicator, but estimates of the extent of shore protection were made as part of an IJC reference in 1992. Data collection for this indicator could include estimates based on aerial photography and limited field studies, with a focus on Areas of Concern and sites identified from the 1992 IJC data where shoreline hardening appears to be increasing.

***Illustration***
A bar chart for each lake, or reaches within lakes, could document the annual change in the amount of hardened shoreline.

***Limitations***
The field data needed to assess the actual length of new hardened shoreline each year would be costly. A commitment to collect data within selected areas every 5 years might be more achievable.

***Interpretation***
The degree of negative impact to aquatic life in the nearshore will vary depending on the design of the protection and on the antecedent conditions. Some types of hardened shoreline induce more severe impacts than do others. A classification scheme that reflects the degree of impacts from different types of shore protection should be developed, based on a literature review.

***Comments***
Some types of shore protection create conditions that are not hospitable to aquatic life in the nearshore. This indicator will measure the extent to which this is occurring.

***Unfinished Business***
< Need to provide a baseline year and a baseline amount of hardened shoreline for the endpoint.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): land
Related Issue(s): habitat
SOLEC Grouping(s): nearshore terrestrial, land use
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 13: Pollution from non-point sources
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 23, 2000

# Nearshore Land Use (Indicator ID: 8132)

***This indicator needs to be linked to #7002 Land Conversion – but we still need to be able to pull out data for 1 km along shore.***

***Measure***
Land use types, and associated area, throughout the Basin. Land use types could include urban residential, commercial, and industrial, non-urban residential, intensive agriculture, extensive agricultural, abandoned agricultural, closed canopy forest, harvested forest, wetland and other natural area.

***Purpose***
To assess the types and extent of major land uses throughout the Basin, and to identify real or potential impacts of land use on significant natural features or processes, including the twelve special lakeshore communities identified in the Biodiversity Investment Area work in SOLEC 1998-2000.

***Ecosystem Objective***
Maintain diverse, self-sustaining terrestrial and aquatic communities. This indicator supports Annex 2 of the GLWQA.

***Endpoint***
No net loss or alteration of significant natural features or processes from current conditions.

***Features***
This indicator will track trends in land uses over time (ideally 5 to 10 year periods) and focus on identifying areas experiencing the greatest changes in land use intensity over time. To identify and map land uses, this indicator will rely on a variety of methods, including remote sensing; aerial photography; available land use planning data for areas identified as already experiencing rapid land use changes (e.g., urban areas and cottage development); municipal data on building permits; and official plan/zoning bylaw amendments. Subsequent yearly monitoring will establish an increase or decrease in the extent of major land use types. This indicator is related to indicator #8136, Nearshore Natural Land Cover and to #7002, Land Conversion.

***Illustration***
For each lake basin, lake, jurisdiction, and ecoregion, a table or graph will display annual changes in the area and degree of interspersion of each land use (same as Land Conversion indicator).

***Limitations***
Data collection may be difficult for many reasons. Collection of detailed data on a regular basis may be difficult due to the large area and the number of different jurisdictions to be examined. Differences in types of land use planning data collected by jurisdictions may also hamper the collection of consistent data to support this indicator. Some limited historical data are available on land use types, but these data are focused on specific areas. A few basin-wide studies have been conducted that would provide a basic description of land use trends (e.g., U.S. National Shoreline Inventory from the early 1970s and a recent IJC water levels reference study) but it may be difficult to compare these data due to differences in methodology and generalizations that may have been used.

***Interpretation***
Developing a baseline for this indicator will require both a review of existing data sources to determine their usability, and a discussion among agencies to establish a common list of land use types and parameters. Computerized analysis of satellite imagery may provide a cost-effective means of data collection. A more detailed study and groundtruthing of selected areas, however, will be needed to assess the relationship of land use changes to the loss or alteration of significant natural features and processes. In particular, results from this indicator should be compared to results from indicator 8129, Area, Quality, and Protection of Special Lakeshore Communities, to assist in identifying land use change patterns that threaten natural habitats.

***Comments***
The twelve special lakeshore communities are sand beaches, sand dunes, bedrock and cobble beaches, unconsolidated shore bluffs, coastal gneissic rocklands, limestone cliffs and talus slopes, lakeplain prairies, sand barrens, arctic-alpine disjunct communities, Atlantic coastal plain disjunct communities, shoreline alvars, and islands. _ Nearshore communities.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): land
Related Issue(s): habitat
SOLEC Grouping(s): **nearshore terrestrial**, land use
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***

# Contaminants Affecting Productivity of Bald Eagles
## (Indicator ID: 8135)

***Measure***
1) Concentrations of DDT Complex, PCB, PCDD, PCDF and other organic contaminants and mercury and other heavy metals in Bald Eagle eggs, blood, and feathers; 2) number of fledged young produced; and 3) number of developmental deformities.

***Purpose***
To assess the number of fledged young, number of developmental deformities, and the concentrations of organic and heavy metal contamination in Bald Eagle eggs, blood, and feathers. The data will be used to infer the potential for harm to other wildlife and human health through the consumption of contaminated fish.

***Ecosystem Objective***
This indicator supports Annexes 2, 12 and 17 of the GLWQA.

***Endpoint***
1) Concentrations of organic and heavy metal contaminants less than the NOAEL in eggs, blood, and feathers; 2) productivity rate of 1.0 young per occupied breeding area annually; and 3) no observed developmental deformities in nestlings.

***Features***
Annual productivity data exists for Bald Eagle breeding areas in the Great Lakes since early 1960s. Data exists on the concentrations of contaminants in eggs and feathers since late 1960s. Annual inspection of nestlings during banding provides rates of expressed deformities.

***Illustration***
For each lake, and subunits within each lake, the following trends will be shown graphically: concentrations of organic and heavy metal contaminants; yearly productivity; and, areas where deformities have been documented. Illustrations for this indicator will also present territories and habitat suitability indices. The data from 1970-1998 will be displayed; data prior to 1970 may have inconsistencies.

***Limitations***
Eagles do not nest on every shoreline of every Great Lake. They are highly viewed by the public and not a good laboratory animal. They can be linked with the presence of colonial waterbirds and osprey using conversion factors to generate a better geographic representation.

***Interpretation***
Biological endpoints specifically related to PTS addressed by the GLWQA are well known and are published in the peer-reviewed literature on cause-effect linkages.

***Comments***
This indicator is one of few that has been tested in the field. It is one of the best indicators identified by the IJC in relation to the GLWQA because long-term data are available and there are known reproductive effects.

Reproductive failure, depressed reproduction, increased incidence of teratogenic effects, and behavioral effects (related to food gathering or parenting skills) are used as endpoints and related various PTS concentrations. Since different PTS have different effects, multiple endpoints are necessary. Also, since the effects change based on concentrations in the biological matrix measured (blood, egg, feather), multiple endpoints are necessary so that progress toward recovery from PTS can be measured.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): biota
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): open waters, nearshore waters, **nearshore terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances, 17: Research and development
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 5: Bird or animal deformities or reproductive problems

***Last Revised***
Feb. 23, 2000

# Extent and Quality of Nearshore Natural Land Cover
## (Indicator ID: 8136)

***Measure***
Percent of natural land cover types within 1 km of the shoreline that meet minimum standards of habitat quality.

***Purpose***
To assess the amount of natural land cover that falls within 1 km of the shoreline, and to infer the potential impact of artificial coastal structures, including primary and secondary home development, on the extent and quality of nearshore terrestrial ecosystems in the Great Lakes.

***Ecosystem Objective***
Maintain the health and function of a representative number of shoreline natural land cover types. This indicator supports Annex 2 of the GLWQA.

***Endpoint***
Shoreline natural land cover types will be 1) well represented, and 2) healthy. To determine if natural land cover within 1 km of the shoreline is well-represented and healthy, additional work is required to develop quantitative endpoints.

***Features***
This indicator will track changes in the number of hectares of coastal communities on the Great Lakes over time. Natural land cover within 1 km of the shoreline generally includes areas that: provide important habitat to migrating birds; contribute sediment and chemical loadings to streams and the lake; preserve the integrity of river-mouth wetlands; and sustain other nearshore natural processes. Only cover type occurrences that meet minimum quality standards would be included. These standards could be based on occurrence size (e.g., over 2 acres), condition, and landscape context, using similar criteria to those in indicator 8129, Special Lakeshore Communities. It is not likely that the natural land cover within 1 km of the shoreline has been assessed in many areas around the Great Lakes. A baseline should be established (i.e. 2000) with re-mapping occurring every ten years (i.e., 2010, 2020) to track trends in land cover change. Data from this 1 km zone can be linked with land cover analysis occurring further inland to report on the health of entire watersheds. Data collection for this indicator should be done in conjunction with indicator 8132, Nearshore Land Use.

***Illustration***
The percentage of land cover within 1 km of the shoreline can be mapped using remote sensing products, such as satellite imagery, and then displayed on geographic information systems (GIS). Different types of vegetation communities can be analyzed and displayed for a particular area of shoreline, or for the entire shoreline of a Great Lake using the GIS. The resulting information could be portrayed as bar charts for each area, showing both comparisons between cover types and changes over time.

***Limitations***
Information on historical vegetation communities is likely available in surveyors records, early journals, and old air photos and will need to be assembled. Although this is a relatively inexpensive indicator, because much of the remote sensing mapping and GIS software is likely already available, there will be costs involved in adapting existing data to report on the 1 km shoreline zone (i.e., joining maps, integrating data at different scales). Establishing a baseline should not be very costly. Costs will rise as this indicator is related to other information (see Interpretation field).

***Interpretation***
This indicator will show whether the nearshore natural land cover is increasing or decreasing in comparison to the baseline, and what kinds of changes are taking place. The information contained in this indicator will be more useful if coupled with other indicators that measure changes in other components of the Great Lakes nearshore terrestrial ecosystems. For example, information on changes in the presence and abundance of birds, reptiles, amphibians, plants and other nearshore terrestrial species dependent on land cover within 1 km of the shoreline will provide a better understanding of how changes in the percentage of natural land cover affects the ecosystem.

***Comments***
The information needed to develop endpoints for this indicator is likely available, but will require a literature search and discussions with additional experts. Representatives from the Long Point and Whitefish Point Bird Observatories should be consulted on the requirements of migratory birds in the shoreline zone. Assembling the historical and current vegetation community information for the 1 km shoreline zone should be undertaken in partnership with other SOLEC groups who are interested in adjacent watersheds because much of the baseline information will be common to both interests.

A more detailed definition of the types of natural land cover to be included in this indicator needs to be developed. Data collection efforts should use satellite imagery at the best resolution available (i.e., 5 or 20 metres) and refine information for specific areas of interest along the lakes using aerial photography.

***Unfinished Business***

***Relevancies***
Indicator Type: state

Environmental Compartment(s): land
Related Issue(s): habitat
SOLEC Grouping(s): **nearshore terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environment integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 24, 2000

# Nearshore Species Diversity and Stability (Indicator ID: 8137)

***Measure***
The type and number of plant and wildlife species, and vegetation regeneration rates within the nearshore area, defined as the area within 1 kilometre (km) of the shoreline.

***Purpose***
To assess the composition and abundance of plant and wildlife species over time within the nearshore area, and to infer adverse effects on the nearshore terrestrial ecosystem due to stresses such as climate change and/or increasing land use intensity.

***Ecosystem Objective***
This indicator supports Annex 2 of the GLWQA.

***Endpoint***
Naturally-regenerating nearshore plant and wildlife communities with a diversity of native species equivalent to historical populations.

***Features***
This indicator will track changes in nearshore plant and wildlife species composition and abundance over time. Plant and wildlife species in the nearshore area are sensitive to changes in environmental and habitat conditions. This indicator could draw on several existing sources of information, as well as encourage new data collection. Ontario, Canada, and most States have comprehensive data sets for breeding birds on a geo-referenced 10 km x 10 km grid that is periodically updated. Similar data are available for herptiles, mammals, and trees, although they are less likely to be comprehensive. For some sites along the shoreline, historical data are available on the regeneration of species such as White Cedar, White Pine, and Canada Yew. Changes in regeneration rates of these species, or of other communities such as lichens, are indicative of either local pressures such as deer browsing, or broader-scale environmental changes, such as air pollution. As new data becomes available (on a 10-15 year cycle for comprehensive coverage), changes over time can be observed.

***Illustration***
Using existing breeding bird data, a map could be readily generated showing shoreline cells (i.e. the number of species within their normal breeding range) with the number of breeding species within each as a percentage of the total number of species within their breeding range.

***Limitations***
Comprehensive data is not available for all species groups, and data collection is laborious and largely volunteer-based. Even for the best data sets, such as the data set on breeding birds, coverage is incomplete in more remote areas. Historical data on regeneration rates is highly site-specific, and available for relatively few sites.

***Interpretation***
These data can be compared to the total number of species that could be expected within each shoreline cell. For some species, population ratios could also be derived as well, as a comparative measure of stress - for example, classing the population of a species within each cell as abundant, common, scarce, or rare. The nature of observed changes over time can indicate different kinds of stresses. For example, a uniform decrease in the diversity of breeding species could indicate a broad-scale stress such as climate change; decreases only on urban fringes while more remote areas stay the same would more likely point to local habitat changes. It would be useful to divide the data between resident and long distance migrant birds in order to separate local from broad impacts.

***Comments***
As part of the indicator development, priority species, which could be groups of birds, woodland frogs, etc., should be selected.

In regional studies carried out in southern Ontario by the Federation of Ontario Naturalists, this method showed a range in values from 100% of expected species in good habitats to less than 70% in areas with degraded conditions.

***Unfinished Business***
< Need to develop a more quantitative endpoint.

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): exotics
SOLEC Grouping(s): **nearshore terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity
GLFC Objective(s):
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations

***Last Revised***
Feb. 24, 2000

# Sediment Available for Coastal Nourishment (Indicator ID: 8142)

***Measure***
Streamflow and suspended sediments at the mouth of major tributaries and connecting channels.

***Purpose***
To assess the amount of water and suspended sediment entering the Great Lakes through major tributaries and connecting channels, and to estimate the amount of sediment available for transport to nourish coastal ecosystems.

***Ecosystem Objective***
This indicator supports Annex 2 of the GLWQA.

***Endpoint***
Functioning longshore transport process necessary for healthy coastal ecosystems.

***Features***
The role of streamflow in sediment transport and nourishment of coastal ecosystems is needed to evaluate and predict the health of the ecosystems. Data for the streamflow and suspended sediments to the lakes from the largest tributaries and for the total combined flow for each lake will be collected every three years. Trends will indicate a change in the amount of sediments available for coastal nourishment. Monitoring of streamflow and sediment load is one of the oldest and most well established programs in both the United States and Canada.

***Illustration***
Data for the streamflow and suspended sediments to the lakes from the largest tributaries and for the total combined flow for each lake will be depicted as line graphs.

***Limitations***
Recent dramatic cuts in the Canadian budget may influence this monitoring. An evaluation is needed to prioritize the location of monitoring locations.

***Interpretation***
Once baseline values are determined, streamflow at the mouths of specified tributaries and concentration of suspended sediments will be tracked.

***Comments***
Data may be eventually used to help evaluate the impacts of climate change.

***Unfinished Business***
< Need to provide a unit of measurement to increase specificity.
< Need to determine a quantifiable endpoint.

***Relevancies***
Indicator Type: state
Environmental Compartment(s): water, sediments
Related Issue(s): habitat
SOLEC Grouping(s): **nearshore waters**, **nearshore terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 23, 2000

# Artificial Coastal Structures (Indicator ID: 8146)

***Measure***
The number and type of artificial coastal structures (including groynes, breakwalls, riprap, piers, etc) on the Great Lakes shoreline. Artificial coastal structures include structures that extend into shallow waters at an angle from the shoreline, or are placed offshore for the purpose of breaking the force of the waves. They are distinct from the hardened shoreline works described in indicator 8131, Hardened Shoreline, which modify the shoreline edge itself.

***Purpose***
To assess the number of artificial coastal structures on the Great Lakes, and to infer potential harm to coastal habitat by disruption of sand transport.

***Ecosystem Objective***
Limit impact to natural features and processes in the terrestrial nearshore and nearshore waters environments. This indicator supports Annex 2 of the GLWQA.

***Endpoint***
Modification or removal of artificial coastal structures which are shown to negatively affect coastal sand transport, and restoration of natural coastal transport and deposition processes.

***Features***
This indicator will present trends in the number of coastal structures over time. From aerial photos and existing data sets, a baseline of artificial shoreline structures will be established. Yearly monitoring will be performed to determine if there is an increase or decrease in the structures. An increase will signify potential increased coastal sand transport disruption.

***Illustration***
A graph with the number of artificial structures on the y axis and the year on the x axis.

***Limitations***
It may be difficult to monitor the number of structures on a yearly basis and correlate with the degree of disruption of sand transport in specific sites. Monitoring could be done every 3-5 years, or in periods directly following high lake levels, when many of these structures tend to be built.

***Interpretation***
An increase in the number of artificial shoreline structures in comparison to the baseline will signal a disruption of the coastal process of sand transport.

***Comments***
Refer to IJC water level reference study for a classification of shore protection types and summaries of the % length by lake and shoreline reach.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): land
Related Issue(s): habitat
SOLEC Grouping(s): nearshore waters, **nearshore terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 24, 2000

# Contaminants Affecting the American Otter (Indicator ID: 8147)

***Measure***
1) Concentrations of heavy metals (e.g., Hg, Pb, Cd) found in hair, blood, liver, and brain of the American otter; and 2) concentrations of DDT and metabolites, PCBs/ PCDFs/PCDDs, Dioxin, and other organic contaminants found in fatty tissues, liver, and blood of the American otter.

***Purpose***
To assess the contaminant concentrations found in American otter populations within the Great Lakes basin, and to infer the presence and severity of contaminants in the aquatic food web of the Great Lakes.

***Ecosystem Objective***
This indicator supports Annexes 1, 2, 12 and 17 of the GLWQA.

***Endpoint***
1) Maintenance of otter populations in the upper lakes, and restoration of sustainable otter populations to lower Lake Michigan, Lake Ontario and Lake Erie watersheds and shorelines; 2) Great Lakes shoreline and watershed populations of American otter should have an annual mean production > 2 young/adult female; and 3) concentrations of heavy metal and organic contaminants should be less than the NOAEL found in tissue samples from mink as compared to otter tissue samples.

***Features***
American otters are a direct link to organic and heavy metal concentrations in the food chain. The species has primarily a piscivorous diet, but feeds on a wide array of other aquatic organisms. It is also more sedentary than avian species associated with aquatic food chains and subsequently synthesizes contaminants from a smaller area. It has an appropriate application to measure environmental contaminants on a Great Lakes level, but also on a localized scale. Changes in the species population and range are also representative of anthropogenic riverine and lacustrine habitat alterations. Indications of contaminant problems have been noted by decreased population levels, morphological measures (i.e. baculum length) through necropsies and declines in fecundity. Most State resource management agencies perform necropsies to determine an index of fecundity, deformities, growth rates, age and general health of a given population. Fecundity data from necropsies should be expressed by county and provincial management district annually. Limited toxicological studies have been conducted on Great Lakes otter. Trapping data has been intermittently available since 1835 in the Great Lakes region as an index of species abundance. In Ontario and the Great Lake States, except Ohio, trapping success has been used to model populations.

***Illustration***
Annual trapping success expressed by total killed and number of otter killed/trapper by county and provincial management district adjacent to Great Lake shorelines from 1950 to the present. Contaminant concentrations and trapping success data could be presented as bar charts showing trends over time, or on a map of the Great Lakes basin showing comparative data among management districts.

***Limitations***
American otters are difficult to maintain for controlled experiments and are highly visible to the public. There is very little toxicological data available on the species for the Great Lakes. Otters have limited populations in the lower Great Lakes. The method of modeling otter populations by harvest success and using indices of fecundity does not accurately measure population levels in the Great Lakes. Little published data exists on the ecology of otters in the Great Lakes region.

***Interpretation***
Interpretation of this indicator may prove difficult since the ecology of the species and toxicological profiles from the region remain essentially unknown. No data are available on cause and effect linkages for otter in the Great Lakes. Otter are usually compared to contaminant levels in mink because the end points of a toxicological effect are better understood.

***Comments***
The potential of the American otter as a Great Lakes Indicator makes intuitive sense. However, more information on its ecology and cause and effect linkages to contaminant problems in the Great Lakes region need to be determined to increase the utility of this indicator.

Resource management agencies should be encouraged to search for and monitor otter toilets on or near Great Lake shorelines for activity annually to note changes in distribution and stability in populations in relationship to sub-units of the Great Lakes that are known to be contaminated.

This proposed indicator was the most contentious of the nearshore terrestrial set, with some commenters suggesting that it be dropped, or replaced with monitoring of otter reproduction. In their view, otter reproduction would provide a measure that is more useful in assessing progress toward the GLWQA objectives versus evidence of reductions inferred from chemical analyses and conservative benchmarks. There is also concern that otter contaminant monitoring duplicates the mink indicator.

In response, other reviewers noted that mink are less common than otters in Lake Superior island environments (where they could provide an indicator that would not be influenced by mainland anthropogenic influences), and that mink are extremely problematic to study in the field. Otter differ entirely from mink in their habits and habitats. Otter are far more easy to trap safely and study in the field, and transmitter durations of 3-5 years are possible. They are observable during the day, and their sign is more obvious than that of mink. The territorial behavior of the American otter facilitates the determination of population densities and assists in monitoring efforts. They also live longer than mink, therefore, they synthesize environmental influences for a longer period. Study skins and furs up to 150 years old are available, allowing a historical analysis of metal concentrations in hair. This historical information could not be collected using mink. Literature worldwide documents anthropogenic toxins as one reason for otter populations declining in many parts of the world.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): biota
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): coastal wetlands, **nearshore terrestrial**
GLWQA Annex(es): 1: Specific objectives, 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 12: Persistent toxic substances, 17: Research and development
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 7: Virtual elimination of inputs of persistent toxic substances
GLFC Objective(s):
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 5: Bird or animal deformities or reproductive problems

***Last Revised***
Feb. 24, 2000

# Protected Nearshore Areas (Indicator ID: 8149)

***Measure***
The percentage of the Great Lakes shoreline under various levels of protection in six classes as defined by the International Union for the Conservation of Nature (IUCN). The six IUCN classes are 1) strict protection, such as nature reserves and wilderness; 2) ecosystem conservation and recreation, such as national parks; 3) conservation of natural features, such as natural monuments; 4) conservation through active management, such as wildlife management areas; 5) protected landscapes/seascapes; and 6) managed resource protected areas, such as sustainable use areas.

IUCN. 1994. Guidelines for Protected Areas Management Categories. Commission on National Parks and Protected Areas with the assistance of World Conservation Monitoring Centre. Gland, Switzerland, and Cambridge, U.K.

***Purpose***
To assess the kilometres/miles of shoreline in protective status. This information will be used to infer the preservation and restoration of habitat and biodiversity, the protection of adjacent nearshore waters from physical disturbance and undesirable inputs (nutrients and toxics), and the preservation of essential habitat links in the migration (lifecycle) of birds and butterflies.

***Ecosystem Objective***
The Great Lakes shall be free of... net loss of fish and wildlife habitat (GLWQA, Annex 2, item xiv). Also relates to several of Lake Superior LaMP's Habitat Objectives including: land and water uses should be designed and located in harmony with the protective and productive ecosystem functions; degraded features should be rehabilitated or restored; and, land use planning and regulation should eliminate or avoid destructive land-water linkages, and foster healthy land-water linkage.

***Endpoint***
Significant increase in extent of Great Lakes shoreline within formal protected areas.

***Features***
The reference values are the kilometres/miles of shoreline which are protected as a percent of the total shoreline and the percent of increase or decrease over time as measured every two to four years.

***Illustration***
For each selected area (e.g., basin-wide, lake, special shoreline community, ecoregion, etc.) graphs will be displayed with the percentage of protected area on the y axis and years on the x axis. Additionally, for each selected area, maps will be displayed that show the protected shoreline and its class of protection.

***Limitations***
Data on national parks and RAMSAR sites should be relatively easy to obtain. However, data from other locations require the cooperation of state/provincial and local authorities, who may not always have the resources to collect or maintain this information. If baseline data is not readily available, collecting the data will be resource-intensive, and therefore expensive. Subsequent data updates will require only moderate expense. This indicator is useless unless the data inventory is kept up to date and there is consistency in data treatment (database management and GIS) which will require readily available expertise, a continuing, low-level, effort in data management, and a consistent approach.

***Interpretation***
Once the baseline is established, the percent of the shoreline in protected status can be tracked. “Bad” or “good” trends will be determined by how the percent of the shoreline in protected status is changing over time. An increase in the percent of shoreline in protected status would be considered “good;” a decrease would be considered “bad.” The indicator may be complemented by information on the status (ecological integrity, quality) of wetlands, natural land cover along the shoreline, and information on special communities. It may be interesting to show where protected areas and AOC/RAP or Biodiversity Investment Areas coincide, and where the information for this indicator is useful for the evaluation of RAPs or Biodiversity Investment Areas.

***Comments***
A protected area database has been kept at Environment Canada; whether it is up-to-date or not is unknown. Precise spatial information (precise location and extent, which part of the shoreline, how far inshore) is either not available or poor. In Canada, data for RAMSAR sites, national parks, or MAB sites should be easy to locate. It is not known how often this data is updated, or whether the sites are periodically monitored for their quality (ecological integrity). In the U.S., data on protected areas would have to be compiled from federal and state agency sources. A useful starting point for relevant data can by found in the Environmental Sensitivity Atlases for each of the lakes and connecting channels.

This indicator overlaps with coastal wetland indicators. It would be good to link the information with an indicator on the location, extent and quality of wetlands; also, to what extent these wetlands are protected. The indicator may need some refinement to express "representativeness" (proportion of special lakeshore habitat types included) or better links to "Important Bird Areas", or conservation plans.

MAB Man and the Biosphere. Initiated by UNESCO to address problems relating to conservation of resources, resources systems, and human settlement development.

| | |
|---|---|
| RAMSAR | The Convention on Wetlands, signed in Ramsar, Iran in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |

***Unfinished Business***

***Relevancies***
Indicator Type: human activity
Environmental Compartment(s): land
Related Issue(s): habitat, stewardship
SOLEC Grouping(s): **nearshore terrestrial**, societal
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 24, 2000

# Breeding Bird Diversity and Abundance (Indicator ID: 8150)

***Measure***
Diversity and abundance of breeding bird populations and communities in selected habitat types, and an avian index of biotic integrity.

***Purpose***
To assess the status of breeding bird populations and communities, and to infer the health of breeding bird habitat in the Great Lakes basin.

***Ecosystem Objective***
This indicator supports Annex 2 of the GLWQA.

***Endpoint***
For this indicator, the desired outcome would vary by species and habitat type. A target of no decline in area-sensitive bird species (forest/grasslands/savannah) could be established for a select group of species within each habitat type being sampled. A target of increasing populations of contaminant-sensitive bird species in coastal breeding territories could also be established and monitoring protocols designed to assess attainment. A target of 90% of the monitoring stations achieving species presence equal to 90% of the expected number based on habitat and range could be a third type of desired outcome.

***Features***
The Great Lakes basin supports a rich diversity of breeding bird species. This region is one of the most important regions on the North American continent for abundance and diversity of breeding birds. Long-term, comprehensive monitoring of the status and trends of bird populations and communities can allow resource managers to determine the health of bird communities and habitat conditions. Because breeding birds are strongly linked to habitat conditions, this indicator has potential to have cross applications to other wildlife taxa and other indicators.

An "index of biotic integrity" has been used successfully in other areas and while its application to bird communities is in the experimental stages, it should be considered. For this approach to be successful across the Great Lakes basin, reference areas with healthy bird communities would be identified and compared with other, potentially less healthy areas. Commonly-used indices of diversity (e.g., species richness, Shannon-Weiner, Simpson's) could be used to describe the health of the bird community in selected habitat types and could be tracked over time.

***Illustration***
Data from this indicator could be presented in a variety of ways. Population status and trends for bird species of interest could be illustrated by simple line graphs representing selected geographic areas or the whole basin. Comparison graphs showing area sensitive forest bird species and species pre-adapted to highly modified landscapes could be used to show effects of land use changes across the basin. Indices of biotic integrity for areas surveyed would be presented in bar graph form and compared to other areas for which the index has been calculated. Broader scaled biodiversity patterns across the Great Lakes basin could be presented in map form that identify key habitat areas (biodiversity investment areas, protected areas, biodiversity hot spots). These maps could also be used to illustrate changes in bird population patterns over time.

***Limitations***
Confidence in using these data to express the health of a large-scale, diverse ecosystem, would depend on having site specific data that adequately represented the range of habitat conditions in the region. For example, relying only on bird monitoring activity in National Parks, where disturbance and fragmentation of habitat is likely low, could result in overly optimistic pictures of population trends or ecosystem health. Conversely, reliance on data from easily accessible areas such as road-side counts, could lead to indices threat suggest conditions are worse than they really are. Data gathering for this indicator is personnel intensive during the short, early-summer breeding season. To adequately survey the Great Lakes basin will require large numbers of trained staff and substantial travel expenses.

***Interpretation***
Changes in abundance, density, and productivity are caused by many factors both on and off the breeding territories. Care must be used in determining the causes of these changes, especially for birds that spend much of each year on migration or in distant wintering habitats. Utilizing information from ongoing research and management on migration routes and wintering areas will be essential for interpreting these data.

***Comments***
Populations and communities of birds have been used to indicate a wide variety of ecological stressors and processes. Birds are abundant in many habitat types. They make up about 70% of the terrestrial vertebrate species in Great Lakes forests for example. Understanding population dynamics and habitat associations of breeding birds will aid in understanding major elements of ecosystem health.

By following a consistent protocol of 10 minute point counts by highly trained professional bird surveyors, stratifying points by habitat, prioritizing habitats to be surveyed, and conducting surveys only on rain-free, calm days, compatible data can be collected by many researchers and agency staff. Substantial agreement and consistency has already been achieved on survey methodology by researchers across the Great Lakes basin.

Habitat analysis and landscape assessment of the Great Lakes basin (see habitat cover indicators) would allow a monitoring protocol to be developed that would identify priority habitat types. It would also allow a stratified, random sampling design, based on relative area of habitat types to be developed. This would provide a more valid, robust and geographically integrated monitoring program than what now exists. Monitoring efforts ongoing in several National Forest (Superior, Chequamegon) and National Parks (Apostle Islands, Isle Royale) and the USFWS Breeding Bird Survey can be used to take model elements for developing this indicator. The Ontario Forest Bird Monitoring Program and Marsh Monitoring Program also provide site-specific data which could be integrated into this indicator. A Great Lakes basin-wide monitoring protocol for gathering habitat-specific information on the status and trends of bird populations and communities, coordinated with systematic, landscape-scale vegetation data will allow basin-wide biodiversity mapping based on bird populations. For most habitat types and bird taxa, monitoring is most efficient when survey data on all singing birds are collected. Multiple indices of ecosystem health can then be calculated based on data gathered.

This indicator allows interpretation at multiple scales. Population trends of an individual species within a limited geographic area provides useful information to land managers and may suggest specific management activities that should be undertaken. Comparisons of indices of biotic integrity among sites would provide a way to evaluate the variety of management strategies employed in similar environmental settings. Analysis of broad patterns, using biodiversity maps provide opportunities to identify landscape level activities that influence ecosystem health.

Expansion of ongoing monitoring and efforts to standardize data gathering and quality control would be one way to approach the development of this indicator with the funds that might realistically be expected.

***Unfinished Business***

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota
Related Issue(s): habitat
SOLEC Grouping(s): **unbounded**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 14: Loss of fish and wildlife habitat

***Last Revised***
Feb. 24, 2000

# Threatened Species (Indicator ID: 8161)

***Measure***
Number, extent, and viability of species ranked as G1-G3 or S1-S3 in the Biological Conservation Database. A global or "G" rank is assigned on the basis of relative endangerment based primarily on the number of occurrences of the element globally. A rank of G1 means critically imperiled globally due to extreme rarity or due to factor(s) making it very vulnerable to extinction. A rank of G2 means imperiled globally due to rarity or due to some factor(s) making it very vulnerable to extinction throughout its range. A rank of G3 means either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range or due to other factors making it vulnerable to extinction throughout its range. A state or "S" rank focuses on the status of a species or ecosystem within the boundaries of a state. A rank of S1 means critically endangered with less than five known occurrences. A rank of S2 means six to twenty occurrences which are to some extent threatened. A rank of S3 means very rare or local throughout its range.

***Purpose***
To assess the number, extent and viability of threatened species, which are key components of biodiversity in the Great Lakes basin, and to infer the integrity of ecological processes and systems (e.g., sand accretion, hydrologic regime) within Great Lakes habitats.

***Ecosystem Objective***
Healthy populations of all vegetation and wildlife, including the rarest of species. This indicator supports Annexes 2 and 17 of the GLWQA.

***Endpoint***
Viable populations of G1-G3 or S1-S3 species that are stable and persistent over the long term, even though local populations may fluctuate significantly in time and space.

***Features***
The rarest species of an ecosystem are indicators of the health of and stresses on the ecosystem. This indicator would emphasize vascular plants for ease of sampling, and would include wildlife to the extent possible. Optimum sampling methods would need to be determined. Representative areas of large size (e.g. 10 km x 10 km square with appropriate habitat) would be selected with ecological subdivisions supporting the species, and sampled at 2-5 year intervals at coarse and fine scales to document locations, aerial extent, and numbers target species. Sampling area size and timeline for trend analysis might vary by species, depending on the habitat and life history. Comparison of successive sampling results would be used to identify short and long term trends. It would be important to select sampling areas that are ecologically relatively intact, as well as some with varying degrees of observable human impact.

***Illustration***
Graphs of population numbers for each target species over time per sampling site, ecoregion, and basin-wide.

***Limitations***
It would be costly to annually monitor all populations of all species. A subset could be sampled annually, to determine trends that might be applicable to the entire set. Certain species are more sensitive to change than others.

***Interpretation***
Natural environments are dynamic by nature, therefore, local decreases or even extirpations of a threatened species may be normal. On the other hand, local extirpations can also be linked to human alterations of habitats through activities such as development. Measures will need to be interpreted with contextual information on anthropogenic disturbances, and need to be taken over sufficient space and time to generate a "big picture" of metapopulations in contiguous or semi-contiguous habitats. Overall stability or increases in viable populations indicates integrity of key supporting processes to which the species are adapted. Overall decreases in population numbers and/or extent can signal deterioration of key processes that maintain suitable habitat.

***Comments***
Experts from the states/provinces should collectively decide which species would be the best indicators. Using the ranking system from the Biological Conservation Database provides a more uniform assessment of status across jurisdictions, and provides access to an existing digital database.

***Unfinished Business***
< Need to provide quantitative values for "viable populations."

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota, fish
Related Issue(s): exotics, habitat
SOLEC Grouping(s): **unbounded**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring, 17: Research and development
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 3: Degraded fish and wildlife populations, 14: Loss of fish and wildlife habitat

***Last Revised*** Feb. 24, 2000

# Health of Terrestrial Plant Communities (Indicator ID: 8162)

***Measure***
Trends in time and space of 1) non-native insect or disease infestation of plants and 2) plant mortality or damage (including deformities) throughout the Great Lakes basin.

***Purpose***
This indicator will assess the presence, abundance, distribution and trends over time of non-native insects and diseases infesting plants, and their impacts on plant mortality or damage (including deformities), as well as the impact of airborne and groundwater pollution on plant community health.

***Ecosystem Objective***
Healthy, diverse plant communities throughout the Great Lakes basin, providing habitat to support diverse communities of animals. Plants should be abundant and readily available for human medicinal, cultural and decorative use.

***Endpoint***
None at present, but presumably something such as "Absence or minimization of non-native disease or insect infestations of plants, also, minimization of airborne and groundwater pollution, and therefore absence or minimization of plant mortality or damage including deformities."

***Features***
Healthy native plant communities dominated the Great Lakes basin before European settlement. Many of these plants were used by First Nations / Tribes as an integral part of their culture. Some of these communities have sustained multiple ecological insults though non-native diseases, insect infestations and pollution from atmospheric and groundwater sources. Re-establishment of healthy plant communities means that appropriate habitat will be available for dependent animal communities as well. Human use of these plants can then occur at a sustainable rate throughout much of the basin.

***Illustration***
To be developed

***Limitations***
- Areal extent of insect and disease infestation on non-commercial plant communities.
- Areal extent of pollution impacts on plant communities.
- Control of the entry of non-native diseases and insects.

***Interpretation***
The target is an increase in areal extent of healthy plant communities, free of non-native insects, diseases and impacts due to pollution. If the target values are met, the system can be assumed to be healthy; if the values are not met then there is health impairment.

***Comments***
To be developed

***Unfinished Business***
To be developed

***Relevancies***
Indicator Type: state
Environmental Compartment(s): biota, plants
Related Issue(s): pathogens, non-native species, habitat, atmospheric pollution, ground water pollution
SOLEC Grouping(s): **terrestrial**
GLWQA Annex(es): 2: Remedial Action Plans and Lakewide Management Plans, 11: Surveillance and monitoring; 15: Airborne toxic substance; 16: Pollution from contaminated groundwater
IJC Desired Outcome(s): 6: Biological community integrity and diversity
Beneficial Use Impairment(s): 14: Loss of (fish and) wildlife habitat

# Status and Protection of Special Places and Species
## (Indicator ID: 8163)

***Measure***
Area, quality, and protected status of special places at the landscape level, and counts of those species of special cultural or spiritual significance to peoples in the Great Lakes basin.

***Purpose***
To assess the status and degree of protection (at the landscape level) in area and quality of special places and special species of cultural and spiritual significance especially to First Nations/ Tribes. Special places include: ecologically unique areas e.g. rocky outcrops, large dead trees; and cultural treasures, e.g. burial grounds and areas where medicinal herbs grow. Special or iconic species are ones such as pileated woodpeckers, turtle, wolf, martens, medicinal herbs, bald eagles, American Otter, or rare species.Additionally this indicator will infer the success of management activities associated with the protection of areas and species.

***Ecosystem Objective***
This indicator supports the overall goal of the GLWQA: "…maintain…biological integrity of the Great Lakes basin." and Article IV,1,c "outstanding resource value" and Annex 2, 1(c) xiv & 4(a), iii

***Endpoint***
No net loss in area or quality of special places or of the number and abundance of special species.

***Features***
To be developed

***Illustration***
Colour mapping could show the size and distribution of each special place including trends over time (net losses or net gains). Graphs and maps could show population distributions of special species and trend in time information on populations.

***Limitations***
Data collection may be difficult because many of the special places may only be identified through cultural association. It may not be possible to use remote sensing, for example. Data collection will depend on individual memories. Special species counts may be easier, in that communities may be willing to provide volunteers to do the counts.

***Interpretation***
Baseline information, frequency of monitoring (suggest 3-5 years) – see #8129 for other points to add.
*Comments*
This indicator provides easily understood information on the status of special places and culturally significant species throughout the Great Lakes. The information conveyed by this indicator will help aboriginal peoples and others to focus attention and management efforts on preserving and / or rehabilitating these places and species.

***Unfinished Business***
To be developed

***Relevancies***
Indicator Type: state and societal response
Environmental Compartment(s): land, biota
Related Issue(s): habitat, societal response
SOLEC Grouping(s): **societal**
GLWQA Annex(es): ?????
IJC Desired Outcome(s): 6: Biological community integrity and diversity, 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s): 14: Loss of fish and wildlife habitat

***Last Revised***
July 2002

# Forest Health Criterion #1: Conservation of Biological Diversity (Indicator ID: 8500)

***Measures***

(1) Extent of area by forest type relative to total forest area
(2) Extent of area by forest type and by age-class or successional stage
(3) Extent of area by forest type in protected area categories as defined by IUCN or other classification systems

***Purpose***

Criterion 1 indicators describe the extent, composition and structure of Great Lakes basin forests. They address the capacity of forests to perform the hydrologic functions, and host the organisms and essential processes that are essential to supplying high quality water and protecting the physical integrity of the watershed.

***Ecosystem Objective***

Indicator (1) summarizes total forest area and area by forest type. The extent and diversity of forest cover are positive indicators of basin health. Water draining forested watersheds is of high quality, as measured by sediment yields, nutrient loadings, contaminant concentrations and temperatures. Forests also control soil erosion, increase groundwater infiltration, stabilize shorelines and regulate storm run-off. Leaf litter and woody debris provide critical food and habitat for fish and other aquatic wildlife.

Indicator (2) summarizes the structure of forest based on age class. Many ecological processes and wildlife species are associated with vegetative structures (age, diameter and height of vegetation) and successional stages (variable species of vegetation).

Indicator (3) summarizes the extent of forest by type in a protected area category. Protected status ensures that specified tracts of land remain under forest cover, and is indicative of the value a society and its policymakers place on forest conservation.

***Endpoint***

No endpoints yet. Establishing endpoints requires consensus on desired forest cover patterns.

***Features***

U.S. data from U.S.D.A. Forest Service, Forest Inventory and Analysis Database. Raw data available online at: http://ncrs2.fs.fed.us/4801/fiadb/fiadb17_dump/fiadb17_dump.htm. These are statewide data sets and therefore require geoprocessing using GIS software to extract data relevant to basin only. Canadian data courtesy of Ontario Ministry of Natural Resources.

***Illustration***

Indicator (1): Pie chart to show proportions of total forest area that lie within each forest type.

Indicator (2): Line graphs to compare age-class distributions, by area, of the major forest types (maple-beech-birch, aspen-birch, white-red-jack pine, spruce-fir) to the age-class distribution of the forest at large. Separate graphs will be used for the U.S. and Canadian basin forests, because there are significant differences in the age-class distributions of the two countries' basin forests.

Indicator (3): Bar chart to highlight the protection rate (percentage of area under protected status) for major forest types. Again, separate charts will be used for the U.S. and Canada because definitions of protected forest differ slightly.

***Limitations***

Indicator (1): Data do not indicate if forests are located in riparian zones, where the impact on the watershed is the greatest. More importantly, the data do not indicate if the expansion in forest area is occurring in riparian zones.

Indicator (2): No data on extent of forest by successional stage. Although certain species are associated with the various successional stages (aspen-birch tends to be early successional and maple-beech-birch is mid- to late-successional), designation of successional stage is currently made by professional judgment rather than a standard protocol.

Indicator (3): IUCN, U.S. and Ontario definitions of protected areas differ slightly. There is substantial overlap among these definitions, but a more consistent classification system would ensure proper accounting of protected areas and would enable aggregation of the two countries' data. Moreover, existing definitions only incorporates public land and does not include forests that may be protected through conservation easements and land trusts, or timber lands managed in a sustainable manner.

***Interpretation***

Implications for water quality and quantity are difficult to establish, but the data provide insight on general trends in forest sustainability. Healthy, vigorous forests are indeed crucial to basin ecosystem health. Interpreting the data with respect to forest health, however, will require additional assistance from forestry experts and stakeholders.

***Comments***

Once the U.S.D.A. Forest Service updates Ohio data (current set is from 1991), then the area covered by riparian forests within the U.S. basin can be calculated. Changes in data definitions made in 1999 make it difficult to aggregate Ohio data with data from other states, which were collected in 2001-2002.

***Relevancies***
Indicator Type: state
Environmental Compartment(s): land
Related Issues: habitat, water quality, run-off regulation, shoreline stability
SOLEC Groupings: forests
GLWQA Annex(es): 1 (indirectly)
IJC Desired Outcome(s): Biological Community Integrity and Diversity, Physical Environment Integrity (Quality and Quantity of Stream Base Flow)
Beneficial Use Impairment(s): Degradation of aesthetics, Loss of fish or wildlife habitat, Degradation of fish or wildlife populations

***Last Revised***
August 20, 2004

## Forest Health Criterion #2: Maintenance and Productive Capacity of Forest Ecosystems (Indicator ID: 8501)

***Description not available at this time***

## Forest Health Criterion #3: Maintenance of Forest Ecosystem Health and Vitality (Indicator ID: 8502)

***Description not available at this time***

## Forest Health Criterion #4: Conservation & Maintenance of Soil and Water Resources (Indicator ID: 8503)

***Description not available at this time***

# Acid Rain (Indicator ID: 9000)

***Measure***
1) Levels of pH in precipitation in the Great Lakes Basin, and 2) the area within the Great Lakes basin in exceedance of critical loadings of sulphate to aquatic systems, measured as wet sulphate residual deposition over critical load (kg/ha/yr).

***Purpose***
To assess the pH levels in precipitation and critical loadings of sulphate to the Great Lakes basin, and to infer the efficacy of policies to reduce sulphur and nitrogen acidic compounds released to the atmosphere.

***Ecosystem Objective***
The Canada/U.S. Accord on Air Quality pledges the two nations to reduce the emissions of acidifying compounds to the point where deposition containing these compounds does not adversely impact aquatic and terrestrial biotic systems. This indicator supports Annexes 1 and 15 of the GLWQA.

***Endpoint***
Levels of sulphate in wet deposition are not to exceed critical loads, defined by ecozone to be from 8 - 20 kg/ha/yr.

***Features***
Measurements of sulphate deposition and pH are made by the US NDDN and Canadian CAPMoN networks along with provincial and state partners. These data are stored in databases on both sides of the border.

***Illustration***
Data are routinely extracted from databases into annual maps of sulphate and pH deposition. These maps will be used to depict this indicator.

***Limitations***

***Interpretation***
This measure is not sufficient to fully understand the deposition problem and trends in pH concentration throughout the basin is another related indicator. Areas exceeding the sulphate critical load continue to be ecologically stressed due to high levels of acidity.

***Comments***
Current projections how that this may not occur until after 2010. The two specific measures tracked both provide indication of progress towards the goal of reducing acidifying substances.

Further progress in reduction of acidifying substances are required.

***Unfinished Business***
< Need to determine what the target pH level is.
< Need to add more information on how often measurements of sulphate and pH are made, and the spatial trends (i.e., location of monitoring sites within the Great Lakes basin) described by this indicator.

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): air, water, land
Related Issue(s): contaminants & pathogens
SOLEC Grouping(s): **unbounded**
GLWQA Annex(es): 1: Specific objectives, 11: Surveillance and monitoring, 15: Airborne toxic substances
IJC Desired Outcome(s): 9: Physical environmental integrity
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
Feb. 24, 2000

# Exotic Species (Indicator Code: 9002)

***Measure***

***Purpose***
This indicator will assess the presence, abundance and distribution of invasive exotic species in the Great Lakes basin ecosystem and their impacts on ecosystem functioning. *This indicator is under development. It has been added to the SOLEC list in response to suggestions from multiple reviewers of the Version 3 list of SOLEC indicators.*

***Ecosystem Objective***

***Endpoint***

***Features***

***Illustration***

***Limitations***

***Interpretation***

***Comments***

***Unfinished Business***

***Relevancies***

***Last Revised***
Feb. 25, 2000

# Climate Change: Effect on Crop Heat Units (Indicator ID: 9003)

***Measure***
The temporal change in seasonal Crop Heat Units (CHU) in the Great Lakes basin. Crop Heat Units are indicators of crop suitability, used to assist farmers in selecting the most appropriate varieties or hybrids of crops specifically corn and soybeans suitable for their area. They represent the total accumulated CHU for the frost-free growing seasons in each area.

***Purpose***
To assess the trends in Crop Heat Units in the Great Lakes basin as an indicator of climate change. A change in atmospheric temperature due to climate change has the potential to increase Crop Heat Units. This indicator may also aid to infer the potential impact climate change has on species diversity and crop productivity.

***Ecosystem Objective***
GLWQA General Objective: "These waters should be free from materials and heat directly or indirectly entering the waters as result of human activity that . . . produce conditions that are toxic or harmful to human, animal or aquatic life." Change in atmospheric temperature will potentially affect the CHU in the Great Lakes basin. Changes in Crop Heat Units will affect the spatial variability, species diversity and productivity of crops in the Great Lakes basin.

***Endpoint***
An endpoint will need to be established, based on a literature search of historical data, to determine the average Crop Heat Units in the Great Lakes basin prior to when the effects of climate change are evident.

***Features***
Crop Heat Units are essentially crop development units, they are used to predict how climate, affects the growth and development of crops from planting to maturity. Temperature is the most important among all environmental factors that influence rate of plant development.

Daily temperatures are influenced by latitude, elevation and location (such as the proximity to large water bodies). Lower overall temperatures tend to impede crop growth where as warmer temperatures support crop growth. It is predicted that increases in temperature and subsequent increases in CHU due to climate change will eliminate many natural habitats and change their potential productivity making them more suitable to human economic activities such as farming. It is predicted that climate change will produce a positive change in agricultural productivity such as increased yields in corn and soybeans in the Upper Great Lakes region.

According to Rochefort and Woodward (1992), climate is often hypothesized to be the primary factor in determining species composition and defining plant distribution. It is predicted that a 3°C increase in temperature as determined from General Circulation Models (GCM's) will increase the diversity of approximately one third of the worlds floristic regions. Bootsma (2002), also predicts using Canadian General Circulation Model (CGM1) scenarios that CHU in Ontario, near the Great Lakes would increase by over 400 for the period 2010– 2039 and between 800 for the period 2049 – 2069. It is also predicted that areas on the US side of the basin that presently have CHU ~2800 will display increases in crop yield of up to 2025. For grain corn and soybeans, the earliest available hybrids/varieties require ~ 2300 CHU.

These GCM also predict that the mean surface temperature will warm by 3°C, and the global mean precipitation will increase by 10%. However, it must be noted that GCM's are essentially mathematical formulations of atmosphere, ocean and land surface processes, they do not include vegetation. According to Rochefort and Woodward (1992), the exclusion of vegetation leads to significant errors in surface energy balance and hydrological calculations.

***Illustration***
A graph showing the Seasonal Crop Heat Units for different regions in the Great Lakes basin on the y-axis and years on the x-axis, beginning with the cutoff date for the historical data. The graph will indicate the overall trend and also will display extreme events. Time series maps showing the contours of CHU in the Great Lakes basin and how these contours have migrated or changed would also provide useful information.

***Limitations***
A limitation of the CHU method is that it assumes temperature will have the same response on a crop regardless of its developmental stage. However, corn responds more sensitively to temperature in the vegetative to silking stage as opposed to the stage from silking to maturity.

In addition, CHU assumes that plant growth is directly related to temperature only, however other environmental factors such as photoperiod (the daily period from sunrise to sunset), soil fertility, soil moisture, slope and location also affect plant growth.

***Interpretations***
Information on changes in species diversity and crop yield from vegetation surveys and harvest data collected over time in the Great Lakes basin will help to strengthen the link between CHU, species diversity and productivity. It also should be noted that past and

future changes in species diversity and crop yields may be attributed to development of higher yielding hybrids and to changes in input costs of production.

Increased temperature and subsequent increases in CHU could expand areas where corn and soybeans can be economically produced, allowing longer season hybrids to be grown provided that increased temperature does not lead to increased water deficits. Thus producers in the Great Lakes basin will likely shift to corn and soybeans as the climate warms.

***Comments***
To interpret this indicator, climatological data including daily maximum and minimum temperature will need to be collected. Separate calculations need to be conducted for both day and night, as the daily CHU is the average of the two. According to Brown and Bootsma (1993), the daytime relationship uses 10°C (50°F) as a base temperature and 30°C (86°F) as an optimum, because warm season crops do not develop when daytime temperatures fall below 10°C and they develop fastest at 30°C. The nighttime relationship uses 4.4°C (40°F) as the base temperature and does not specify an optimum temperature because nighttime minimum temperature seldom exceeds 25°C in Ontario. The seasonal CHU are obtained by adding all the daily CHU values between the start and the end date.

CHUday = 3.33 (Tmax – 10.0°C)) –0.084 (Tmax –10.0°C)2
CHUnight = 9/5 (Tmin – 4.4°C)
CHU = (CHUday + CHUnight)/2

When doing calculations the start and end date of the daily accumulations need to be determined to get annual sums. According to Brown and Bootsma (1993) the date to start accumulating CHU is estimated as: 1) The last day of 3 consecutive days with daily mean air temperature less than 12.8°C (55°F) and 2) The starting date for this 3-day period each year occurred after the date the 30 year average daily mean temperature reached 10°C (50°F) in spring for each weather station site. The end date which CHU stop accumulating is either 1) the first occurrence of –2°C (28°F) or 2) the date when the 30 year daily mean air temperature dropped to 12°C or lower.

Climatological data is easily accessible from meteorological stations in Canada from Environment
Canada's, Meteorological Service of Canada and in the U.S. from the National Climatic Data Center. CHU is recognized around the U.S. and Canada as one of the best methods to quantify the effect of temperature on corn development.

***Unfinished Business***

***Relevancies***
Indicator Type: pressure
Environmental Compartment(s): biota
Related issue(s): climate change, species diversity
SOLEC Grouping(s): unbounded
GLWQA Annex(es):
IJC Desired Outcome(s):
GLFC Objective(s):
Beneficial Use Impairment(s):

***Last Revised***
August 9, 2002