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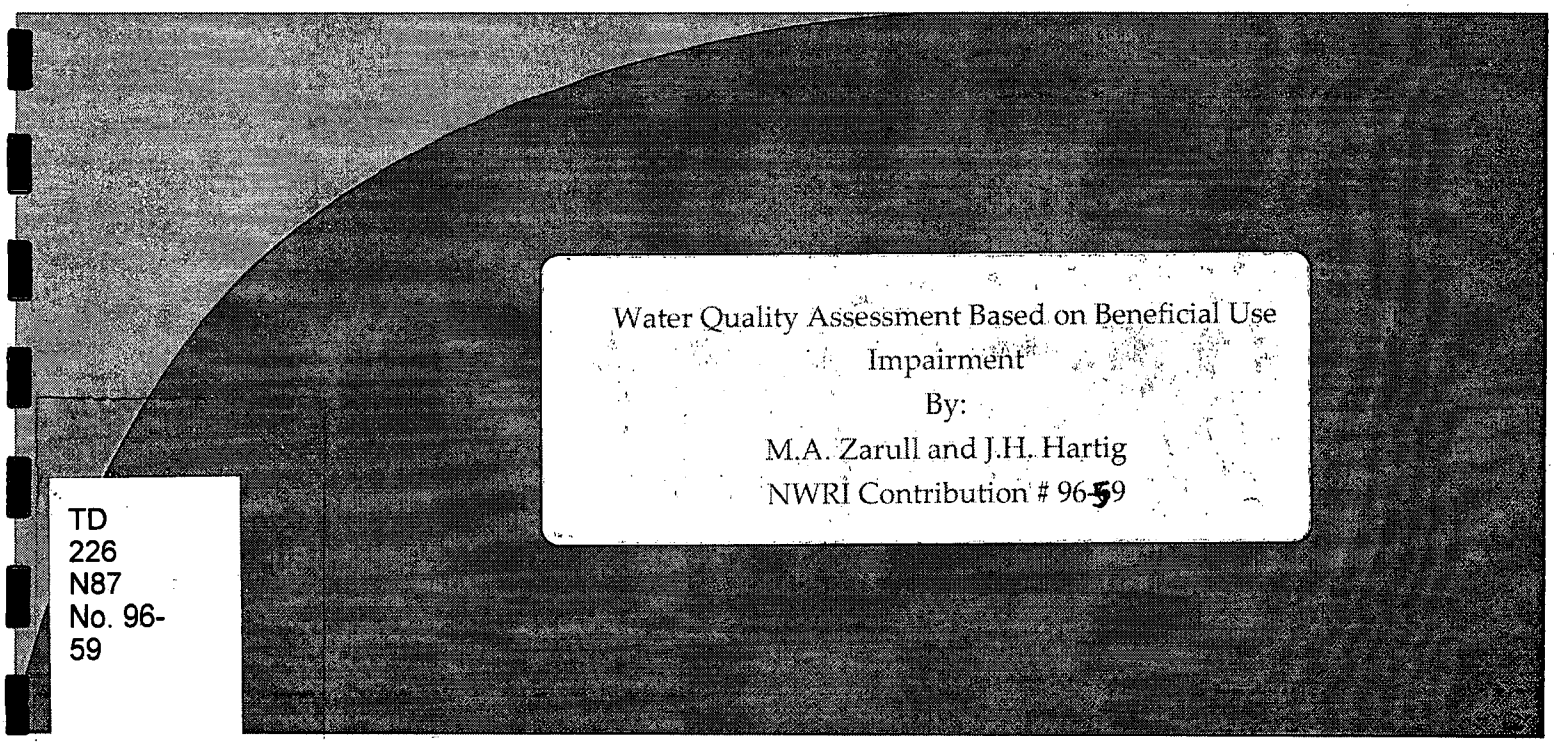

Water Quality Assessment Based on Beneficial Use Impairment

By:

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# FRESHWATER QUALITY: DEFINING THE INDEFINABLE?

*Edited by*
*P. J. Boon and D. L. Howell*


*EDINBURGH: THE STATIONERY OFFICE*

# 17 Water Quality Assessment based on Beneficial Use Impairment

*M. A. Zarull and J. H. Hartig*

Summary

1. The development of use-based objectives provides a common foundation for assessment, rehabilitation and protection of the Laurentian Great Lakes Basin ecosystem.

2. The first step in this process was the development of narrative objectives based on cumulative scientific research, followed by a process of peer review and public consultation.

3. The next step was the development of numerical criteria or indicators that provide quantification of the identified use. These indicators are area-specific (although they may apply to more than one area) and are developed by specialists working in the geographic area along with local stakeholders.

## 17.1 Introduction

The Laurentian Great Lakes have a combined surface area of approximately 246,000 $km^2$ and hold almost one-fifth of the total surface liquid fresh water of the earth. The drainage basin population exceeds $37 \times 10^6$ with more than $24 \times 10^6$ depending on the lakes for drinking water. Due to the availability of abundant fresh water, for consumption, transportation, irrigation and waste disposal, the region became the industrial heartland of North America. Approximately 50% of the USA's steel production and 62% of Canada's comes from this area. However, this development and accompanying prosperity has not been without environmental cost. The lakes have been, and continue to be, stressed by the presence of excess nutrients, oxygen-consuming wastes, eroded soil and persistent toxic substances. They also have experienced severe losses of wetlands and other habitats, invasions and impacts from many exotic species, and significant losses of natural biodiversity from these and other human-induced stresses (Hartig and Zarull, 1992; Allan and Zarull, 1995). Perhaps the greatest or more obvious

expression of impact from these stresses has been in the nearshore embayments, harbours and river mouths adjacent to the human population centres.

Canada and the USA have signed a series of water-quality agreements for the Laurentian Great Lakes in 1972, 1978 and 1987, as part of their 1909 Boundary Waters Treaty (USA and Canada, 1972, 1978, 1987). The purpose of these agreements is to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin ecosystem. As part of this process, the two countries adopted some common, general and specific objectives to assess water quality. These objectives are used to determine both the need for remedial and preventative actions and their effectiveness. The latest Agreement also committed the governments to develop plans and take specific actions to remediate contaminated nearshore areas, which are referred to as Areas of Concern. These are defined as areas that fail to meet the general or specific objectives of the Agreement, and where such failure has caused or is likely to cause impairment of beneficial use(s) or impairment of the areas' ability to support aquatic life.

This approach attempts to reconcile general and specific water quality objectives (which can be different among the eight Great Lakes states, the Province of Ontario and the two federal governments) with an ecosystem, use-based assessment. However, the Agreement does not provide detailed definitions of impairments or guidance on their quantification. Recently, attempts have been made to quantify ecosystem integrity and the beneficial use impairments identified in the Agreement, through a series of scientific symposia and workshops, and through the use of public review and comment.

## 17.2 Goals and Objectives

The statements of beneficial use impairment, contained in the Agreement, provide a common means of defining existing problems along with their causes and a standard way of assessing future conditions throughout the lakes. The absence of a single numeric expression for each impairment acknowledges the need for site-specific indicators. The process includes developing a narrative objective which, when achieved, will satisfy or indemnify a particular use goal, and then developing a quantitative indicator that identifies the achievement of the objective. The process is often iterative. Once a better understanding of the state and functioning of the system is gained, the indicator may need to be revised.

The 14 beneficial uses described in the Agreement can be grouped into four aspects of ecosystem health or performance: human health, societal value, economic value and biological or ecological performance. These groupings also illustrate the need to have a variety of professionals and the public collectively involved in the process, to ensure their effectiveness through technical accuracy and consensual development. The following sections provide a summary of the narrative objectives for the Laurentian Great Lakes and selected examples of local numeric indicators that have been established to demonstrate the achievement of those objectives.

### 17.2.1 *Restrictions on fish and wildlife consumption*

The use is deemed to be impaired when contaminant levels in fish or wildlife populations, due to contaminant input from the watershed, exceed current standards, objectives or guidelines, or public health advisories that are in effect for human consumption of fish or wildlife.

### 17.2.2 *Tainting of fish and wildlife flavour*

The use is considered impaired when ambient water quality standards, objectives, or guidelines, for the anthropic substance(s) known to cause tainting, are being exceeded or survey results have identified tainting of fish or wildlife flavour.

### 17.2.3 *Degraded fish and wildlife populations*

This beneficial use is impaired when fish and wildlife management programmes have identified degraded fish or wildlife populations due to a cause within the watershed. In addition, this use will be considered impaired when relevant, field-validated, fish or wildlife bioassays, with appropriate quality assurance/quality controls, confirm significant toxicity from water column or sediment contaminants.

In Hamilton Harbour (Lake Ontario), the overall objective is to shift from a fish community indicative of eutrophy, to a self-sustaining community indicative of mesotrophy. Quantitative fishery targets include: 200–250 $kg\,ha^{-1}$ total biomass of fish in littoral habitats; 40–60 $kg\,ha^{-1}$ piscivore biomass in littoral habitats; 70–100 $kg\,ha^{-1}$ specialist biomass in littoral habitats; 30–90 $kg\,ha^{-1}$ generalist biomass in littoral habitats; native piscivores representing 20–25% of total biomass; 80–90% native species; and a species richness of six to seven species per survey transect (Hamilton Harbour Remedial Action Plan Writing Team, 1992).

### 17.2.4 *Fish tumours or other deformities*

When the incidence rates of fish tumours or other deformities exceed rates at unimpacted control sites or when survey data confirm the presence of neoplastic or pre-neoplastic liver tumours in bullheads or suckers (demersal fish), this use is declared impaired.

### 17.2.5 *Bird or animal deformities or reproductive problems*

When wildlife survey data confirm the presence of deformities (e.g. cross-bill syndrome) or other reproductive problems (e.g. egg-shell thinning) in sentinel wildlife species, this beneficial use is regarded as being impaired.

In the Fox River and Green Bay (Lake Michigan, Wisconsin), historical discharges from the world's largest concentration of pulp and paper mills are believed to be the primary source of 30,000 kg of PCBs that reside in river sediments downstream of Lake Winnebago and up to 15,000 kg of PCBs in Green Bay. Studies have demonstrated avian exposure to contaminants through aquatic food chains. A 1983 study of two colonies of Forster's tern showed reproductive

success of a lower Green Bay colony to be significantly impaired when compared with a relatively clean reference colony on Lake Poygan, upstream from industrial activities in the Fox River. Based on the 1983 study and an additional study in 1988, reproductive success was defined using four criteria: hatching rate (90% success rate), fledging rate (one chick/pair), incubation time (23 days), and chick growth rate.

### 17.2.6 *Degradation of benthos*

This use is deemed impaired when benthic macroinvertebrate community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when toxicity (as defined by relevant, field-validated, bioassays with appropriate quality assurance and quality controls) of sediment-associated contaminants at a site is significantly higher than controls.

In Canada, site-specific guidelines for benthos are being established from a reference site database (biological attributes and environmental variables) using multivariate techniques, such as cluster and ordination analysis (Reynoldson and Zarull, 1993). Reference site benthic communities are grouped using cluster analysis. The site environmental variables, which are not affected or minimally affected by human activity, are then used as predictors to group the sites into the appropriate biological clusters. The benthic community structure and the same nine environmental variables (depth, $NO_3$, silt, aluminium, calcium, loss on ignition, alkalinity, sodium, pH) are measured at the test sites. Using the environmental predictors and the discriminant model (derived from the reference site database), each site is assigned to a biological cluster. The benthic invertebrate data are then similarly analysed. If the site in the Area of Concern lies outside the reference site cluster, then that site is judged to be impaired. In the Great Lakes, 335 sites have been sampled and the multivariate 'model' developed from this database correctly predicts benthic invertebrate communities with 90% accuracy (Reynoldson *et al.*, 1995). In addition, acute and chronic measures of 'toxicity' (including growth and reproduction) performed at these same sites provide measures of background performance for the appropriate, indigenous organisms that are to be used in assessing sediment toxicity (see Section 17.2.7).

### 17.2.7 *Restrictions on dredging activities*

When contaminants in sediments exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities, this use is viewed as impaired.

Great Lakes dredging guidelines were developed to provide protection against the short and long-term impacts associated with the disposal of dredged sediments. These guidelines employ bulk chemistry measurements for a few parameters that are assessed using either water quality equivalent standards or background concentration classifications (International Joint Commission, 1982; Zarull and Reynoldson, 1992). More recently, the Ontario Ministry of Environment and

Energy (OMOE) has released biologically-based, sediment contaminant concentration guidelines for use in assessing bottom sediments in Areas of Concern and for use in assessing dredged material disposal. These chemical concentration guidelines are also supported through the use of site-specific bioassays (OMOE, 1992). In many areas outside the Great Lakes, the Sediment Quality Triad Approach (i.e. chemistry, benthos community structure, and bioassays) is being used to assess sediment problems and recommend remedial actions (Chapman, 1990). A similar method has been recommended for use in the Great Lakes (International Joint Commission, 1987, 1988; Zarull and Reynoldson, 1992).

End-points for benthos community structure are being established as described in Section 17.2.6, using reference sites throughout the nearshore Great Lakes. Sediment bioassays (using species such as *Chironomus riparius*, *Hexagenia limbata*, *Hyallella azteca*, and *Tubifex tubifex*) provide confirmation that sediment is the source of the impact, rather than the water column or other factors, which are integrated by the benthos. As with community structure, a reference site (bioassay) database has been established (Reynoldson *et al.*, 1995).

### *17.2.8 Eutrophication or undesirable algae*

When there are persistent water quality problems (e.g. dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, etc.) attributed to cultural eutrophication, the use is considered impaired.

In Saginaw Bay, Lake Huron, modelling phosphorus loading/phosphorus concentration-threshold odour value relationships has led to establishment of a $15 mg L^{-1}$ total phosphorus (TP) concentration for the inner bay (Bierman *et al.*, 1983). The TP loading target is 440 t $yr^{-1}$, which will result in threshold odour values $<3$ and a TP concentration of 15 mg $L^{-1}$ (US Public Health Service Standard).

### *17.2.9 Restrictions on drinking water consumption or taste or odour problems*

This use is impaired when treated drinking water supplies are impacted to the extent that: (a) densities of disease-causing organisms or concentrations of hazardous/toxic chemicals or radioactive substances exceed human standards, objectives or guidelines; (b) taste and odour problems are present; or (c) the treatment needed to make raw water suitable for drinking is beyond the standard treatment used in comparable portions of the Great Lakes, which are not degraded (settling, coagulation, disinfection).

### *17.2.10 Beach closings*

This use is deemed impaired when waters, which are commonly used for total body-contact or partial body-contact recreation, exceed standards, objectives, or guidelines for such use.

### *17.2.11 Degradation of aesthetics*

When any substance in water produces a persistent objectionable deposit, unnatural colour or turbidity, or unnatural odour (e.g. oil slick, surface scum), this use is considered impaired.

In New York, narrative standards for suspended sediment and colour are set at 'none' that would adversely affect the waters for their best use (New York State, 1991). For turbidity, the standard is no increase that would cause a visible contrast from natural conditions and, for oil and floating substances, it is no residue that would be visible. If conditions are attributable to unnatural causes and sources, New York ambient water quality standards are used to establish reduction targets in order to make a determination. Examples of quantitative targets that have been established for dischargers causing such conditions include: $3.0 mgL^{-1}$ for suspended solids, and $15 mgL^{-1}$ for oil and floating substances.

### *17.2.12 Added costs to agriculture or industry*

This use is judged as impaired when there are additional costs required to treat the water prior to use for agricultural purposes (including, but not limited to, livestock watering, irrigation and crop spraying) or industrial purposes (that is, intended for commercial or industrial applications and non-contact food processing).

### *17.2.13 Degradation of phytoplankton and zooplankton populations*

When phytoplankton or zooplankton community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics, this use is impaired. In addition, this use will be considered impaired when relevant, field-validated, phytoplankton or zooplankton bioassays (e.g. *Ceriodaphnia*; algal fractionation bioassays) with appropriate quality assurance/quality controls confirm toxicity in ambient waters.

Limited attempts have been made to qualify objectives based on zooplankton and phytoplankton community structure, due to the expensive and time-consuming nature of plankton identification and enumeration. Bioassay end-points are more frequently used. Degraded zooplankton populations were identified as an impaired use in the Cuyahoga River (Ohio) due to chronic toxicity of ambient waters below the Akron Wastewater Treatment Plant. Toxicity was measured by the seven-day, three brood *Ceriodaphnia* test. *Ceriodaphnia* are easily cultured, found in the Great Lakes, sensitive to toxic substances and have a short maturation time. Based on standard *Ceriodaphnia* bioassay protocols (International Joint Commission, 1987), zooplankton populations were considered not impaired when there was no significant difference in survival and number of young per female relative to controls ($p < 0.05$).

### *17.2.14 Loss of fish and wildlife habitat*

This use is impaired when fish and wildlife management goals have not been met as a result of loss of fish and wildlife habitat due to a perturbation in the physical, chemical or biological integrity of the Boundary Waters, including wetlands.

Approximately 80% of the wetlands in Hamilton Harbour, Lake Ontario have been lost to development. The water use goal for the fishery is 'that water quality and fish habitat should be improved to permit an edible, naturally-reproducing

fishery for warmwater species, and water and habitat conditions in Hamilton Harbour should not limit natural reproduction and the edibility of cold water species'. This water use goal has been translated into the following targets for fish habitat (Hamilton Harbour Remedial Action Plan Writing Team, 1992): increase the quantity of emergent and submerged aquatic plants in the Hamilton Harbour, Cootes Paradise, Grindstone Creek delta, and Grindstone Creek marshes to approximately 500 ha in accordance with the Fish and Wildlife Habitat Restoration Project; rehabilitate 344 ha of littoral fish habitat; rehabilitate 39 ha of pike spawning marsh and nursery habitat; provide additional 10 km of littoral shore by creating 5 km of narrow islands; and achieve water clarity as measured by Secchi disc during the summer season of 3.0 m in the harbour and 1.0 m in Cootes Paradise and Grindstone Creek.

## 17.3 Conclusions

To restore and maintain the chemical, physical and biological integrity of an aquatic ecosystem, traditional, single-chemical, concentration objectives and standards should be replaced with ecosystem objectives and quantitative indicators or targets based on beneficial uses. These objectives and their quantitative targets should be developed openly and consensually, using input from both technical experts and the public.

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