4

Role of international policy and science in addressing Great Lakes management and Lake Erie eutrophication

M. McCone, T. Endreny, J. Atkinson, J. DePinto, and J. Manno

4.1 INTRODUCTION

The majestic nature and abundant resources of the Great Lakes Basin is home to nearly 25 percent of the U.S. and Canadian population, however, population growth has brought increased, and often competing, demands for land and water, and has triggered concerns regarding resource health and sustainability. Accelerated eutrophication of Lake Erie serves as a case example for documenting how advances in water science and engineering have led to advances in water policy and law affecting the management of the Great Lakes basin.

Work on eutrophication management for Lake Erie and the other four Great Lakes in turn guided subsequent science and informed problem responsive policy. Lessons from these successes enabled the Great Lakes community to use a coupled science-policy approach in addressing subsequent threats to the Great Lakes health and integrity, such as toxic chemical contamination, habitat destruction, navigation and hydropower water-level controls, and disruptive invasive species. This chapter will examine how national and international law, policy and science interact and inform management of the North American Great Lakes.

4.2.1 Great Lakes Basin: physical background

4.1.1.1 Geologic origins

Lakes Superior, Michigan, Huron, Erie, and Ontario comprise the five interior freshwater lakes that extend across a total area of 244,000 km^2 (0.16% of world land area), occupy parts of eight states and two provinces in two nations, and contain nearly 20 percent of the world's freshwater supply (see Figure 4.1). Lake Erie is the twelfth largest lake in the world, and of the Great Lakes it is the shallowest, southern-most and warmest. The lake has a surface area of ~25,690 km^2 with a 92 km width at its widest point and a 388 km length. Lake Erie has three main basins that are divided geologically into the western, central and eastern basins. The western basin of Lake Erie comprises 13 percent of the total lake surface area and has an average depth of 7.4 m. The central and eastern basins compose 63 percent and 24 percent of the lake's surface area, and have maximal depths of 29 m and 64 m, respectively. Via the Detroit River, drainage into Lake Erie comes from the discharges of Lake Superior, Lake Michigan and Lake Huron. The annual average flow of the Detroit River represents approximately 95 percent of the total inflow to Lake Erie (Hartman 1972, cited in Makarewicz and Bertram 1991).

Glaciers, although frozen, are the only contiguous surface freshwater volume that contain more freshwater than the Great Lakes, and they were the geologic forces that carved these lakes and the surrounding drainage area from the Precambrian rocks and overlying marine deposits from earlier inland seas, which are now rocks classified by their Cambrian, Ordovician, Silurian, Devonian, Mississippian and Pennsylvanian periods. The current Pleistocene Epoch of glacier activity, with vertical heights at 2 km, compressed and scoured the area during numerous advances and retreats. During each icesheet retreat, the ice-excavated lake basins were filled by meltwater and the absence of ice overload burden triggered areas of earth uplift and the creation of drainage outlets. Prior to the St. Lawrence drainage that followed the most recent Wisconsin icesheet retreat, lake drainage had spilled through the Illinois River Valley toward the Mississippi, the Hudson River Valley, the Trent River and the Ottawa River Valley. Uplift continues today, although more slowly.

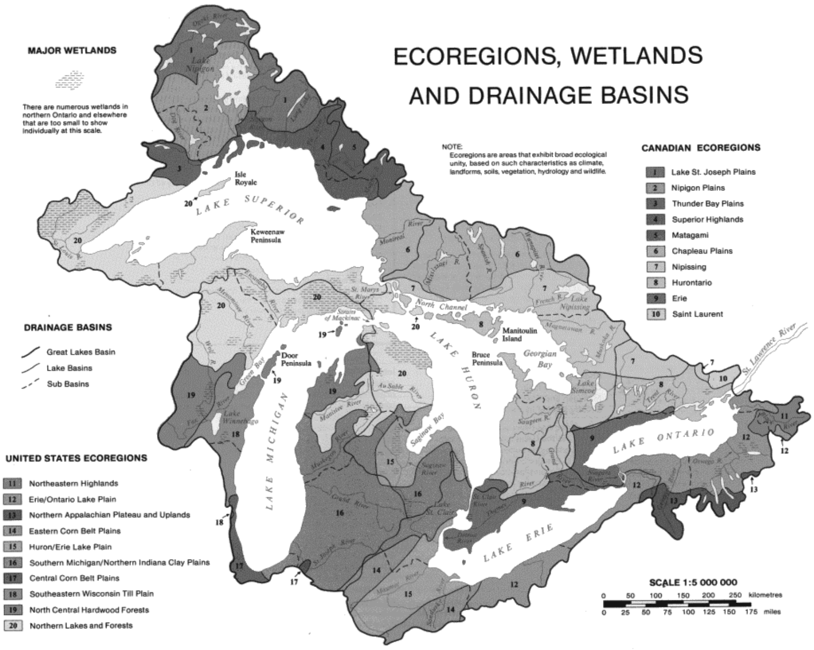

Figure 4.1. Great Lakes eco-regions, indicating unique features of the basin formed by geological forces, such as low-lying wetland areas.

Deposits from the glacial scour and retreat are largely poorly sorted mixtures of boulders, gravel, sand, silt and clay, referred to as glacial drift and till. Exposed consolidated rocks of limestone, shale, sandstone, halite and gypsum were formed during the pre-glacial period of inland seas from sedimentary deposits and are found in many river and glacial carved valleys, while outcrops of igneous and metamorphic rocks are also revealed. Landforms include sand dunes, flat till plains, linear moraines, ramp shaped drumlins, and meltwater deposited eskers, kames and outwash. While relatively low relief defines the drainage basin, the lakes feature remarkable depth gradients, widths and lengths, which are recorded in Table 4.1. It is apparent that extremes exist between the lakes, with Erie and Superior having nearly 350 m difference for maximum depth. While the lakes are stunning, the wetlands occupying the low gradient lands, as well as the isolated gorges and ravines carved by active rivers, also provide both ecologic and geologic complexity.

Table 4.1. Physical features of Great Lakes system

Category	*Superior*	*Michigan*	*Huron*	*Erie*	*Ontario*
Elevation at low level (m)	183	176	176	173	74
Length (km)	563	494	332	388	311
Breadth (km)	257	190	245	92	85
Average Depth (m)	147	85	59	19	86
Maximum Depth (m)	406	282	229	64	244
Volume (km^3)	12,100	4,920	3,540	484	1,640
Water Area (km^2)	82,100	57,800	59,600	25,700	18,960
Land Drainage Area (km^2)	127,700	118,000	134,100	78,000	64,030
Total Basin Area (km^2)	209,800	175,800	193,700	103,700	82,990
Shoreline Length (km)	4,385	2,633	6,157	1,402	1,146

4.2.2.2 Hydrologic flows and climate

Great Lake flows are from Lake Superior and Michigan into Huron, Huron into Erie, and Erie into Ontario via the Niagara River, which flows via the St. Lawrence Seaway through Canada and into the Atlantic. Numerous smaller inland lakes, rivers and wetlands lie within the Great Lakes basin, including some famous water bodies such as the Finger Lakes, Lake Nipigon, Lake St. Clair and the Montezuma Wetlands of New York. Alterations to flow have occurred, such as diversions of Long Lac and Lake Ogoki to capture water from the Hudson Bay watershed, dams to drown the Lachine Rapids, and reversing the Chicago River to keep sewage from mixing with drinking water. Interesting dynamics of circulation within the Great Lakes system include fall and spring turnover that breaks the lakes' thermocline strata and mixes hypolimnion and epilimnion waters, seiche, or sloshing of lake water height from shore to shore, an oscillation due to the large fetch of lake surface and strong winds piling water against the coast, and devastating surface waves caused by gale force winds. The Welland Canal is a unique man-made feature of the system, forming a navigable channel between Lakes Erie and Ontario, vertically separated by nearly 100 m, a drop that is dramatically illustrated by Niagara Falls.

Surface water resources are enormous in volume and area, with the precipitation, evaporation, and runoff components of the hydrologic cycle maintaining this system with high flux rates, as shown in Table 4.2. Runoff into the lakes is smallest for Erie and Ontario, almost half that for Superior and Huron, but is augmented by the inflows from those same upper Great Lakes. The retention times follow a logarithmic decrease of 100-year intervals from the headwater Lakes of Superior and Michigan, which have large volumes and small inflows, to the yearly intervals for Erie and Ontario, which have enormous inflows and relatively small volumes. Fluctuation in lake levels has dramatic impacts on the internal and surrounding ecosystems and, despite management efforts, is largely regulated by seasonal and annual (e.g. persistent) weather patterns. Groundwater reserves in the Great Lakes are present in multiple locations and at many different depths and flow rates. Besides their role in providing drinking water supplies for numerous communities, they provide important baseflow release to keep the lakes' feeder rivers perennial and flowing year-round.

Table 4.2. Water budgets for Great Lakes water system ($m^3\ s^{-1}$)

Category	*Superior*	*Michigan*	*Huron*	*Erie*	*Ontario*
Runoff to Lake	14,000	10,000	14,000	7,000	9,000
Precipitation to Lake	21,000	15,000	15,000	7,000	5,000
Evaporation from Lake	14,000	12,000	12,000	7,000	4,000
Flow in by diversions	2,000	-1,000	0	-2,000	2,000
Flow in from upper Lake	0	0	37,000	53,000	58,000
Flow out to lower Lake/River	22,000	15,000	53,000	58,000	71,000
Retention Time (yr)	191	99	22	2.6	6

Wetlands in the Great Lakes region are extensive, and are represented by four distinct types classified as swamps, marshes, bogs, and fens. Swamps are distinguished by the presence of trees and shrubs with significant annual water cover. Marshes are known for their thick stands of aquatic plants rather than trees, and like swamps are most likely located in the southern lake region. Bogs are most well known for their stagnant, acidic water with thick, slowly decaying mats of sphagnum mosses, while fens are filled by slowly moving, less acidic groundwater and dominated by sedges and grasses, but may have stunted shrubs and trees. Many of these wetlands are located along the coastal area, and include the UNESCO Biosphere Reserve at Long Point on the north shore of Lake Erie.

Weather patterns, and their long-term average condition known as climate, have dynamic annual fluctuations in temperature and precipitation, due to the lake's middle latitude location, which is a global meeting area for continental polar and maritime tropical air masses pushed by the Jet Stream. Climatic variation is extreme between the five Great Lakes, and averages for the system do not always reflect the specifics of any individual lake. January mean daily air temperature ranges from –20 to 0°C and July mean daily air temperature ranges from 7.5 to 25°C. Mean annual precipitation ranges from 600 to 1300 mm, while snowfall ranges from 150 to 350 mm. The mean annual frost-free period ranges from 220 days to a period of less than 2 months located north of Lake Superior. Rossby long waves perturbed by short wave upper airflow patterns trigger the deepening of low-pressure systems, termed cyclogenesis, which results in open wave cyclones defined by the overrunning of warm fronts by cold fronts. Several such open wave cyclones can cover the Great Lakes region and, depending on the season, this can result in synoptic snowfall and rainfall events as the cold dry air mixes with the saturated Gulf Coast air.

Several other weather patterns are also familiar to the region. When the semi-permanent Bermuda high pressure system moves off the south-eastern coast after autumn's first frost, the area may experience an Indian Summer as warmer Gulf Coast air is pushed north. Winter weather patterns common to this region include the severe lake effect snows, caused by cold air warming and absorbing lake water, and then cooling on the leeward shore and precipitating, and the northeastern (locally called, *Nor'easter*) winds caused by a strong high pressure system in Quebec that bring Atlantic Ocean moisture into the region, with ice-storms and wet snows. Spring weather is famous for its oscillation between extreme heat and cold, again as a result of the dynamic middle latitude looping of the Gulf Stream that can drag very warm spring Gulf Coast air northward, or extremely cold spring Hudson Bay air southward. Summer weather in the Great Lakes is moderated from extreme heat by the lake temperatures, which may set up lake–land breezes, as well as provide water vapor for convective afternoon thundershowers.

4.1.2 People and resource use

Settlement into the Great Lakes extends back to Native American occupation following the Wisconsin ice sheet retreat 10,000 years ago, with an estimated population during the 16th century between 60,000 and 117,000. During this period, five nations (Cayuga, Mohawk, Onondaga, Oneida and Seneca) occupied much of the New York lands draining into Lakes Erie and Ontario; the Tuscorora nation later migrated to New York. European settlers arrived in the early 17th century, with boats initially limited to the St. Lawrence valley due to severe rapids. By 1680 French fur trading in Canada was well established and protected by army forts, while by 1730 the British Fort Oswego protected colonies along the southern shore of Lake Ontario. The British captured many French forts by 1759, and the British retained control of the Great Lakes during the American Revolution, granting lands to nearly 40,000 loyalists fleeing New England. The two-year war of 1812 between America and Britain for the Great Lakes was claimed as a victory by both sides, America securing the southern coast, Canada retaining its northern control.

Approximately 1 million people in the western Great Lakes region, who sowed crops, worked dairy and built canals to ship exports and bring in new products, firmly established an agricultural heritage for the region by the mid-1800s. Wetlands were drained, soils eroded by denuded lands, rivers were clogged by sediment and many fish spawning habitats were destroyed. Soil conservation measures have helped stabilize soils, and chemical fertilizers, pesticides, herbicides and irrigation have increased production. Chemical byproducts of agricultural production such as excess phosphorus and historic use of DDT and other pesticides, along with modern row crop monoculture and hormone-disrupting chemicals, have impacted the ecosystem significantly. Agricultural production brings vital income and needed food to the region, and occupies between 3 and 67 percent of basin land and upwards of 33 percent of shoreline land, as reported in Table 4.3.

Logging and forestry activities occupy even greater amounts of land, from 21 to 91 percent in the basin (see Table 4.3), and began commercially in the 1830s by targeting the light and strong white pine, desired for ship and building construction. Forest industrial uses, primarily pulp and papermaking but also tannins, created additional revenue and development of the region. Again, however, several negative environmental consequences of this industry have since been identified, such as water pollution and extensive area, high grade, clear cutting, and forest-based industries are now operating at lower volumes and using best management practices to target sustainable operations. Commercial fisheries were also of major importance, and in the late 1890s harvests had grown by 20 percent per year since 1820, and annual harvests of 65,000 tonnes were recorded. Today, lake trout, sturgeon and lake herring have largely been replaced by introduced species of smelt, alewife, splake and Pacific salmon, and average harvests have been around 50,000 tonnes. Recreation boating, swimming and eco-tourism along with sport fishing also represent significant uses and income on the Lakes.

Table 4.3. Basin and shoreline land-use type (%)

Category	*Superior*	*Michigan*	*Huron*	*Erie*	*Ontario*
Basin Land Use					
Agricultural	3	44	27	67	39
Residential	1	9	2	10	7
Forest	91	41	68	21	49
Other	5	6	3	1	5
Shoreline land use					
Agricultural	n/a	20	15	14	33
Residential	n/a	39	42	45	40
Recreational	n/a	24	4	13	12
Commercial	n/a	12	32	12	8
Other	n/a	5	7	16	7

Table 4.4. Municipal, manufacturing, and power production water withdrawals (10^6 m^3 yr^{-1})

Category	*Superior*	*Michigan*	*Huron*	*Erie*	*Ontario*
Withdrawals					
Municipal	98	2,622	384	2,685	927
Manufacturing	1,133	8,608	2,158	9,820	2,935
Power production	740	12,131	4,852	12,791	13,282
Consumptive use					
Municipal	18	169	170	189	152
Manufacturing	71	785	89	1,409	125
Power Production	9	214	62	178	174

Human population numbers for the Great Lakes in the early 2000s was 27.3 million US and 6.7 million Canadian residents. Development along Lake Michigan is only accessible to the US population, and with 12.1 million people, it has the greatest number of US residents than any other lake. Lake Ontario has the greatest number of Canadian residents, with 3.0 million, mostly clustered within and between the towns of Hamilton and Toronto. The US economy of the Great Lakes region has a gross domestic product (GDP) of US$819 billion, and the Canadian economy of the Great Lakes region has a GDP of US$168 billion. The US has reported that approximately 13 percent of the basin population is below the economic poverty line, and water poverty index values are in the upper 60s for both nations, which is considered low risk. Flows of water to supply human, economic and most ecological needs of the Great Lakes are listed in Table 4.4.

4.1.3 Great Lakes Basin: law and management background

4.1.3.1 Historical water resource law and management

Pioneering international water resources management has been forged along the shores of the Great Lakes between two countries with relatively stable political and economic systems. Legal frameworks supporting management extend beyond the scope of the written document, and to cover some of this material a series of tables has been generated. Table 4.5 provides a list of US management agencies, Table 4.6 provides a list of Canadian management agencies, Table 4.7 provides a list of major international laws, and Tables 4.8 and 4.9 provide specific US laws and Canadian laws, respectively. (Tables 4.5 to 4.9 appear at the end of this chapter). In 1909 the Boundary Waters Treaty (BWT) established bi-national guidance on regulating water levels and flows for generation of electricity, and in formulating the BWT was the concept of a politically strong institution with the authority to conduct research and make binding policy and management agreements. The institution created by the BWT was the International Joint Commission (IJC), an agency of and for Canadian and United States interests. Negotiations in 1972 led to the Great Lakes Water Quality Agreement (GLWQA) that established guidance on regulating water quality, again overseen by the IJC, and implemented by numerous national, provincial, state and small government agencies. Dams are operated on the St. Marys River, Niagara Falls and the St. Lawrence, and only directly affect Lake Superior and Lake Ontario water levels. These few control points prevent the IJC from dampening all fluctuations. Water withdrawals for municipal supply, manufacturing, and power production affect and are affected by water levels. Incoming diversions (from the Hudson Bay watershed) and outgoing diversions (into the Mississippi drainage) also affect levels. Weather holds the largest control on water level variability. Following several large-scale studies of the feasibility of additional controls, the IJC concluded that costs outweigh benefits. Beginning in 1973 the IJC has included erosion control with its water level management objectives of hydropower and navigation. In 2001 the IJC began a new study of water level regulation that will consider allowing greater fluctuation, only in Lake Ontario, for ecosystem health purposes.

Water quality management under the GLWQA, signed in 1972 and amended in 1978, began with analysis of the mass balance loading of phosphorus and other pollutants, leading the way for major subsequent advances in setting target loading limits and current total maximum daily load analysis. Nutrients and carcinogens have received the greatest research and management focus, but the initial analysis of hormone disrupting chemicals in the Great Lakes food chain has identified new concerns and represents a growing issue.

An ecosystem approach to management was adopted in the GLWQA under the Specific Objectives, Supplement to Annex 1 (Section 3) which reads:

> 3. **Lake Ecosystem Objectives.** Consistent with the purpose of this Agreement to maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem, the Parties, in consultation with State and Provincial Governments, agree to develop the following ecosystem objectives for the boundary waters of the Great Lakes System, or portions thereof, and for Lake Michigan:
>
> (a) <u>Lake Superior</u>
>
> The Lake should be maintained as a balanced and stable oligotrophic ecosystem with lake trout as the top aquatic predator of a cold-water community and *Pontoporiea hoyi* as a key organism in the food chain; and
>
> (b) <u>Other Great Lakes</u>
>
> Ecosystem Objectives shall be developed as the state of knowledge permit for the rest of the boundary of the Great Lakes System, or portions thereof, and for Lake Michigan.

Efforts towards focusing on an ecosystem approach to management can be seen in the development of Lakewide Management Plans (LaMPs) and Remedial Action Plans (RAPs). Annex 2, Section 2 of the GLWQA states that Remedial Action Plans and Lakewide Management Plans shall embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern or in open lake waters. Innovative water resource management methods developed by the IJC, the U.S. Environmental Protection Agency and Environment Canada have encouraged citizen involvement in seeking and implementing solutions. These have since been studied and shared within the UNESCO Hydrology for the Environment Life and Policy (HELP) Initiative, a needs-driven hydrology policy–management–science program which has adopted Lake Ontario as one of its model watersheds. Advanced hydrological research, such as remote sensing driven modeling and monitoring, coupled with consensus based watershed management, will ideally answer pressing water resource issues.

Ecosystem-based management seems poised to better handle future problems. Systems-based management issues that link multiple trophic levels have replaced the historic water chemistry concerns that serve as the focus of this chapter. Such new issues include the impacts on drinking water supply, industrial manufacture, power generation, commerce, recreation and fishing imposed by invasive aquatic species. Of the many invasives, including crustaceans, fish, molluscs and plants, the spiny water flea and zebra mussel are wreaking havoc on industrial to recreational use of the Great Lakes. Ballast dewatering operations of commercial shipping vessels have been identified as the major pathway for invasives, and US Coast Guard regulations discouraging this practice are in place.

Other challenges include the restoration of coastal wetlands, many of which have been degraded by the removal of extreme peaks of high and low water levels that are responsible for the killing back of mono crop grasses that out-compete the more complex ecosystems needed for proper fish spawning. Lake Ontario, the outlet for the upper lakes and connector with the St. Lawrence Seaway, is most greatly affected by water level regulation, and has been the focus of several wetland restoration studies. Restoration of urban streams feeding the lakes has included separation of storm and sanitary sewers, reduction of impervious watershed areas, and reintroduction of aquatic plant and animal species. Reductions are needed in agricultural, suburban and urban non-point source runoff, currently the biggest source for sediment, nutrient, metal, organic and chemical pollutant loading now that point source discharges have largely been controlled.

Climate change provides new challenges. Management must address the recent climate change analysis performed as part of the U.S. Global Change Research program, which predicts a most likely scenario of lower lake levels due to the establishment of greater evaporation rates, which would potentially have devastating impacts on many recreational, commercial, industrial, navigational and other Great Lakes activities. Rivers flowing to new lake levels will undergo significant adjustments, as will operation of navigation, hydropower, and water removal and supply facilities. Developing indicators that reflect the impact of stressors and health of the lake system is an un-proven science. The biennial State of the Lakes Ecosystem Conference (SOLEC), hosted by the US Environmental Protection Agency and Environment Canada, developed and tested 80 indicators for field practicality and information delivery. This work continues today, informed by, and informing, current science on lake ecosystem dynamics and response to stressors.

4.1.4 Water data for water law: the evolution of good practice

4.1.4.1 Water science of eutrophication

Early limnological studies that classified lakes of low and high productivity as oligotrophic and eutrophic, respectively (from the Greek terms for poorly and well-nourished), led to the term eutrophication. The consensus among limnologists is that the term *eutrophication* is synonymous with increased growth of the biota of lakes and that the rate of increasing productivity is accelerated over that rate that would have occurred in the absence of perturbations to the system (Wetzel, 2001). Production is defined as a flow or flux of mass or energy over time and has the dimensions of mass per area formed over a period of time and includes any losses from respiration, excretion, secretion, injury, death and grazing (Wetzel, 2001). The limiting factors for primary production (new plant biomass) are phosphorus (P) and nitrogen (N). When additional N and P are made available, primary production often increases. Although some increase may prove beneficial, providing more energy to consumers and thus boosting secondary production, excessive algal growth frequently causes adverse effects such as algal blooms.

Cultural acceleration of this nutrient enrichment process is distinguished from natural rates for accumulation of nutrients. Although lakes naturally acquire nutrients from their surrounding landscapes, human activity increases the nutrient supply to water bodies significantly. This increase in nutrient supply due to human activity accelerates eutrophication and has therefore become known as cultural eutrophication. Cultural eutrophication mainly results in excess P and N from agricultural and urban activities. Nutrient inputs, although derived from many sources, are categorically defined as point and non-point sources. Point sources supply nutrients to a water body through a pipe or at a specific location, and include municipal wastewater treatment plants and industrial discharges. Non-point sources can be episodic in association with the seasonal activity of agriculture and construction, or irregular in association with rainstorms; a larger area usually supplies the nutrients, which are transported via hydrologic flowpaths and by wet and dry deposition. Agricultural runoff of fertilizers and animal waste, urban runoff, septic tank leaching, construction runoff and atmospheric deposition are all considered to be non-point sources.

Eutrophication was found to be the cause of anoxic zones in the central basin of Lake Erie. The process increased nutrients and production of organic matter beyond that which could be effectively utilized by the grazing food chain, hence this excess organic matter settled through the thermocline until reaching the hypolimnion (a deeper, darker, colder zone of the lake that is isolated from the surface water and re-oxygenation by thermally-induced density stratification). Due to respiration and decomposition, oxygen consumption eventually leads to anoxia of the hypolimnion. Benthic communities and coldwater pelagic fish species located in the hypolimnion due to thermal requirements are affected as a result of eutrophication-induced anoxia.

There are obvious connections between nutrient loading and the resulting health of fish communities. However, fish may affect the rate of phosphorus recycling due to the advection of nutrients through immigration or emigration from spawning and nursery habitats. Fish communities also affect the rate of phosphorus recycling through the process of alternating zooplankton communities based on size selective predation. Although the role of fish in nutrient export to Great Lakes coastal systems may be significant, it is insignificant in Lake Erie. Reductions in nutrient loading, in combination with introductions of exotic species and fisheries regulations, has led to notable changes in fish communities within the Great Lakes aquatic ecosystem since 1970. These changes can be partially attributed to attempts by fisheries management to take an ecosystem approach that not only helps to balance predator prey fish communities but also aids in the improvement of water quality. Some of the changes in fisheries management have been the control of sea lamprey *Petromyzon marinus*, the introduction of Pacific salmonids and the rehabilitation of native predator stocks (lake trout *Salvelinus namaycush*, walleye *Stizostedion vitreum*).

Studies such as those done in the central basin of Lake Erie during the early 1970s recognized the importance of external phosphorus loading and internal recycling (microbial activity and zooplankton excretion) on driving eutrophication. With binational influences such as the ecosystem approach of the GLWQA, Lake Erie began to be treated conceptually as an open system that should be coupled with the rates of nutrient loading from the drainage basin. Based on this approach, quantitative models could be made to assess the quantity of phosphorus entering a water body and the response to this input. From a management viewpoint, one could also define loadings of nutrients in terms of whether they were acceptable or excessive in terms of the algal productivity generated under the lake conditions of morphometry and water retention times (Vollenweider, 1990, cited in Wetzel, 2001).

4.1.4.2 Water law of eutrophication

Scientific concern for the health of the lakes and public demand for action led the governments of Canada and the U.S. to ask the IJC in 1964 for a study of water pollution problems in the lower lakes; Erie, Ontario and the St. Lawrence (Manno, 1992). Many of the water quality concerns addressed by the IJC in 1970 stemmed from public concerns over eutrophication in Lake Erie. Some of the problems associated with eutrophication were found to include excessive algal growth, changes in phytoplankton composition, turbidity, and taste and odor problems. Eutrophication of the Great Lakes gained the most attention in the 1970s as Lake Erie was found to have floating algal blooms, the disappearance of certain benthic organisms and oxygen depletion in the deep bottom waters of the lake (Boyce *et al*., 1987, cited in Makarewicz and Bertram, 1991).

The 1972 Great Lakes Water Quality Agreement (GLWQA) was established between Canada and the U.S. to "*restore and maintain the chemical, physical, and biological integrity of the Great Lakes*" (IJC 1972:5, cited in Manno, 1992). The GLWQA keyed in on municipal sewer treatment plants and household laundry detergents, which are discharged by septic and sewer systems, to initiate the reduction in phosphorus. Phosphorus restrictions in laundry detergents were not established until the 1978 GLWQA. A technological approach was taken towards municipal sewage treatment plants that required all municipal discharges with flows in excess of 1 MFD (million gallons per day) to reduce their effluent total phosphorus (TP) concentration to less than 1.0 mg l^{-1} (ppm). This stated TP concentration was the target phosphorus load. The GLWQA, using models such as that developed by DiToro and Connolly (1981), defined a target load as the level that will not cause undesirable effects, including over-production of algae and anoxic conditions on lake bottoms (U.S.E.P.A. and Government of Canada, 1995). The total load limit set for Lake Erie was 11,000 metric tons per year (1978 amended GLWQA). However, this effluent guideline was based largely on the level deemed to be achievable by available technology (DePinto *et al*., 1986), and not based on the amount that would trigger eutrophication. The average phosphorus loading in Lake Erie between the years of 1974 and 1976 was 18,663 t yr^{-1}; which resulted in a phosphorus concentration in the western basin = 45 *u*g l^{-1}, and in the central basin = 22 *u*g l^{-1}. Converting between concentration and load was performed using Great Lakes tested ratio estimators as well as corrected logarithmic regression approaches. Establishing target loads aided in the reduction of phosphorus, and the target loads set by the 1972 GLWQA were determined according to model mass balance results. Implementation of the load reductions had to consider technological aspects of waste water treatment facilities present at that time.

The 1972 GLWQA greatly supported and advanced the Great Lakes basin ecosystem approach because the legislation required a long term, large-scale systematic multifaceted study. This ecosystem-based approach, involving the systems analysis of lake response to nutrient concentration in the form of computational models, was thought to prove more beneficial than the approach previously used in which standards were set according to the levels deemed to be achievable by available technology. The next step towards advancing the ecosystem approach was to adopt the nutrient loading analysis of land use activity and runoff volumes and concentrations entering the lake. The nutrient loading concept implies that a relationship exists between the quantity of nutrient entering a water body and its response to that nutrient input (Wetzel, 2001). Prior to this concept, the relationships between phosphorus loading and resulting in-lake phosphorus concentrations had not been quantified in water quality analyses. The nutrient-loading concept allowed for development of models that predicted water quality parameters based on statistical loading relationships. The ability to predict and assess water clarity, hypolimnetic dissolved oxygen concentrations and algal biomass as a result of loading enabled a change in legislative focus to set target phosphorus loads based on ecosystem needs rather than achievable technological output.

The knowledge gained from various water quality models was needed to carry out the comprehensive review required by Section IX of the 1972 GLWQA, which assessed the effectiveness of the agreement during the fifth year after its establishment. The results of this review (as conducted by Task Group III) were incorporated into the 1978 GLWQA, which established new target loading rates for each lake that would result in the desired water quality conditions. Recommendations for a phosphorus control program were presented in Annex 3 of the 1978 GLWQA. The recommendations helped to establish the goals for Lakes Erie and Ontario of reducing algal biomass and related nuisance conditions, for Lake Michigan of eliminating algal nuisance growths, and for Lakes Huron and Superior of preventing degradation from their current states of low biological productivity.

Also incorporated into the 1978 GLWQA was the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG) that contributed identification of the significance of the lakes and the development of a strategy for managing these diffuse sources (DePinto *et al*., 1986). The 1978 GLWQA provided for the continued evaluation of progress toward the desired level of phosphorus control and for the further development of the most viable phosphorus management strategies for the Great Lakes (DePinto *et al*., 1986).

Annex 3, Section 2, in the GLWQA states the programs to be developed and implemented to reduce input of phosphorous to the Great Lakes.

(a) Construction and operation of municipal waste treatment facilities in all plants discharging more than one million gallons per day to achieve, where necessary to meet the loading allocations to be developed pursuant to paragraph 3 below, or to meet local conditions, whichever are more stringent, effluent concentrations of 1.0 milligram per litre total phosphorous maximum for plants in the basins of Lake Superior, Michigan, and Huron, and of 0.5 milligram per litre total phosphorus maximum for plants in the basins of Lakes Ontario and Erie.

(b) Regulation of phosphorous introduction from industrial discharges to the maximum practicable extent.

(c) Reduction to the maximum extent practicable of phosphorous introduced from diffuse sources into Lakes Superior, Michigan and Huron; and the reduction by 30 percent of phosphorous introduced from diffuse sources into Lake Ontario and Erie, where necessary to meet the loading allocations to be developed pursuant to paragraph 3 below, or to meet local conditions, whichever is more stringent.

(d) Reduction of phosphorous in household detergents to 0.5 percent by weight where necessary to meet the loading allocations to be developed pursuant to paragraph 3 below, or to meet local conditions, whichever are more stringent.

(e) Maintenance of a viable research program to seek maximum efficiency and effectiveness in the control of phosphorous introductions into the Great Lakes.

The following table establishes phosphorous loads for the base year (1976) and future phosphorous loads. The Parties, in cooperation with the State and Provincial Governments, shall within eighteen months after the date of entry into force of this Agreement confirm the future phosphorous loads, and based on these establish load allocations and compliance schedules, taking into account the recommendations of the International Joint Commission arising from the Pollution from Land Uses Activities Reference. Until such loading allocations and compliance schedules are established, the Parties agree to maintain the programs and other measures specified in Annex 2 of the Great Lakes Water Quality Agreement of 1972.

Basin	*1976 phosphorous load in metric tonnes per year*	*Future phosphorous load in metric tonnes per pear*
Lake Superior	3,600	3,400*
Lake Michigan	6,700	5,600*
Main Lake Huron	3,000	2,800
Georgian Bay	630	600*
North Channel	550	520*
Saginaw Bay	870	440*
Lake Erie	20,000	11,000**
Lake Ontario	11,000	7,000**

* These loadings would result if all municipal plants over one million gallons per day achieved an effluent of 1 milligram per litre of phosphorous.

** These loadings are required to meet the goals stated in paragraph 1 above.

In the Great Lakes, a cause–effect relationship connects science and law. The efforts leading up to the 1978 GLWQA demonstrate that sound scientific research has resulted in responsive law and management of the Great Lakes. Issues such as nutrient loading, eutrophication and mass balance analyses continue to provide opportunities for the challenging, yet powerful, approach of combining research with management in process of policy-making. The ecological processes of the Great Lakes cross the boundaries of state, provincial and national governments. The 1978 GLWQA formed the concept that ecological imperatives could be translated into regime governance based on the acceptance of scientific advice.

The 1987 amendments to the GLWQA began the policy of establishing Lakewide Management Plans (LaMPs) for each of the lakes, LaMPs focused on identifying sources, pathways and concentrations of critical pollutants; which provided for a systematic and comprehensive approach to managing the ecosystem. In the amended GLWQA the US and Canadian governments also committed to preparing Remedial Action Plans (RAPs) for the 42 Areas of Concern designated by the IJC Water Quality Board.

4.1.5 Lake Erie: a focused view of the ecosystem approach

During the 1970s Lake Erie proved to be the most prevalent attention-getter in terms of eutrophication of the Great Lakes, the world's largest body of fresh water. Overall interest in the eutrophication of the Great Lakes severely increased due to a focus on Lake Erie experiencing the resulting effects of nutrient enrichment, such as benthic anoxia and other water quality problems. As a result of the phosphorus abatement program, annual phosphorus loadings from US and Canadian municipal discharges were reduced by 84% – from 15,260 tons in 1972 to 2,449 tons in 1985 (IJC 1987, cited in Makarewicz and Bertram, 1991). During this time, the reduction in phosphorus entering Lake Erie from another major source, the Detroit River, which itself received municipal discharges, declined 68% – from 12,000 tons to 3,796 tons (Fraser, 1987; IJC, 1987, cited in Makarewicz and Bertram, 1991). However, due to the small volume of Lake Erie and the increasing influence of non-point source loads, a point source control program was found by the Phosphorus Management Task Force of the IJC to be inadequate to meet the set target load of 11,000 tons. This being said, the 1972 GLWQA has still managed to lower annual phosphorus loads dramatically, incorporating decreased cultural eutrophication along with reductions in point source loadings. It has been the unfortunate experience of Lake Erie that today, reduced primary production has led to concern that the food web in the western basin could be altered by a shift in energy from the pelagic to benthic components of the ecosystem. Reduced primary production is aided by the invasion of zebra mussels and their natural filtering activity. As a result of this invasive species, the idea that phosphorus loadings should be increased has arisen.

4.1.5.1 Mass balance models of eutrophication

A mass balance analysis is a very simple approach and can be used for any system. It is formed around the basic concept that changes in storage (amount) are given by differences between inputs and outputs, or

$$Inputs = outputs \pm storage$$

In developing mathematical models, this relationship is usually expressed in terms of rates. This equation illustrates that all inputs to a watershed should be balanced by equal outputs, unless changes in storage occur. When taking an ecosystem approach, elements that are biologically reactive, and cycle between living and non-living stores, are of greatest interest. Nitrogen and phosphorus are two elements that are of great interest for use in an ecosystem approach. Within an ecosystem approach, land use of the watershed can play an important role in nutrient loading. However, nitrogen concentrations and loads consistently correlate with land use, whereas phosphorus does not. Difficulty in understanding the relationship between phosphorus and land use results from the highly dynamic cycling of phosphorus among its four basic forms. These forms include reactive (inorganic) dissolved phosphorus, reactive (inorganic) particulate phosphorus, dissolved organic phosphorus and dissolved particulate phosphorus. Phosphorus is also difficult to measure accurately during episodic stormflows, as its particulate form adheres readily to sediments. Relative to understanding the relationship between the watershed and phosphorus loading, it is important to remember that the major focus of the 1978 GLWQA was to restore year-round aerobic conditions in the bottom water of Lake Erie, to reduce algal biomass to levels that would not produce nuisance conditions, and to maintain the upper lakes in oligotrophic conditions. Therefore, because phosphorus is the initial limiting nutrient to algae, and because nitrogen cycling has numerous processes which create difficulty obtaining accurate measurements (such as nitrification, denitrification and nitrogen fixation), mass balance and loading criteria focus on phosphorus relationships.

By focusing on phosphorus relationships, models can be utilized to predict loading rates accurately and the effects that reductions would have on phytoplankton biomass. All loading relationships are based on the mass balance rate equation for a substance, *M*, between its inflow, outflow, sources, sinks and reactions in an open system. One such form is given as (Vollenweider *et al*., 1980, cited in Wetzel, 2001):

$$\Delta M / \Delta t = I - O - (S - R)$$

where:

$\Delta M / \Delta t$ = storage gain or loss of nutrient M over time Δt

I = external nutrient loading rate (inputs)
O = rate of nutrient loss by outflow
S = rate of nutrient loss to sediments
R = rate of nutrient regeneration from sediments (internal loading)

Various units of time can be used to evaluate the rates for processes in this equation, and some models assume steady state conditions, where the left-hand-side is set equal to zero. Although in reality steady state does not exist in a lake, lakes that oscillate around relatively constant nutrient loads over periods of several years exhibit a set of trophic characteristics and may be viewed as having a tendency toward a repetitive steady state (Wetzel, 2001). The ultimate goal of water quality models is to develop quantitative and predictive relationships between loadings, or stressors, in a system and the response of the system to those stressors.

4.1.5.2 Including Lake Erie hydrological science in Lake Erie policy decisions

Of all the ecosystems in the Great Lakes, Lake Erie is the most productive and complex, leading to many focused studies of eutrophication within the lake's ecosystem. These studies have helped to establish the combination of cooperative research and resource management required to improve the health of Lake Erie. One of the major focuses of the 1978 GLWQA was to restore year-round aerobic conditions in the bottom water of Lake Erie and to reduce algal biomass to levels that would not produce nuisance conditions. However, current loading rates have not resulted in establishing year-round aerobic conditions in central Lake Erie. An overall shift in the way energy and organic matter production is cycled due to the presence of the zebra mussel, *Dreissena polymorpha*, may be causing an increase in the anoxia. The natural behavior of the basin also needs to be taken into account in that seasonal periods of anoxia may be inherent to the basin.

Joint efforts by the United States and Canada to reduce phosphorus loadings to Lake Erie are responsible for much of the decline in chlorophyll *a* between the early 1970s and the mid 1980s (GLWQB, 1987, cited in Leach. 1993). However, the filtering activities of zebra mussels have aided the decline in chlorophyll *a* since 1988. Impacts of the decline in planktonic algae on the pelagic food web are not yet known. There is concern that the food web in western Lake Erie could be altered by a shift in energy from the pelagic to benthic components of the ecosystem (Leach, 1993). The ratio of the number of species indicative of eutrophic conditions to those indicative of mesotrophic conditions has declined. The pelagic ecosystem has become less eutrophic

(Makarewicz and Bertram, 1991). Along with the issues associated with zebra mussels, other top-down controls in relation to a resultant decrease in phytoplankton are the grazing effects of *Daphnia galeata mentodae* and *D. pulicaria* (both zooplankton species are dominant herbivores). For example, the nuisance blue-green algae *Aphanizomenon flos-aquae* decreased 89 percent from 2.0 g/m^3 in 1970 to an average of 0.22 g/m^3 for the 1983–1985 period (Makarewicz and Bertram, 1991). However, this decrease is not solely a result of top-down control of zebra mussels and zooplankton. The decrease in phosphorus concentration and an increase in the phosphorus: nitrogen ratio represents a bottom-up influence on phytoplankton populations. With the recovery of walleye and the introduction of pacific salmonids, *D. pulicaria* has become more dominant in the zooplankton community. With the size-selective grazing activity of zooplankton and the effects of nutrient control, a decrease in the size of phytoplankton species has resulted in a bottom-up effect on planktivorous fish species. Both top-down and bottom-up controls of trophic biomass appear to be working simultaneously to improve water quality in Lake Erie (Makarewicz and Bertram, 1991).

Lake Erie has endured the most scrutiny of the five Great Lakes, and has both suffered and benefited from the impacts of increased attention. The ecosystem approach, as used on Lake Erie, has influences from both the scientific regime and the political regime. Although both Canada and the United States share a degree of common interests, the voices of the political community, the environmental community and the various public communities need to be fully taken into consideration. The roles of non-government organizations (NGOs) in the decision-making process has encouraged the ecosystem approach in Lake Erie. When expanded to the scope of the entire Great Lakes basin, NGOs represent a way to connect the generally separated environmental and political rhetoric, and set common interests into action. Decision-making in Lake Erie is an example of how the interactive process of gathering and reviewing science takes into account ecosystem needs and informs human understanding of ecosystems.

4.2 FUTURE ENVIRONMENTAL MANAGEMENT OF THE GREAT LAKES

Changes occur constantly in the Lake Erie ecosystem. This of course makes it difficult to predict what ecological challenges are ahead for the rest of the Great Lakes. One view of the smaller water volume in, and concentrated human development around, Lake Erie is it serves as an early warning for future symptoms of the other lakes. Of course, this is not always the case, such as with invasives that have appeared first outside of Lake Erie. Forecasting specific future stresses is an imprecise and risky approach, and instead policy makers and scientists are trying to adopt an ecosystem approach for monitoring and responding to future ecological stresses.

The 12th Biennial Report on Great Lakes Water Quality (IJC) summarizes the recent environmental trends in this freshwater system, and its later editions provide a follow-on document for interested readers. In Lake Erie, ecosystem quality since the early 1990s has had both positive and negative trends, occurring simultaneously. The positive trends have been: increased water clarity, re-establishment of rooted aquatic plant communities, burrowing mayfly recovery, walleye recovery, lake whitefish recovery (central basin). The negative trends included: lake whitefish decline (eastern basin), phosphorous increase in water column, phytoplankton decline in offshore waters, blue-green algae blooms, new establishment of invasive species, and fish and wildlife die-offs from botulism. Based on these science data points, the IJC has suggested the following policy for the US and Canada:

- Improve phosphorous monitoring from point and non-point sources to determine relative contributions of external loadings versus internal cycling;
- Improve research to resolve questions about cause-and-effect linkages between observed ecosystem changes and various stressors, using a collaborative approach between water quality research and fisheries research; and
- Ensure that these research and monitoring improvements employ an ecological modelling framework that enables the most cost-effective and ecologically meaningful programs to be developed and implemented.

Once again, science and policy formulation in Lake Erie may guide developments in the other four Great Lakes. Following the management successes in Lake Erie, the IJC recommends the Lake Erie Millennium Network institutional model provide a basis for enhanced binational cooperation and communication in the other Great Lakes.

On May 18, 2004, President Bush signed an executive order creating the Great Lakes Interagency Task Force. With the U.S. Environmental Protection Agency as the lead, the Task Force brings together ten agency and cabinet officers tasked to provide strategic direction on federal Great Lakes policy. The agencies administer more than 140 federal programs and will influence future lake management (see Table 4.5).

4.2.1 Public involvement for social and ecosystem benefits:

An ecosystem approach, although critical for the systematic understanding and protection of the Great Lakes basin, entails the unforgiving challenge of translating sound scientific information into a correct political representation of these findings. The way in which, as well as the degree to which, political imperatives incorporate the scientifically defined ecosystem needs, is dependant upon the intended direction of political goals. The direction of political goals regarding issues such as the Great Lakes basin reflects the expressed interests and concerns of those who participate in the science and policy process.

John Jackson, one resident of the Great Lakes and participant in stakeholder discussion groups, was quoted in a *Voices of the Watershed* anthology, saying, *"Citizens will continue to be the driving force for the protection of the Great Lakes and St Lawrence watershed. Those living around the region are the ones most directly affected, and who enjoy and value the lakes, rivers, and surrounding lands for their multitude of essential and delightful facets. We have learned that it is only by bringing pressure to bear in a united and simultaneous way on all responsible jurisdiction and polluters that there is hope for protecting the watershed."* (Beck and Litteljohn, 2000)

The awareness and acknowledgement of issues in the Great Lakes begins with those who reside in the basin. These citizens have the important role of recording short-term changes; these changes tend to be observational day-to-day differences in their surrounding ecosystem. These observations provide the basis for questions pertaining to a larger-scale ecosystem, such as the ecosystem of Lake Erie in its entirety as opposed to sections of the shoreline. The next step in awareness and acknowledgement can be derived from the inclusion of environmental advocates for the protection of the Great Lakes. Although environmental advocacy ultimately reaches the levels of the federal, state and provincial agencies, the initial steps begin with such social components as members of the fishing community, members of the academic community and those with a general interest in the Great Lakes basin of both a political and scientific nature that become the driving force of protection. Beierle and Konisky (1999) conducted an external assessment of public participation in decision-making and in environmental planning for Great Lakes programs, such as the RAP process to restore contaminated hot spots. The assessment looked at the beneficial result of greater public involvement and the influence of this on programs and planning efforts in the Great Lakes region.

Success of participation is measured using five criteria: educating participants; improving the substantive quality of decisions; incorporating public values into decision making; reducing conflict; and building trust. It was found that stakeholders learned a great deal through workshops, reports by technical advisory committees and direct discussions with experts, which are informal education venues. Education plays an important role as a motivating factor to get participants more involved in the decision-making process. Conveying information in a manner that allows the public to become informed and responsive is a role that freshwater scientists can accomplish through increased involvement as an advisor and influence at the community level. The role of freshwater scientists should be to examine and explain the scientific implications of national policies and local, state and national statutes (Naiman *et al*., 1995).

Through international cooperation and public advocacy, Lake Erie is no longer considered "dead," and people in general have a better understanding and concern for the effects of human activity on water quality in the Great Lakes and beyond. A well known attempt to increase awareness of the eutrophication problems in Lake Erie was by the brilliant author Dr. Seuss himself. In his 1971 publication of *The Lorax*, Dr. Seuss sent out an environmental warning that still rings true today; a powerful message that Seuss implored both adults and children to heed. Dr. Seuss captured his audience, especially those living within the Great Lakes basin, with the mention of Lake Erie in *The Lorax*:

"You're glumping the pond where the Humming-Fish hummed!
No more can they hum, for their gills are all gummed.
So I'm sending them off. Oh, their future is dreary.
They'll walk on their fins and get woefully weary
In search of some water that isn't so smeary.
I hear things are just as bad up in Lake Erie."

-*The Lorax*, by Dr. Seuss, Random House, 1971.

The Great Lakes have gained a transnational, transformative foundation of governance implemented and enforced by the Great Lakes Water Quality Agreement. As the ecosystem approach continues to enhance understanding of the issues facing the Great Lakes, the entailment of society's beliefs and values has become increasingly important in the management of the Great lakes basin. Along with this relationship, the relationship between research and management also proves to be a challenge. The Freshwater Imperative (FWI) recommends a new approach that builds a solid foundation of knowledge about the structure, function, and dynamics of freshwater ecosystems so that socioeconomic and political processes influencing water policies can interact with a fully informed management process. The cohesive element in this new approach is effective information transfer between the scientific and managerial disciplines involved in understanding and regulating regional freshwater ecosystems (Naiman *et al*., 1995). As we strive to maintain the integrity of the Great Lakes basin, pursuing the enactment of legislation to gather accurate and comparable data/information will largely determine the quality and effectiveness of management within the Great Lakes basin.

Table 4.5. United States agencies and programs working under the Great Lakes Interagency Task Force and the science, management & policy. An asterisk (*****) indicates that the programs are specific to the Great Lakes.

Environmental Protection Agency
Air Program
Aquatic Stressors Research Program
Children's Health Program
Clean Water Act (CWA) Water Quality Monitoring and Section 106 Grants
Clean Water State Revolving Fund
*Coastal Environmental Management
Drinking Water State Revolving Fund
Environmental Justice Small Grants
Environmental Justice Through Pollution Prevention Grants
Environmental Monitoring and Assessment Program
Food Quality Protection Act/Strategic Agricultural Initiative
*Funding Guidance – Competitive Grants
Global Climate Change Research Program
*Great Lakes Air Deposition Grant Program
*Great Lakes Legacy Act
*Great Lakes Binational Toxics Strategy
Indian Environmental General Assistance Program
*Integrated Atmospheric Deposition Network
*Lakewide Management Plans
*Monitoring Program
National Pollution Discharge Elimination System
*Niagara River and New York State Areas of Concern
Non-Point Source Programs
PCB Program
Pollution Prevention (P2) Demonstration Grants
Public Water Supply Program
*Resource Conservation and Recovery Act (RCRA): Subtitle C State Program Support – Great Lakes Initiative
Regional Geographic Initiative (RGI)/Environmental Priorities Program (EPP)
State and Tribal Environmental Justice Program
*State of the Lakes Ecosystem Conference
Superfund
Total Maximum Daily Load Program
Tribal Solid Waste Assistance Grants
Underground Injection Control
Waste Pesticide Collection Program
Water Quality Management Planning
Water Quality Standards Program
Wetlands
Army Corps of Engineers
Aquatic Ecosystem Restoration
Beneficial Use of dredged Material

Cleaning and Snagging
Confined Disposal Facilities
Emergency Stream Bank and Shoreline Protection
Environmental Dredging
Environmental Improvements
Flood Plain Management Services
*Great Lakes Fishery and Ecosystem Restoration
*Great Lakes Remedial Action Plans and Sediment Remediation
*Great Lakes Tributary Models
Planning Assistance to States
Shore Protection
Small Flood Control Projects
Small Navigation Projects
Tribal Partnership Programs
Department of Agriculture
Agricultural Research Service (ARS)
ARS Research Units
Cooperative State Research, Education, and Extension Service (CSREES)
Hatch Act Research Program
Integrated Activities Program
McIntire-Stennis Cooperative Forestry Research Program
National Research Initiative Program
Small Business Innovation Research Program
Special Research Grant Program
Farm Services Agency (FSA)
Conservation Reserve Programs
Emergency Conservation Program
Forest Service (FS)
Atmospheric Ecosystem Interactions at Multiple Scales
Cooperative Forestry
Forest Health Management
Recreation, Heritage, and Wilderness Management
Soil, Water, and Air Management
Watershed, Lake, Riparian and Stream Analysis, and Restoration
Wildlife Fire Management
Wildlife, Fish, and Rare Plants Resource Management
Natural Resources Conservation Service (NRCS)
Environmental Quality Incentives Program
Farmland Protection Program
*Great Lakes Program for Soil Erosion Sediment Control

National Cooperative Soil Survey (NCSS)
Plant Materials for Conservation
Resource Conservation and Development
River Basin Studies, Watershed Surveys and Planning, and Watershed Protection and Flood Prevention
Soil and Water Conservation/Conservation Technical Assistance
Wetland Reserve Program
Wildlife Habitat Incentive Program
Department of Commerce - National Oceanic and Atmospheric Administration (NOAA)
Coastal Mapping/Mapping and Charting Program
Coastal Remote Sensing, Coastal Change and Analysis Program
Coastal Zone Management Program
*Episodic Events, Great Lakes Experiment
Geodesy Program
*Great Lakes Environmental Research Laboratory
*Great Lakes Restoration Project
Landscape Characterization and Restoration Program
National Estuarine Research Reserve System (NERRS)
National Sea Grant College Program
National Status and Trends Mussel Water Project
National Weather Service (NWS)
Office of Response and Restoration – Coastal Protection and Restoration Division; Damage Assessment Center; Hazardous Materials (HAZMAT)
Department of Health and Human Services – Agency for Toxic Substances and Disease Registry
*Great Lakes Human Health Effects Research Program
Department of Homeland Security – Coast Guard
National Invasive Species Act/Ballast Water Program
Oil Spill Removal Organization Program
Department of Interior
Fish and Wildlife Service (FWS)
*1836 Fisheries Treaty – Implementation of the August 7, 2000 Consent Decree
Aquatic Nuisance Species Regional Coordination and Technical Assistance
Aquatic Nuisance Species Surveillance and Control
*Blue Pike Activities in the Great Lakes
*Detroit River International Wildlife Refuge
*Ecosystem Management in the Lower Great Lakes
Endangered Species Program
*Evaluation and Restoration of Great Lakes Estuaries and Tributaries

Fish and Wildlife Management Assistance – Great Lakes Operations
*Great Lakes Coastal Programs
*Great Lakes Fish and Wildlife Restoration Act
*Great Lakes Lake Sturgeon Rehabilitation Program
La Crosse Fish Health Center
*Lake Ontario Atlantic Salmon Reintroduction Program
*Lake Ontario/St.Lawrence River American Eel Restoration Program
*Lower Great Lakes Lake Trout Restoration Program
*Lower Great Lakes Lake Ruffe Surveillance Program
*National Fish Hatchery System – Great Lakes Operations
National Fish Passage Program
Natural Resource Damage Assessment Program
New York Aquatic Resource Management
New York Natural Resource Management Program
*New York State Canal System Aquatic Nuisance Species Program
National Park Service (NPS)
Partners for Fish and Wildlife (Private Lands Program)
*Midwest Region – Great Lakes Strategic Plan Activities
U.S. Geological Survey (USGS)
Biological Information Management Delivery
Biological Research and Monitoring
Coastal and Marine Geology
Cooperative Research Units Programs
Cooperative Topographic Mapping (CTM) Program
Cooperative Water Program
Geographic Analysis and Monitoring Program
Land Remote Sensing Program
Mineral Resources Program
National Cooperative Geologic Mapping Program
National Water Quality Assessment (NAWQA) Program
USGS Ground-Water Resources Program
USGS Toxic Substances Hydrology Program
Water Resource Research Act Programs
Earth Surface Dynamics Program – Central Great Lakes Geologic Mapping Coalition

Table 4.6. Canadian Organizations with programs involved with Great Lakes Interagency Task Force and the science, management & policy

Environment Canada
Canadian Federal Great Lakes Program
Great Lakes Action Plan
Remedial Action Plans
Lakewide Action Plans
Binational Toxics Strategy
State of the Lakes Ecosystem Conference
Integrated Atmospheric Deposition Network
Niagara River Toxics Management Plan
Great Lakes Wetlands Conservation Action Plan (GLWCAP)
Water Use and Supply Project
Funding Programs
CEPA Environmental Registry – Permits
Canadian Bird Banding Permit
Ocean Disposal Permit
Endangered Species and Fauna and Flora Permits
Canada Centre for Inland Waters (CCIW)
Canadian Wildlife Service (CWS)
Environmental Protection Branch (EPB)
Great Lakes Environmental Office (GLEO)
Ministry of the Environment (MOE)
Ontario Ministry of Natural Resources
Transport Canada
Canadian Coast Guard
Ship Source Oil Pollution Fund

Table 4.7. Prominent international agreements and organizations involved with the Great Lakes science, management & policy

Title	Involvement / Focus
Boundary Water Treaty (1909)	Original agreement between Canada and US to study and manage Great Lakes.
The Great Lakes Charter (1985)	Council of Great Lakes Governors & Premiers of Ontario and Quebec. Discourages new proposals to divert Great Lakes water.
Great Lakes Water Quality Agreement (1987)	U.S. Environmental Protection Agency (EPA) and agencies in US border States with Environment Canada (EC), and agencies in Canadian border Provinces of Ontario and Quebec
International Joint Commission	Authorizes water level controls on either side of the U.S.-Canadian border; studies, reports, and provides advice on issues of water quality and quantity through numerous sub-committees.
Great Lakes Fishery Commission	Established by the Convention on the Great Lakes Fisheries. National agencies advise the two governments on fisheries issues of common concern, and on problems associated with non-indigenous species.
International Association for Great Lakes Research	Publishes the quarterly Journal of Great Lakes Research and hosts annual conferences

Table 4.8. United States agreements, laws and organizations involved with the Great Lakes science, management and policy

Title	*Involvement / Focus*
Clean Water Act (CWA, 1972)	Federal Water Pollution Control Act of 1948. Improves the nation's water quality by setting national standards for water quality and waste discharge.
Great Lakes Toxic Substances Control Agreement (1986)	Council of Great Lakes Governors. Studies, manages and monitors toxic pollutants in the Great Lakes and their effects.
National Environmental Protection Agency (NEPA)	Established a Council of Environmental Quality in the Office of the President. Analyzes and interprets environmental information, develops policy recommendations and reports findings.
General Environmental Protection Laws	Clean Air Act; Safe Drinking Water Act; Comprehensive Environmental Response, Compensation, and Liability Act; Superfund Amendments and Reauthorization Act; Resource Conservation and Recovery Act; Pollution Prevention Act; Oil Pollution Act; Federal Insecticide, Fungicide, Rodenticide Act.
General Resource Management Laws and Programs	Water Resources Development Act; Coastal Zone Management Act; Endangered Species Act; Shore Protection Act; Shoreline Erosion Control Development and Demonstration Project; Coastal Barrier Resource Act; U.S. National Estuary Program; National Coastal Monitoring Act; Rivers and Harbors Act of 1899.

Table 4.9. Canadian agreements, laws and organizations involved with the Great Lakes science, management & policy

Title	Involvement / Focus
Canadian Environmental Protection Act (CEPA)	Environment Canada. Protects people and the environment from the effects of toxic substances.
Canada-Ontario Agreement (1972)	Federal government and the province of Ontario. Provides funding to adhere to the GLWQA.
Canada Water Act (1970)	Responsibility and both the federal and provincial level. Manages water resource programs on conservation, development and use of water resources.
Fisheries Act (1985)	Conserve and protect fish through allocation of the catch among competing users, and protection of fish habitat.
Great Lakes Action Plan (2001 – 2006)	8 departments of the Canadian government; renewed version of the Government of Canada's Great Lakes Program. Continues to restore areas harmed by pollution and land use practices. Asses new challenges to the health of the Great Lakes basin.
Municipal Industrial Strategy for Abatement (MISA)	Imposes effluent loading and concentration limits for 190 facilities that discharge to Ontario waters.

REFERENCES

Beck, G.G. and Litteljohn, B. (2000) *Voices for the Watershed: Environmental Issues in the Great Lakes—St Lawrence Drainage Basin*, p 179. McGill-Queen's University Press.

Beierle, T.C. and Konisky, D.M. (1999) Public participation in environmental planning in the Great Lakes region, p. 40, *Resources for the Future Discussion Paper 99–50*. Washington, D.C.

DePinto, J.V., Young, T.C. and McIlroy, L.M. 1986. Great Lakes water quality improvement: The strategy of phosphorus discharge control is evaluated. *Environ. Sci. Technol*., **20**(8), 752–759.

DiToro, D.M. and Connolly, J.P. (1980) Mathematical Models of Water Quality in Large Lakes Part 2: Lake Erie, *EPA-600/3-80-065*, ERL-Duluth, 231pp.

International Joint Commission, September 2004. Twelfth Biennial Report on Great Lakes Water Quality, pp 47–55.

Leach, J.H. (1993) Impacts of the Zebra Mussel (*Dreissena polymorpha*) on Water Quality and Fish Spawning Reefs in Western Lake Erie. In *Zebra Mussels: Biology, Impacts, and Control* (eds T.F. Nalepa and D.W. Schloesser), Lewis Publishers. 23:381–397.

Makarewicz, J.C. and Bertram, P. (1991) Evidence for the restoration of the Lake Erie ecosystem: water quality, oxygen levels, and pelagic function appear to be improving. *BioScience*, 41(4), 216–223.

Manno, J. (1992) Advocacy and diplomacy in the Great Lakes: a case history of NGO participation in world environmental politics. State University of New York, College of Environmental Science and Forestry, Syracuse, NY, USA.

Naiman, R.J., Magnuson, J.J., McKnight, D.M. and Stanford, J.A. (eds.) (1995) *The Freshwater Imperative: A Research Agenda*. Island Press, Washington, D.C.

Nalepa, T.F. and Schloesser, D.W. (1993) *Zebra Mussels: Biology, Impacts, and Control*. Lewis Publishers.

U.S.E.P.A. and Government of Canada. (1995) *The Great Lakes: An Environmental Atlas and Resource Book*, (ed. K. Fuller, H. Shear and J. Wittig), 3rd edition.

U.S.G.S. and U.S. Department of the Interior. (2000) Water Quality in the Lake Erie-Lake Saint Clair Drainages: Michigan, Ohio, Indiana, New York, and Pennsylvania, 1996-98. *Circular 1203*.

Wetzel, R.G. (2001) *Limnology: Lake and River Ecosystems*, 3rd Edition. 13:269–285.

Internet: www.glerl.noaa.gov

Internet: www.great-lakes.net

Internet: www.greatlakesseagrant.org

Internet: http://iaglr.org