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Water Quality of Long Point Bay: Issues and Areas of Concern for Planning and Management

Long Point Environmental Folio

Long Point Environmental Folio
Publication Series

Technical Paper 7

Long Point Environmental Folio Publication Series
Managing Editors: J. Gordon Nelson and Patrick L. Lawrence

A study team at the Heritage Resources Centre is developing an Environmental Folio for the Long Point Biosphere to assist management agencies and local citizens in understanding the human and natural components of the ecosystem. The folio will consist of a series of maps and text that would outline current major management issues and areas of concern. A series of project publications is being prepared to accompany the folio. These reports will consist of supplementary information collected during the study. This project is supported by the Royal Canadian Geographic Society and the Social Sciences and Humanities Research Council of Canada.

Water Quality of Long Point Bay: Issues and Areas of Concern for Planning and Management

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PREFACE

This report is intended as an initial assessment of water quality of the Long Point Bay (referring to both the Inner Bay and Outer Bay). The purpose is to provide a review of the current understanding of water quality characteristics such as nutrients, chemicals, eutrophication, toxins and heavy metals, their relationships to natural processes and human activities important to planning and management in the Long Point area. The research was conducted in a four month period from December 1993 to March 1994 and consisted of review of existing documents and meetings with key individuals and agencies with interest or responsibilities in regard to water quality monitoring and research within Long Point Bay. This report provides an overview of the key issues related to water quality and provides information of use to local citizens and those responsible for planning and management in the Long Point Biosphere Reserve and area. It is acknowledged that limited data exists for many sites within the Inner Bay and that ongoing studies conducted by the Ontario Ministry of Environment and Energy and Environment Canada will in the future provide improved information. The opinions expressed in this report are solely those of the authors and not necessarily shared by individuals or agencies contacted during this study.

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SUMMARY

Long Point Bay's water quality is influenced by cultural stresses including human-induced erosion and sedimentation, thermal and salt loading, global warming, eutrophication, and the presence of toxic substances. A management strategy focusing on improving and maintaining water quality would need to address these contributing factors simultaneously. The main water quality issues are sediment associated contaminants (phosphorus, metals, pesticides), and salt loading from non-point sources, storm sewer runoff, nitrate contamination of groundwater, high bacteria levels at beach areas, and herbicide/pesticide use in the agriculturally based watershed area. The areas of concern highlight those sites where problems are chronic and are in need of management attention: Turkey Point, North shore of Inner Bay, Port Rowan, Big Creek Watershed, Big Creek Marsh, Long Point Community, and the Inner Bay.

GLOSSARY

acidity: capacity of a liquid to react with hydroxyl ions, may be attributed to natural causes, industrial wastes and atmospheric inputs.

alkalinity: measure of a waterbody's ability to neutralize an acid, by the presence of hydroxides, carbonates, and bicarbonates.

Biological Oxygen Demand (BOD): used as measure of unstable organic matter present in water which oxidizes to a stable form by use of available oxygen.

carbon: produced from decomposition of organic matter with additional sources from agricultural land and industrial discharge (dissolved organic carbon, total organic carbon).

chloride: natural minerals with large concentrations attributed to domestic sewage discharge, road salting, and industrial wastes.

chlorine: element used as oxidizing agent and disinfectant in industrial processes.

coliform: bacterial organisms found in fecal waste, used as a key indicator of water quality due to human activities (e.g. sewer waste treatment, agricultural). (Fecal Coliform, Escherichia Coliform)

conductivity: measure of the electrolytic properties of water, indicator of the total dissolved solids concentration.

DDT: crystalline insectide that tends to accumulate in ecosystems and has toxic effects on many vertebrates.

dioxin: hydrocarbon existing as a persistant toxic impurity in herbicides.

Dissolved Oxygen (DO): The oxygen dissolved in water, necessary for the life of fish and other aquatic organisms.

eutrophication: process of excessive addition of inorganic nutrients (phosphorus and nitrogen), organic matter and/or silt leaching to increased biological production.

furans: liquid used in organic synthesis

hardness: water's capability to produce lather from soap, hardness caused by dissolved calcium or magnesium, leads to formation of scale on piping, pots, etc.

iron: abundant element in the earth's crust, often added in the form of salts, affecting low pH values.

lead: cumulative poison that can be deposited in bone, loading occurs from industrial and mining effluents.

limnology: scientific study of the physical, chemical and biological conditions of fresh water systems.

mercury: cumulative and toxic to humans and can be concentrated and transferred up the food chain to point where fish may be unsuitable for human consumption.

nitrate: intermediate oxidation product of ammonia, indicator of active biological processes.

non-point source pollution: discharge of runoff not contained within combined sewer overflow or outfall, primarily surface runoff from urban and agricultural land uses.

PCBs (Polychlorinated Biphenyls): industrial chemicals produced by direct chlorination of biphenyl, concern for possible toxic and carcinogenic properties with uptake and concentration in food chain.

pH: acidity is measured on a pH scale of 0-14, a number less than 7 indicates increasing acidity and numbers greater than 7 indicate increasing alkalinity.

phenols: derivatives of benzene, released from industrial processes and decaying vegetation.

pesticides: chemical used to destroy plants or animals.

point source pollution: discharge at a fixed location, e.g. industrial spill (note: atmospheric sources of phosphorus account for 40% of point source loading to the Great Lakes).

sodium: common to natural waters, found in many industrial processes and salts used in road de-icing.

sulphate: natural chemical, it is also produced from oxidation of sulphides and other byproducts.

sulphide: formed from the reduction of sulphate and organic sulphur compounds under anaerobic conditions, commonly found in domestic and industrial wastewater.

thermal loading: discharge of warm water into a cooler water body

total nitrogen: measure of total nitrogenous matter, common constituent of decomposition products, treated sewage, fertilizers, and industrial discharge (total Kjeldahl nitrogen).

total phosphorus: primary nutrient for plant and animal life and includes both dissolved and particulate form.

turbidity: measure of reduction of clarity and penetration of light due to suspended solids and matter such as microorganisms and organic matter.

(definations complied from Ontario Ministry of Environment, 1991: Environment Canada, 1993; with assistance from Mike Stone, Wilfrid Laurier University)

INTRODUCTION

The Long Point Spit and a buffer area surrounding this spit, which roughly includes Port Rowan, Turkey Point and the Inner Bay, together form the Long Point Biosphere Reserve (Figure 1). It was so designated in 1987 because it is one of the most extensive natural areas remaining in southwestern Ontario. The area has also been designated as a Ramsar site, meaning that it contains a wetland of international significance. This designation indicates the importance of Long Point as a sensitive area requiring protection in terms of water quality and other aspects of the environment. For example wetlands, which occur at the interface where land and water meet, provide a necessary habitat for many fish, amphibians and reptiles. Numerous bird and mammal species make extensive use of these wetlands for habitat, feeding and nesting (Wilcox and Knapton, 1994).

In order to ensure the protection of species dependent on these wetlands, it is important to assess the ecosystem integrity of areas such as the Long Point Biosphere Reserve. Since one component of ecosystem health is water quality, information should be gathered on Long Point Bay's present water quality status. This will help to support effective management strategies for the area. Long Point area citizens have themselves expressed concern about the water quality of the Bay. In a study by Weller (1989) it was noted that area citizens identified water quality as one of the key management issues for their region. The issue of water quality has also been identified as a key concern in the development of an environmental folio for the Long Point Biosphere and Region (Nelson et al., 1993).The objective of this study is to present, in a non-technical format, an overview of Long Point Bay's water quality status. This has involved gathering information from a variety of published sources including government reports and scientific studies. Throughout this paper, the term water quality will be used to describe the physical, biological and chemical characteristics of water with respect to its suitability for various uses in the Long Point area. A review of the importance of human activities and land uses in relation to water quality is followed in the report by a description of specific water quality issues and status within Lake Erie. Current water quality parameters of Long Point Bay as monitored by several agencies are then presented. The report concludes with a summary of the key issues and areas of concern in the Bay and recommendations for future actions by responsible management and planning agencies.

STUDY AREA

The study will focus primarily on Long Point Bay and its major tributaries. Long Point Bay, comprised of both an 'Inner' and 'Outer' Bay, is located on the east side of the Long Point spit (Figure 2). The Inner Bay is enclosed by the Long Point sandspit, the north shore of Lake Erie and a sandbar extending between Turkey Point and Pottohawk Point. The Outer Bay encompasses the area extending from Turkey Point, northeast to Peacock Point, south to the tip of the Long Point spit and west to Pottohawk Point. The major tributaries of Long Point Bay are Big Creek (Photo # 1), flowing into Big Creek Marsh (Photo # 2); Dedrich Creek, flowing into the Inner Bay; and Lynn and Nanticoke Creeks, flowing into the Outer Bay. Long Point's Inner Bay is an important area for many biotic communities. For instance, the open water and shoreline marshes and wetlands (Photo # 3) are major staging areas for migratory waterfowl and small migratory birds. In addition, the Bay is considered to have the most important fish spawning and nursery grounds in Lake Erie (Craig, 1993). This can be partially attributed to the fact that the majority of the Inner Bay is covered with aquatic vegetation (Pauls and Knapton,1993). The Long Point area has been subject to increasing human activity such as urbanization, industrialization (Photo # 4), tourism and recreation in recent years (Figure 3) (Lawrence and Beazley, 1994). Changes in natural areas are important because they support commercial and sports fishing, waterfowl hunting, trapping, and recreation (Wilcox, 1993). Therefore, a change in the water quality of Long Point Bay could affect the biota, which would also then affect human activities.

Figure 1. Long Point Biosphere Reserve and Region

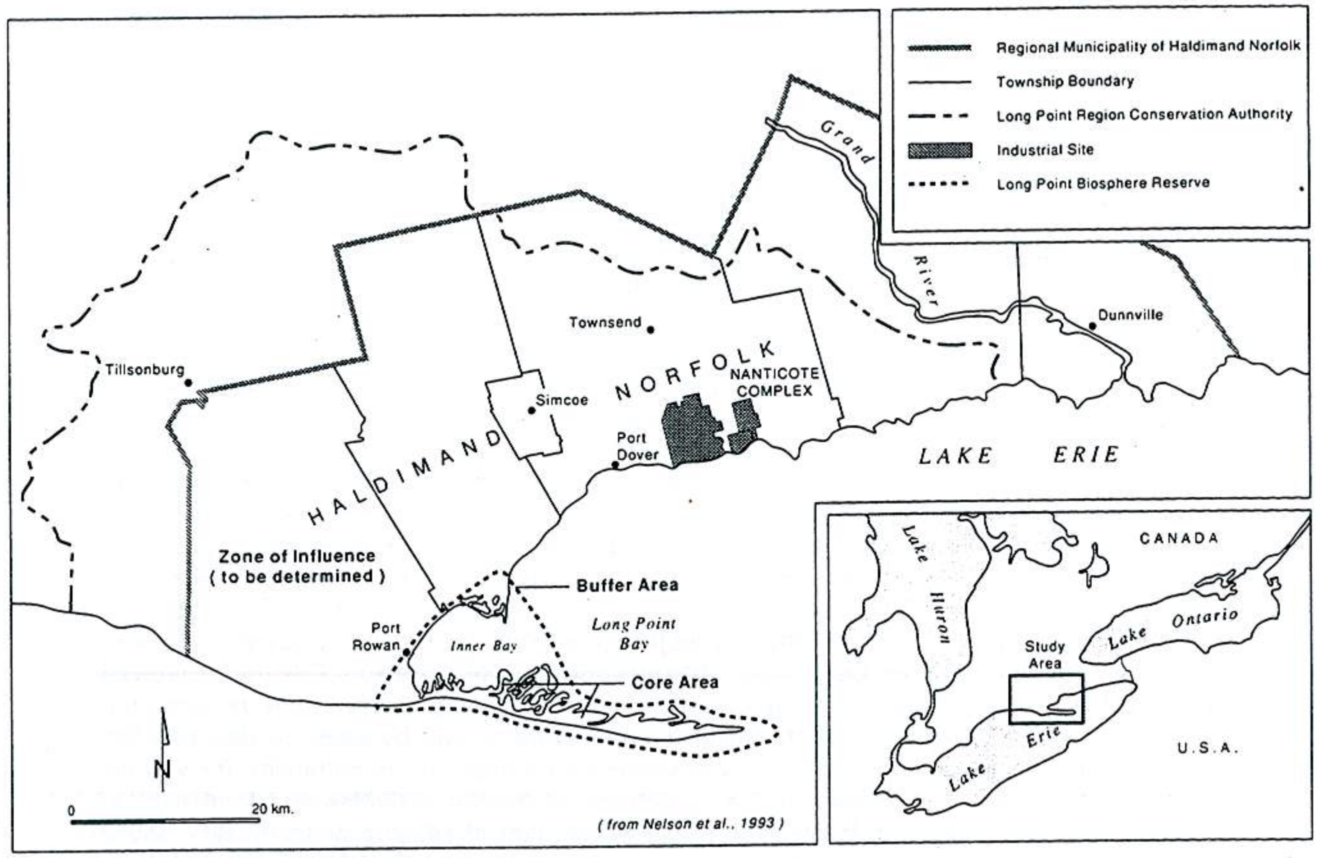


Figure 2. Long Point Inner Bay

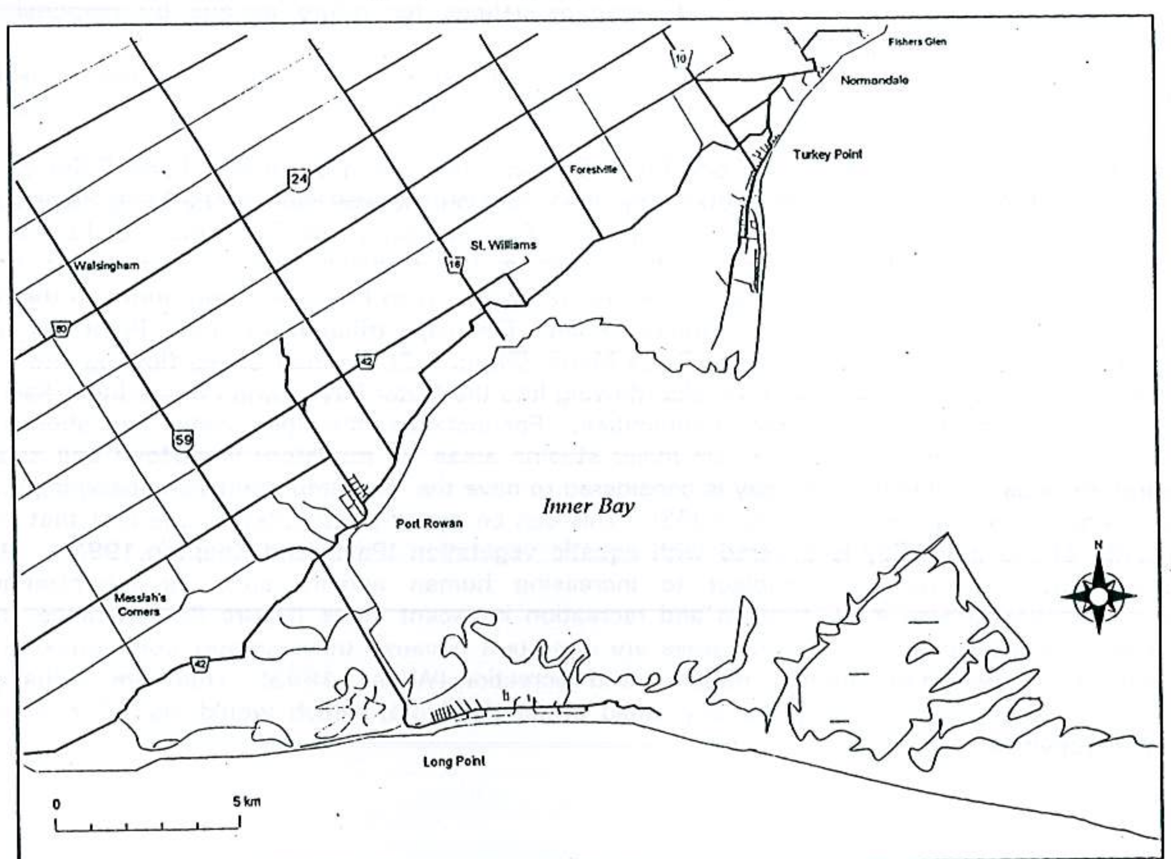


Photo # 1. Big Creek

Typical section of Big Creek, with intensive agricultural land use, extending right to the edge of the stream.

Photo # 2. Big Creek Marsh

Open water and wetlands which characterize Big Creek Marsh, an important staging area for waterfowl and potential sink for sediment and contaminants discharged from Big Creek.

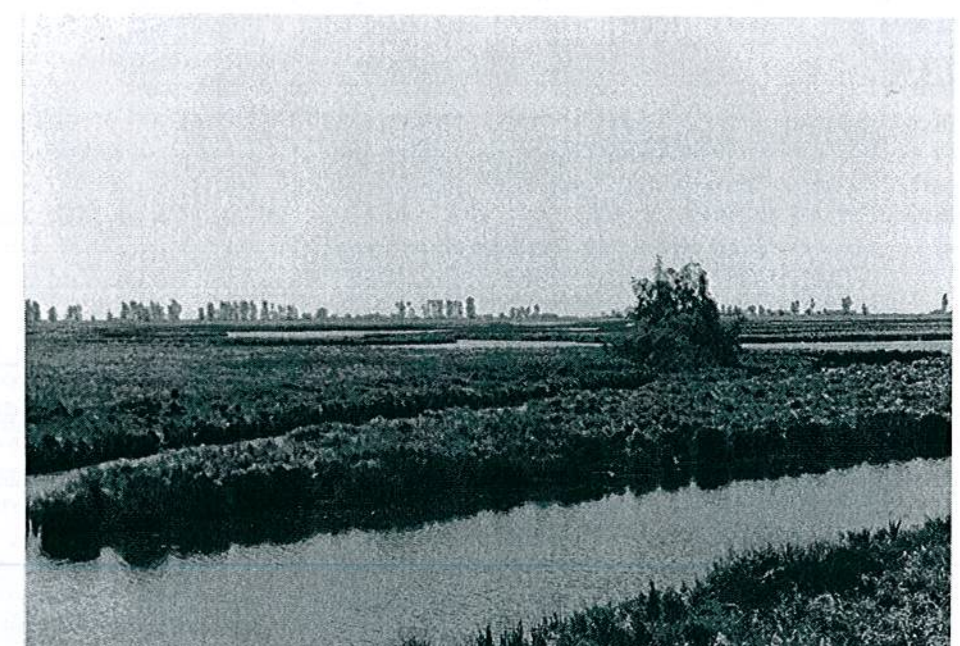


Photo # 3. Wetlands of Long Point Inner Bay

Shoreline marshes and wetlands west of Turkey Point with view extending across the Inner Bay with Long Point in the background

Photo # 4. Nanticoke Industrial Complex

Landscape in the area of the Nanticoke Industrial Complex with oil refinery facilities in the background and rural agricultural land in the foreground.

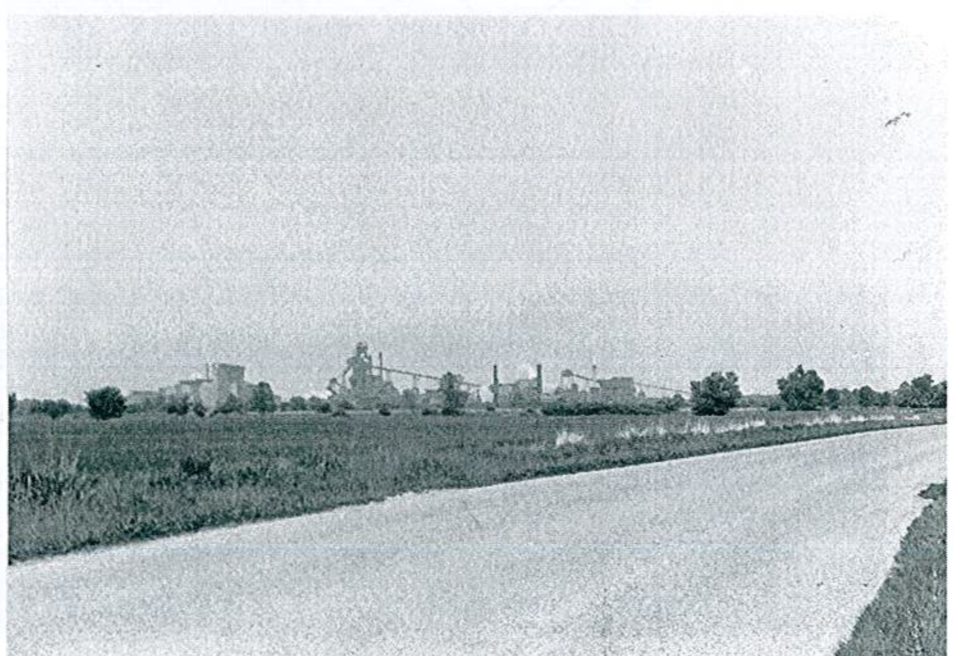
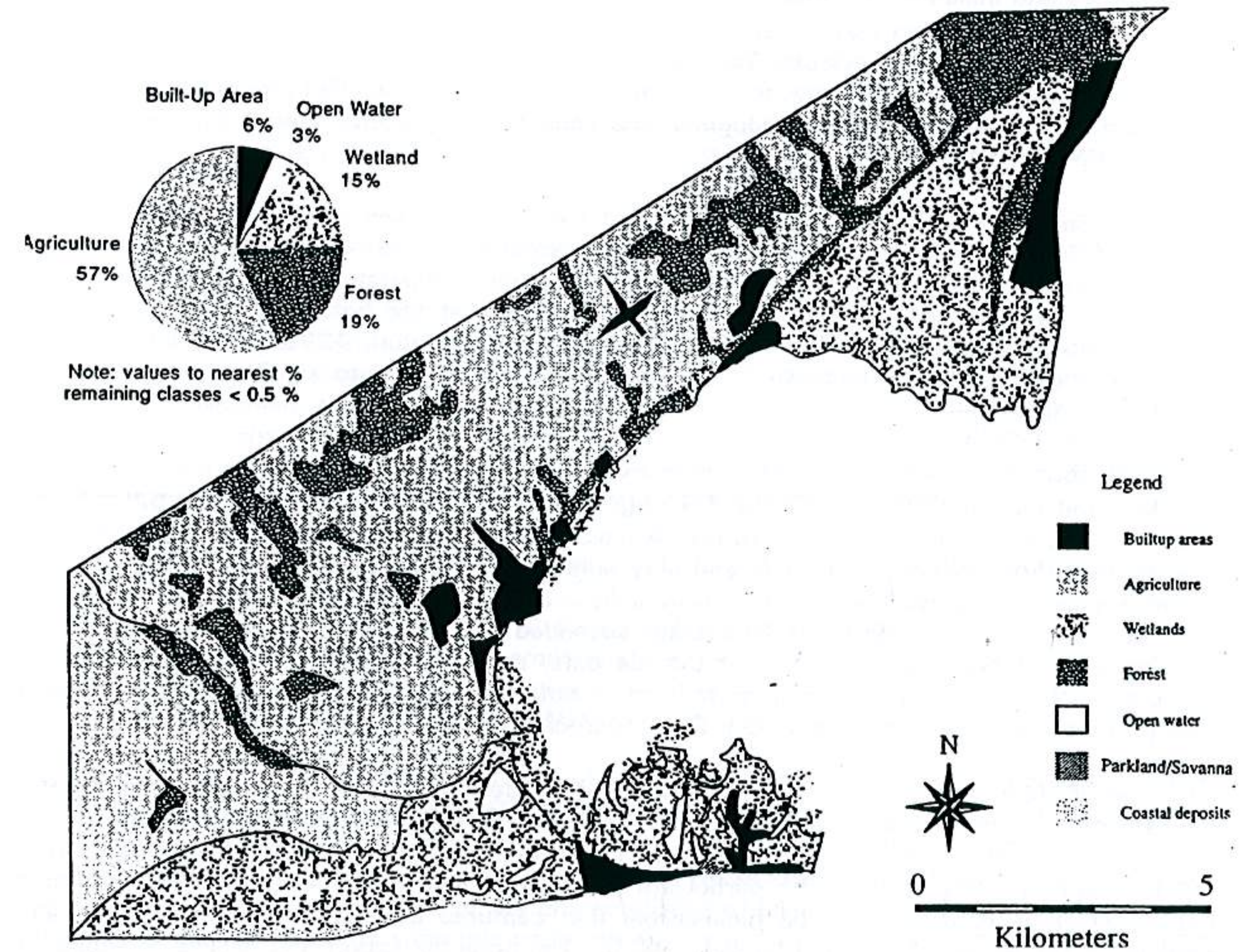


Figure 3. Long Point Land Cover 1990



Historically, the region of Haldimand-Norfolk has been predominantly agricultural. However, this type of land use has declined in recent years. From 1851 to 1986, total farmland area fell from 87 to 73 percent of the Region's total land area (Wilcox, 1993). Despite this overall decline, agriculture still predominates in upland areas (Whillans et. al, 1987). Typically, the primary use of these agricultural areas has been for growing tobacco crops, but the extent of this industry has diminished since the early 1980's. Fertilizers used on tobacco are generally low in nitrogen and high in phosphorus. Herbicides and pesticides are however commonly used on tobacco to control disease (Merriman et al., 1991). On the other hand, small grain production has been on the rise, from 1971 to 1986 it increased by 18 percent (Wilcox, 1993). Recommendations for use of nitrogen fertilizers for cereal crops has more than doubled in past 20 years as acreage of corn crops has increased 7 fold since 1950 (Leach, 1981).

Most of the urban areas of the Long Point area are located at the interface between lower rivers and near-shore zones (Whillans et. al, 1987). The areas include the communities of Port Rowan, Nanticoke and Port Dover. These urban areas have experienced modest expansions since the mid 1970's (Yeung, 1993). Intensive recreational activities and tourism, such as cottages and marinas, predominate along the less exposed and protected shores of the Long Point Area. It is estimated that about 950,000 person-trips are made to Haldimand-Norfolk per year (Norfolk District Futures Corporation, 1988). Popular activities include boating, swimming, hiking, fishing, bird-watching, camping and hunting.

The Nanticoke industrial complex, located on the shore of the Outer Bay was developed in the early 1970's and includes the Ontario Thermal Generating Station, (a 4,000 megawatt coal-fired thermal electric generating station), the Stelco Steel Mill (a 1.35×10^6 ton annual capacity steel plant), and Imperial-Esso (previously Texaco) Oil Refinery (a 105,000 barrel per day oil refinery) (Whillans et. al, 1987). In addition to these industries, there are four fish processing plants and other commercial establishments throughout the Long Point area that service the local fishing industry (Wilcox, 1993).

The Inner Bay is shallow, with a mean depth of 1 metre (Wilcox and Knapton, 1993). The Bay receives diffuse-source nutrient loadings and supports dense stands of aquatic vegetation. The Inner Bay warms rapidly in the spring, attains warm summer temperatures (maximum 25^0 C) and cools rapidly in the early fall. Approximately 90 percent of the bottom of the Inner Bay is covered with submerged aquatic vegetation (Wilcox and Knapton, 1993). The Inner Bay is unique in the Great Lakes because it has not yet been subjected to significant point source pollutant loadings.

The main source of drainage into the Bay is from Big Creek. Big Creek drains a watershed of 730 km^2 and has an mean annual total discharge of approximately $250 \times 10^6 m^3$ (or 6.5 m^3/sec) (Leach, 1981; Environment Canada, 1992). A majority (68%) of the annual suspended sediment load is transported between February and May during peak discharge events (i.e. runoff during storm events and snow melt). The mean annual suspended load for Big Creek is 24,315 ton/year (from 1972 to 1991) and the average suspnded yield for the Big Creek watershed is 41 ton/Km^2/year (unpublished Environment Canada data, provided by Mike Stone, Wilfrid Laurier University). Big Creek Marsh is important as a buffer for sediment-associated contaminant transport from Big Creek into Long Point Bay (Mudroch, 1981).

Loadings of chloride from Big Creek of 4.4 metric tons per km^2 of drainage area are among the lowest north shore tributary loadings to Lake Erie (Ongley, 1976). Estimated loadings of total phosphorus averaged 22 metric tons between 1972 and 1978 with no apparent trends (Leach, 1981). Approximately 23% of the particulate phosphorus load is termed nonapatite inorganic (NAIP) which is considered to be bioavailable (i.e. captured and entrained by sediment and particles in the water) (Stone and English, 1993). The potential export and release of sediment bound phosphorus into Lake Erie from Big Creek can be significant (Stone et al., 1991). Berst and McCrimmon (1966) concluded that nutrient and sediment loading from Big Creek had contributed to eutrophication of the Inner Bay and enrichment has continued (Leach, 1981).

Leach (1981) conducted a detailed survey of water quality parameters in the Inner Bay in 1978-79 with the purpose of comparing it to data collected in 1962 by Berst and McCrimmon (1966). Several of the conclusions of Leach (1981) include:

* Mean concentrations of nitrate in 1979 were high in spring, declined sharply in May to low levels in summer and increased in the fall;
* Chloride loadings from Lake Erie north shore watersheds are probably more closely related to application of road de-icing materials (from Ongley, 1976);
* Total alkalinity in the Inner Bay also followed a seasonal pattern with minimum levels coinciding with summer macrophyte production;
* From 1962 to 1979 mean total alkalinity increased by one third, nitrates not observed in 1962 were present up to 117 *ug*/L ;

* Dissolved oxygen does not appear to be a problem due to lack of thermal stratification and macrophyte photosynthesis.

The Inner Bay is considered eutrophic (Leach, 1981). Apparent changes in the Inner Bay from 1962 to 1979 include increases in nitrate and nitrite nitrogen and total alkalinity (Leach, 1981), indicating greater photosynthesis by macrophytes and continuation of a gradual enrichment process in the Inner Bay. The future eutrophic status of Inner Bay is dependent on nutrient loading.

WATER QUALITY AND HUMAN ACTIVITIES

Water quality problems are generally caused when concentrations of people, industries, and agricultural use create wastes which pollute streams and lakes (Great Lakes Basin Commission, 1977). The various human activities that lead to these potentially harmful wastes can be referred to collectively as cultural stresses. According to Muir (1981) cultural stresses have produced "gross changes in the entire Lake Erie ecosystem". This has resulted in a significant deterioration of the Lake over the past several decades. Because Long Point Bay is contained within this lake, it too has been adversely affected by these cultural stresses.

Urban runoff affects the water quality in rivers and lakes by increasing the concentrations of substances such as nutrients (phosphorus, nitrogen), sediments, animal wastes, petroleum products, and road salts (Environment Canada, 1993). In agricultural areas where intensive farming takes place, rain causes soil to erode, and then carries soil particles into creeks, streams and rivers, and eventually into the Lake. Nutrients from fertilizers, dissolved in the water can then attach to soil particles in suspension (Metro Toronto Remedial Action Plan Office, 1991).

A general response of an ecosystem to cultural stresses is to shift from the characteristics of one level of hydrologic order to characteristics of a higher level of hydrologic order. For instance due to agricultural activities, cool upland streams may get warmer, acquire sediment loads, and support biota more typical of a lower, valley stream. These lower streams, acquiring even more sediment, may then take on some of the characteristics of lakeshore flood ponds. As a result, offshore waters may become eutrophic under an excessive loading of nutrients from the eroded sediments and waters being transported from upstream. According to Whillans et. al (1987), this shift in order is particularly pronounced with respect to pollutants which are transported by water and sediments.

Cultural activities in the upland areas of Haldimand-Norfolk watershed may have serious implications for the water quality downstream into Long Point Bay. Furthermore, in estuaries and bays like Long Point, water quality problems can become even more pronounced because the water in these aquatic systems circulates more slowly than in the encompassing lake. This longer retention time allows pollutants to settle and remain in the system for a longer period of time (Great Lakes Basin Commission, 1977). Therefore, Long Point Bay may be particularly sensitive to the effects of sediment loading, as well as pollutants being circulated in Lake Erie.

In order to establish the effect that cultural stresses have on Long Point Bay's water quality, effective measurements and indicators must be identified. Firstly, direct measurements from the water may be taken. These measurements can include such parameters as the pH, temperature, hardness, colour, turbidity, as well as the concentrations of metals, pesticides and other substances (Table 1). Another way in which to determine the water quality of an aquatic system is to identify species that can act as indicators. The term "indicators" in this sense refers to those species that show sensitivity to changes in water quality.

A change in species composition or an alteration of a species' physical and/or physiological makeup can indicate such a change. Not only has the species composition in Lake Erie changed, but physical and physiological changes in some species have taken place as well. For instance, abnormal vitamin A levels, thyroid function, heme biosynthesis and activities of detoxifying enzymes are found in herring gulls throughout the Great Lakes basin (Department of Fisheries and Oceans, 1991). Furthermore, there is good circumstantial evidence that human-induced pollutants were involved in the mass mortality of Lake Trout embryos in the early 1980's (Department of Fisheries and Oceans, 1991). The presence of certain organisms in an aquatic system can also indicate a decline of water quality. The presence of coliform bacteria for example is a sign that the system may contain human disease-causing organisms such as cholera, diarrhea and typhoid (Environment Canada, 1993).

Table 1
Selected Water Quality Parameters for Freshwater Aquatic Life
(from Environment Canada, 1989)

Organic	**mg/ L (ppm)**
DDT	0.000001
PHENOLS (total)	0.001
Inorganic	
Ammonia (total)	1.37 - 2.2
Chlorine (total residual)	0.002
Copper (total)	0.002 - 0.004
Cyanide	0.005
Iron (total)	0.3
Lead (total)	0.001 - 0.007
Mercury (total)	0.0001
Dissolved Oxygen	5.0 - 9.5
pH	6.5 - 9.0 (pH units)
Zinc (total)	0.003

WATER QUALITY ISSUES

In order to have a full understanding of Long Point Bay's water quality status, it is important to identify which human activities are contributing to any water quality changes. In the next section of the report, the more significant cultural activities believed to be stressing this water system will be examined. These stresses include human-induced erosion and sedimentation, thermal and salt loading, global warming, eutrophication, and the presence of toxic substances. It should be mentioned that even though these issues will be treated separately, they are all interrelated. Therefore, any management strategy focusing on improving and maintaining water quality would need to address these contributing factors simultaneously.

Erosion and Sedimentation

Erosion is a natural as well as a cultural phenomenon. Defined as the process whereby water wears down land surfaces and washes away soil material, this process can be greatly accelerated as a result of human activities and can seriously affect water quality (Stenson, 1993). As soil is being eroded, it carries with it foreign materials contained in the soil. Organic and inorganic substances can greatly exaggerate the water quality degradation caused by erosion.

The eroded sediment can also affect water quality. For instance, sediment suspended and transported by water causes an increase in turbidity or water cloudiness. This turbidity reduces

the amount of light penetration into the waterbody, which then depletes the aquatic vegetation, as well as the aquatic organisms dependent on this vegetation (Environment Canada, 1993). Therefore, cultural activities which accelerate erosion are indirectly responsible for decreases in the quality of the waterbody into which the eroded sediments flow. The sediments do not all remain suspended in the water. Most settle to the bottom of the nearby streams, lakes or other waterbodies. This deposition of sediment, or sedimentation, occurs to a greater extent in areas with poor water circulation such as bays. After sedimentation, sediment associated contaminants (metals, phosphorus, pesticides) can be released into the water through desorption or microbial processes. This can cause a decline in water quality because it can limit human uses of such areas. For instance, recreational boating could be hindered by the partial filling of channels or bays.

The specific cultural activities that result in erosion, sedimentation and turbidity range from poor agricultural practices to construction, dredging and shipping. For example, poor agricultural practices can result in surface erosion of the soil by rain. The soil can then be transported by water over the land and into a nearby stream or lake. Construction and development can further contribute to erosion and its attendant problems. When agricultural land is developed for urbanization, the vegetation and top soil is usually stripped off before construction takes place. As a result, the bare land is easily eroded by rain, and sediment is washed off into nearby streams and waterbodies. This runoff process further contributes to a decline in water quality.

Dredging is another cultural activity related to erosion. It refers to the removal of sediments and earth from the bottom of a waterbody using a scooping or suction machine. This dredging activity is used to remove bottom sediments that have decreased the water depths of embayments and boat slips, to enlarge channels for navigation or to allow larger volumes of water to be drained (Environment Canada, 1993). The undesirable result of this activity is that it resuspends bottom sediments, thus increasing turbidity further. This increased turbidity can result in fish mortality. Wave action from recreational boating and commercial shipping can also resuspend the bottom sediments.

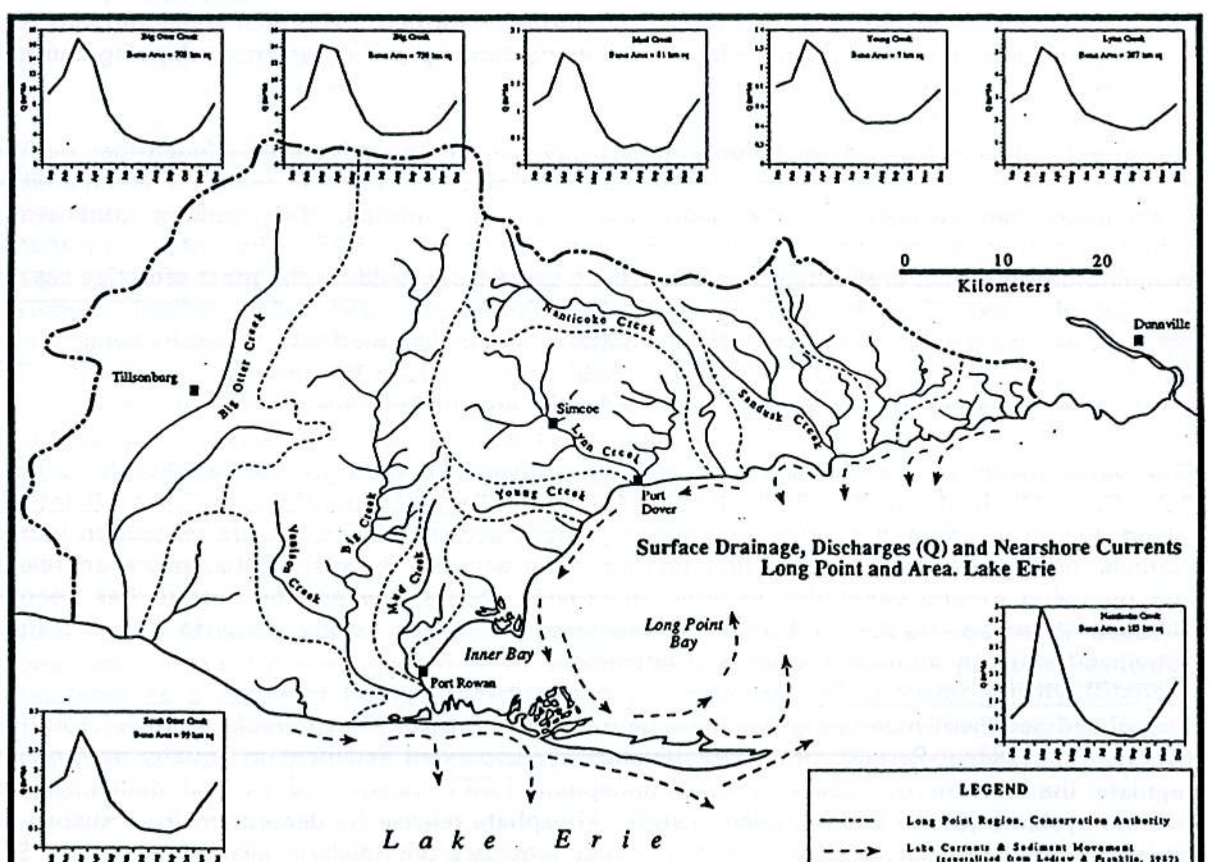
The effects of erosion, sedimentation and turbidity can in turn adversely affect other cultural activities. For instance, we can lose valuable agricultural soil to erosion, while its sedimentation downstream can partially infill navigable channels and boatslips, thus limiting commercial, industrial, and/or recreational water uses (Environment Canada, 1993). Preventative measures, including buffer strips, crop rotation, proper tillage practices, would be the most effective way to minimize the water quality problems associated with erosion and sedimentation. Improved agricultural practices to reduce runoff and better construction methods to retain some of the natural vegetation normally stripped away, could greatly reduce the process of erosion. This would then help to ensure better water quality for the area under management.

The water quality issues resulting from erosion and sedimentation are very applicable to Long Point Bay. Much of the shoreline extending from the village of Long Point to Turkey Point and inland, has been affected by human activities. These activities include shore protection works, marinas, cottage development and dredging for water access. By altering the natural shorelines and removing natural vegetation in order to provide access, the aquatic system has become stressed (Stenson, 1993). This has implications for water quality because these cultural activities frequently increase erosion and turbidity.

Suspended sediment monitoring has been performed by Environment Canada on major southern Ontario tributaries. Particle size characteristics of suspended sediment in aquatic ecosystems regulate the amount of soluble reactive phosphate (SRP) transported by and deposited into riverine systems (Stone and Mudroch, 1989). Phosphate release by desorption from suspended and resuspended fluvial sediment in Lake Erie may provide a potentially available reservoir of SRP over longer time periods. In Big Creek the particle size less than 16μm accounts for approximately 75 per cent of the theoretical sediment-phosphate load transported by this river (Stone et al., 1991; Stone and Sanderson, 1992). This grain size of sediment can remain in suspension for extended periods due to turbulent diffusion and is the most active in phosphate adsorption/desorption. The fate of other chemicals in rivers is controlled by absorption kinetics with sediment (Mudroch and Duncan, 1986). A proposed model may serve as a basis for future studies designed to investigate the transport of other sediment-bound nutrients and contaminants (pesticides and metals) in Big Creek tributary (Stone et, al., 1991).

Longshore drift carries sediments eroded from the north-eastern shore of Lake Erie west to Turkey Point where some of it is deposited (Figure 4). The rest of the sediment is then carried out into the Outer Bay. This means that contaminated sediment east of Long Point would probably settle in the Outer Bay, while the Inner Bay would be less affected. The mouth of Big Creek is another site for deposition. It is the primary source of suspended materials entering the Bay (Berst and McCrimmon, 1966). This has further implications for the Bay's water quality. As mentioned previously, sediment loading upstream can become more concentrated as it reaches the Bay. Several studies have documented the concentration of pesticides (Frank et al., 1974, Frank et al., 1978; Merriman et al., 1991) and metals (Frank et al., 1976) in the Big Creek watershed. More recent work indicates that zine and mercury levels in fine grained sediment exceeds the Ontario Ministry of Environment sediment quality guidelines (Mike Stone, Wilfrid Laurier University, unpublished data). Settling of the sediments at the shore of the Inner Bay could affect the water quality. For instance, high levels of toxic contaminants could make the water there unsuitable for swimming, while excessive nutrients could lead to eutrophication.

Figure 4. Surface Drainage and Nearshore Currents



Cultural activities to the west of Long Point Bay can also indirectly affect the Bay's water quality. Sediment is transported from the western basin, which receives the largest input of sediments, to the central basin and then to the eastern basin. This sediment flow results in about 6 x 10^6 tonnes of silt and clay being transported into the eastern basin every year and accounts for approximately 60 percent of the total annual loading to this basin (Rukavina and Zeman, 1987). The amount of this sediment that reaches the Inner Bay and the dynamics of water current flow are poorly understood.

Cultural activities are also affected by the erosion, sedimentation and turbidity in Long Point Bay. According to Stenson (1993) the Inner Bay, and to a less degree the Outer Bay, are subject to conflict between natural abiotic processes such as erosion and human activities including boating, oil and gas extraction, dredging and fishing. Therefore, human activities not only contribute to erosion and erosion-related processes, but the results of these processes can in turn, affect human activities.

Thermal Loading and Salt Loading

Changes from rural to urban land uses dramatically increase the problems of stormwater runoff where a large proportion of urban surfaces, such as streets, roofs and parking lots, are impervious to rain (Metro Toronto Remedial Action Plan Office, 1991). For instance increased stormwater affects both urban thermal pollution and urban salt loading. As a result, the aquatic system gets a dual shock; that of temperature and acidity level changes.

Thermal loading can be defined as a cultural stress that results from the human activity of directly or indirectly discharging warm water into a cooler water body (Environment Canada, 1993). For example, discharge from industrial activities and power generation can increase the temperature in the water. This can make the water unsuitable for established or potential uses. Therefore, as power generation and industrial activities increase in the future, thermal discharges could potentially become a more significant water quality issue (Great Lakes Basin Commission, 1977).

An increase in temperature reduces the density of the water and oxygen concentration, negatively affecting the aquatic ecosystem (Langford, 1983). However, the general ability of fish to adapt means that large-scale mortalities are infrequent. They occur mainly when populations are trapped in an effluent channel or when sudden discharges of hot water occur. Discharges of thermal effluents into water which is already polluted may also tip the balance for survival (Alabaster and Lloyd, 1982).

Thermal discharges affect coldwater and warmwater fish species in Long Point Bay by changing their habitat. The discharges may also affect the growth of algae and other small organisms on which fish feed. The greatest effects of such discharges are generally localized around the source of such thermal discharges at the Nanticoke Industrial Complex rather than lakewide. As the temperature of the water released by the Nanticoke Thermal Generating Station increases, the biota in the immediate offshore area is affected. The respiration and heart rate of the fish increase in order to obtain oxygen for an increased metabolic rate, but at the same time the oxygen concentration of the water is decreased. At 1^{o} C, a carp (*Cyprinus carpio*) is able to survive in an oxygen concentration as low as 0.5 mg/L, whereas at 350^{o} C the water must contain 1.5 mg/L (Mason, 1991).

Some fish populations are unaffected by rapid temperature fluctuations of 12-15° C (Langford and Aston, 1972), but such temperature changes may be too great for cold water fish species. McFarlane et. al (1976), have shown that three minnow species which inhabit tributary streams survive well in temperatures up to 32° C, but die rapidly at 32-34° C. In Long Point Bay, the whitebass and smallmouthed bass have actually adapted by spawning in the warmwater environment created by the effluents generated by shoreline industries. However, the Nanticoke Environmental Committee has estimated that the worst case scenario a decline in yellow perch and rainbow smelt would be a 3.2 and 5.3 per cent loss respectively in commercial fish catches for the Eastern Basin of Lake Erie (Haymes and Dunstall, 1989).

To reduce the negative impacts on ecosystems, a number of attempts have been made to deal with the "waste heat" that is generated from cooling waters. For instance, power stations could be linked to sewage treatment works. The mixing of warm power station effluents with raw sewage would accelerate the treatment process, while the circulation of partially treated sewage effluent around the cooling tower would accelerate the conversion of organic nitrogenous compounds and ammonia to nitrites and nitrates. Cooling water can also be used to heat glasshouses for the production of high value crops such as tomatoes and for heating in nearby communities (Mason, 1991; Environment Canada, 1993).

Salt loading is also a cultural stress. It refers to the human activity of dumping salts on urban asphalt which then enters the waterbody as runoff. Salt and salt-derivatives, primarily from road runoff, have increased in recent years (Environment Canada, 1993). Seasonally, Long Point Bay is subjected to chloride from road salt suspended in effluents produced from urban run-off and storm sewer discharge. This results in an increase in alkalinity of the receiving waters. A situation of a brackish water environment, similar to estuaries is created. Some fish are tolerant to increases in salt concentration in waters; they survive this environment due to their adaptations but there is a limit that becomes lethal after a certain threshold.

Global Warming

Global warming is another way in which water quality can be affected. It has been included here as a cultural stress because global warming may cause water level changes (Staple, 1993), thereby affecting water quality. Lake water levels fluctuate diurnally, with storms and weather activity, and seasonally, with changing temperatures. In Lake Erie, this constant oscillation results in a yearly average water level ranging from about 169-179 metres above sea level (Stenson, 1993).

Global climatic change may however, alter water levels beyond what would be expected to occur naturally. For example, the General Circulation Model (GCM) at the Canadian Climate Centre (CCC) determined that Lake Erie's water level would drop by 1.35 metres with a doubling of carbon dioxide (Staple, 1993). A change in water level of this magnitude would expose new land in the shallower southwestern and northwestern portions of the Inner Bay, while the remaining "open" water would be concentrated at the northern and northwestern portions of the Bay. The Inner Bay would remain connected to Lake Erie however, because a channel would still connect the Inner and Outer Bays.

A reduction in the size and depth of Long Point Bay would have many implications for its water quality status. The biotic community of Long Point Bay could be adversely affected by a lowering of water levels. For instance, the Inner Bay may be incapable of providing an adequate habitat for the important fish spawning grounds located there currently. This could then have implications for the future success of the fishing industry with this area. Furthermore, lower water levels would mean that whatever contaminants were contained in the Bay would become more concentrated. This could affect the health of the biotic community, as well as human health.

While the larger beach area may attract more tourists, recreational docking facilities may not be fit for use. Problems would also occur for the shipping industry because they could have difficulties loading and unloading their ships in the area. Also, lower water levels could reduce flows through connecting channels, thereby resulting in a need for dredging (Environment

Canada, 1993). Therefore, the water quality of Long Point Bay would decline because of species loss, the concentration of contaminants, and the economic decline of the fishing and shipping industries.

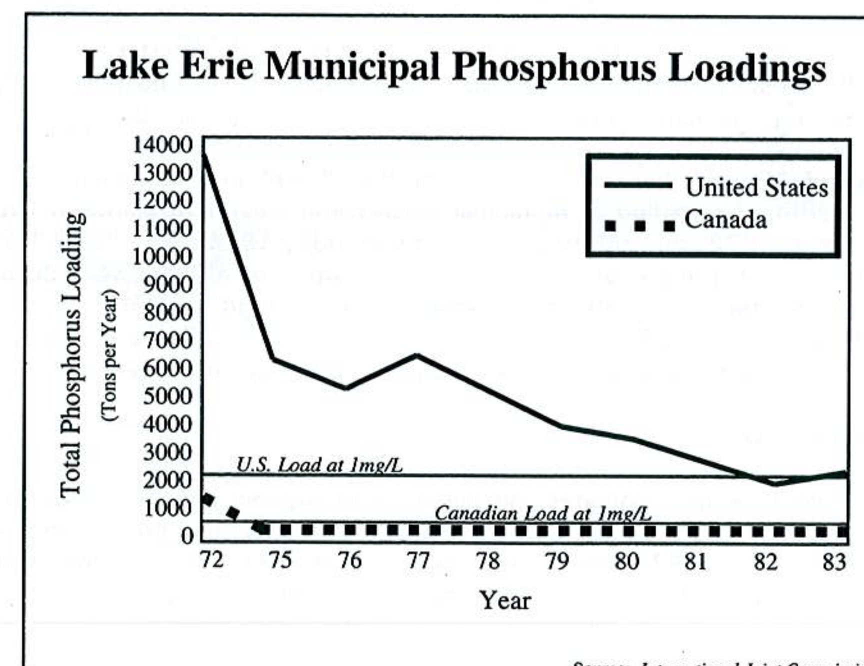
Eutrophication

Eutrophication refers to a water body's natural process of aging by the gradual input of nutrients and sediment through erosion and precipitation (Environment Canada, 1993). This process can however, be greatly accelerated as a result of human activities. This occurs primarily by releasing nutrients, particularly phosphorus and nitrogen into rivers and lakes through municipal and industrial effluent or through increased soil erosion due to poor land use practices. Since eutrophication results in very high organic growth, excessive enrichment of nutrients is a major factor in this cultural eutrophication process. The key nutrient involved in eutrophication is phosphorus. At high levels it can cause algae to grow at an explosive rate (Metro Toronto Remedial Action Plan Office, 1991).

In 1965, Lake Erie was the most eutrophied of all the Great Lakes. Eutrophication was deemed the most important water quality issue by the time of the 1972 Great Lakes Water Quality Agreement (IJC, 1984). An estimated phosphorus load delivered to Lake Erie annually during early the 1970's was 16.6 thousand metric tons (tmt) (Mortimer,1987). This decreased to about 14 tmt in 1977-78. Also during the 1970s, the annual load of soluble reactive phosphorous fell from 11 to 4 tmt (this is a measure of the fraction directly available for phytoplankton growth) (Figure 5).

Phosphorus is present in the form of phosphates in sewage and some industrial waste and this is considered the essential enrichment constituent associated with the extensive growth of algae (IJC, 1976). This nutrient enrichment is more pronounced in areas nearest to the source of enrichment with the greatest point sources being municipal and industrial waste and the main non-point sources being urban and rural run-off caused by household detergents, municipal sewage, and agricultural fertilizers (IJC, 1984; Lesht, 1985).

Figure 5. Lake Erie Municipal Phosphorus Loadings



Algal growth reflect the cumulative load of pollution and decomposition of organic waste products. They can affect water quality adversely by lowering the dissolved oxygen in the lower depths of the water (Environment Canada, 1993) (Figure 6). For example, when the algae die and sink to the bottom of the lake they are fed upon by the microbia, and this in turn depletes the dissolved oxygen. Therefore, the greater amount of algal growth, the faster the dissolved oxygen in the benthic zone is exhausted. Observations show that once a lake has become eutrophic it remains so for a very long time, even if the source of new nutrients is cut off (IJC, 1976). Therefore remedial action plans will not have immediate results. Laundry detergents were once a major source of phosphorus, but regulations controlling their use in detergent manufacture have minimized its impact on receiving waters in Canada (Environment Canada, 1993). The Inner Bay has a higher nutrient level than the Outer Bay probably because it's shallower, and therefore eutrophication would have a greater impact (Leach, 1981).

The main impact of eutrophication on commerical fish species appears related to reproductive behaviour. The inshore areas are important habitats and spawning sites tend to occur in these areas or in rivers (Leach et. al, 1977). Unfortunately, human influence is greatest in the littoral environment, and as nutrients are added there, it is usually first affected by excessive phytoplankton production. In reference to the designation of 'limited-use zones', the degradation (including but not limited to nutrients) of the nearshore habitat may be the greatest threat to aquatic communities (Muir, 1981). In addition, faeces from waterfowl such as Canada geese, ducks and gulls likely contribute to problems with bacteria in localized areas where these birds are found in high numbers (Metro Toronto Remedial Action Plan Office, 1991).

The north-east shoreline of Lake Erie, encompassing Long Point Bay, has had algae problems that are above average for the Canadian side of Lake Erie (Muir, 1981). Algal growths can curtail commercial fishing and recreational activities, impart obnoxious odours, impair filtering operations of industrial and municipal water treatment plants, lower water front property values, interfere with the manufacture of certain industrial products, and generally threaten destruction of the lake as a valuable water resource (Muir, 1981). It was concluded that recreational property along the Lake Erie shoreline from Port Dover to Fort Erie, fronted with algae, averaged 80 to 85 percent of the value of properties with no algae problem. However, algae should not be a problem in municipal intake pipes because they can be designed or situated in areas to avoid the problems associated with eutrophic waters (Muir, 1981). Navigation problems, caused by the rapid expansion of bottom-rooted aquatic plants, have increased for pleasure craft.

It should be noted that tobacco uses high levels of nutrients, so fertilizer must be heavily applied (Wilcox, 1993). Despite Nanticoke complex industrial loadings of phosphorus there has been a decreasing trend in phosphorus levels over recent years in Long Point Bay (Haymes and Dunstall, 1989). Management strategies for cost-effective load reduction measures have resulted in concentrations of 10 µg/L based on studies of the Phosphorus Management Strategies Task Force (Lesht, 1985). Upgrading of municipal wastewater treatment plants in Great Lakes basin has occurred since 1972, but still have a way to go (IJC, 1984). The 1978 IJC Water Quality Agreement stated that 1 mg/L phosphorous concentration in effluent was discharged from all major municipal wastewater treatment facilities and 0.50 mg/L was necessary to meet target loads (IJC, 1984). As of 1984, Lake Erie did not meet the nutrient goals set out by the IJC's Water Quality board, but the phosphorus concentration was on the decline.

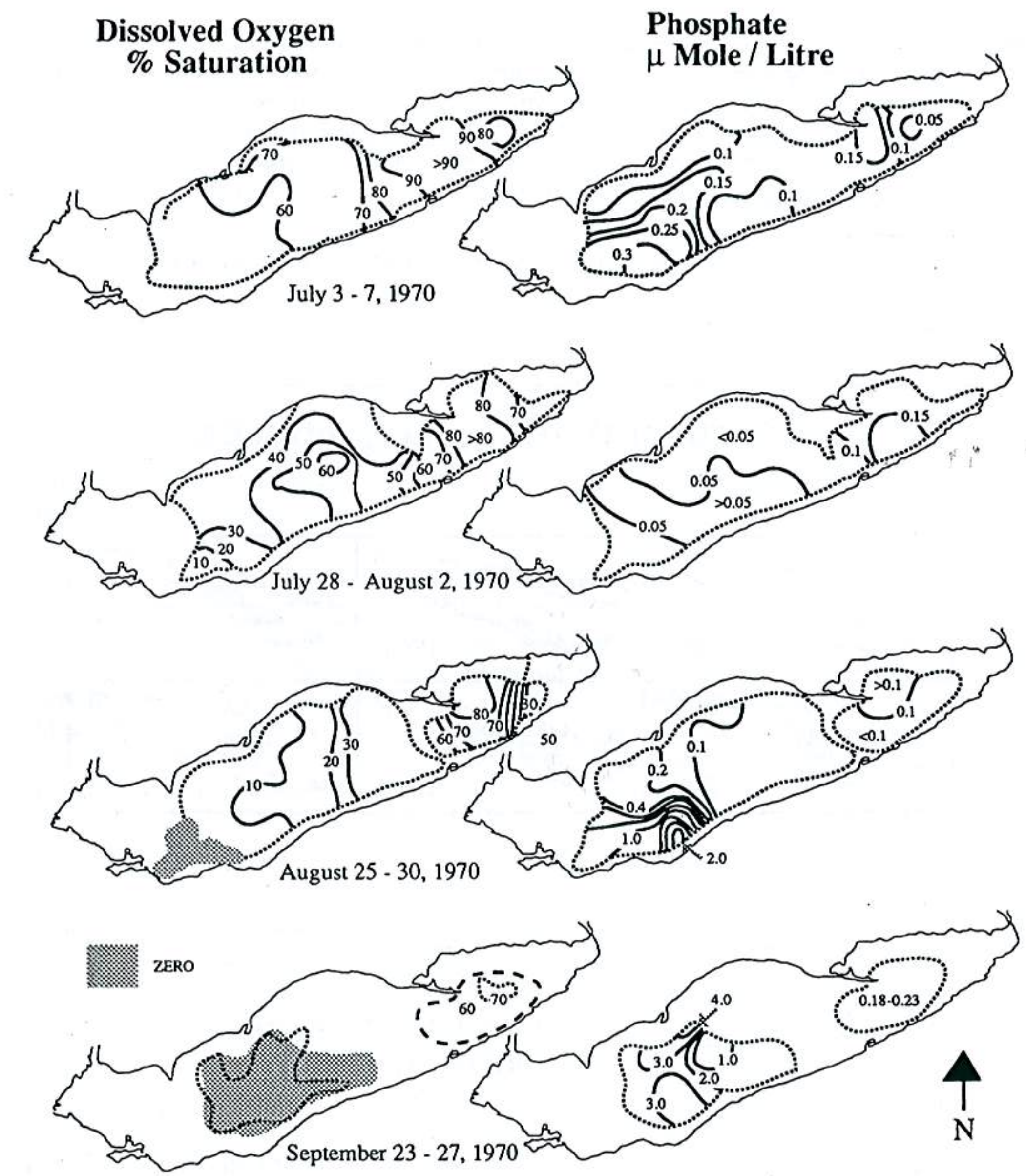
Dissolved Oxygen (DO)

A drop in dissolved oxygen indicates the presence of organic pollution because low dissolved oxygen. (for example, less than one part per million), can adversely affect fish life and important fish food organisms (IJC, 1976; Great Lakes Basin Commission, 1977). Low oxygen levels also cause a release of plant nutrients from the bottom sediments into the water, thereby accelerating

Figure 6. Lake Erie Limnology

(Dissolved Oxygen and Phosphate sampling in 1970)

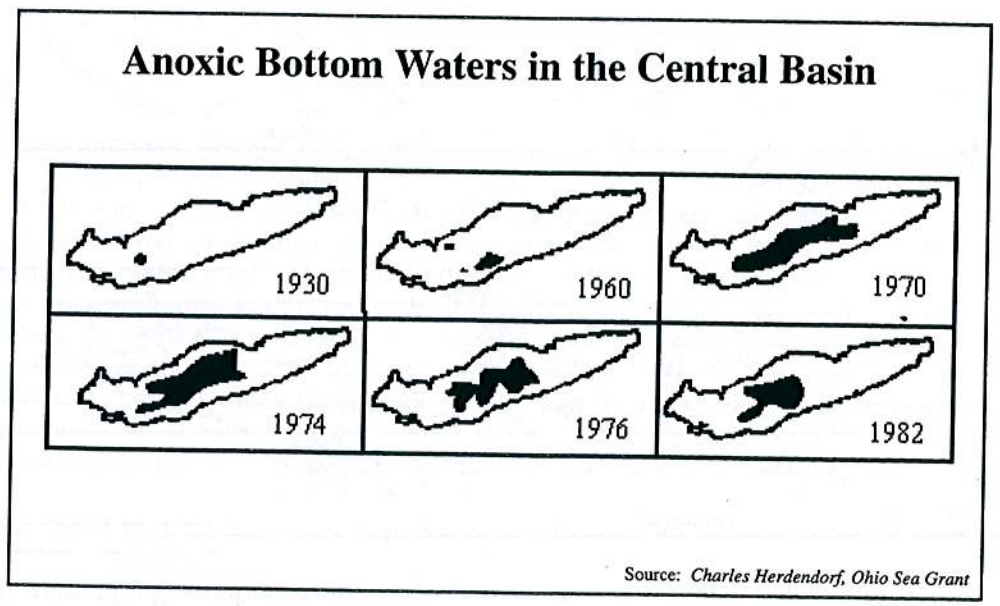
(After: Burns & Ross, 1972; Kuntz, 1978; Mudroch, 1984)



the rate of eutrophication even further. Therefore, dissolved oxygen can serve as an indicator of water quality. The oxygen demand of sewage effluent, or its deoxygenating ability, can be assessed by measuring the rate at which oxygen disappears (diluted if necessary) from a sealed bottle kept for 5 days in darkness at 20^{o} C. The biological oxygen demand (BOD) of crude sewage is around 600mg O_2/L per 5 days, while that of unpolluted water is less than 5 mg O_2/L per 5 days. Good sewage treatment reduces the BOD of the discharged effluent to, at most, 30 mg O_2/L per 5 day and usually less than this amount.

Dissolved oxygen in most parts of the Great Lakes is near maximum saturation levels. At certain times, however, extremely low (less than one part per million) or no dissolved oxygen has been found in bottom waters covering several hundred square miles in central Lake Erie (Figure 7). Such loss of oxygen degrades the quality of the water and the type of distribution of organisms that inhabit it (Great Lakes Basin Commission, 1977). This is reflected in the Lake's eastern basin's phosphorus loading from 1976-82 of 1,407 MT/yr average (Lesht, 1985).

Figure 7. Anoxic Bottom Waters in the Central Basin of Lake Erie



Toxic Contaminants

A toxic substance is one that can cause harm to the environment or human life. Most are synthetic and include PCBs, pesticides, dioxins, and furans (Environment Canada, 1993). There are toxic substances that naturally occur in the environment and are in fact essential to life, such as copper, and lead, but industry has disrupted a lot of naturally occurring metals. The manufacturing of herbicides and compounds released into the environment has increased exponentially since the 1950's, producing very high unnatural levels. Estimates vary, but it is commonly believed that there are up to 100,000 chemicals in commercial use throughout the world, with about 1,000 new ones entering the market every year (Environment Canada, 1991).

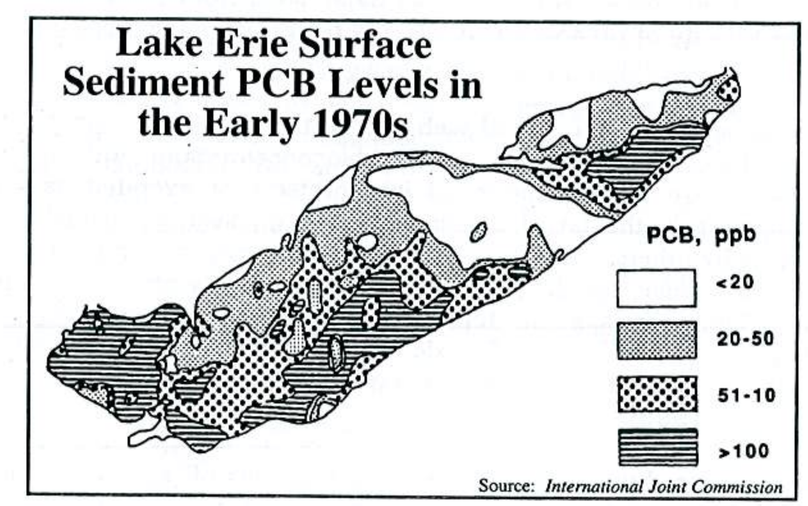
Heavy metals and organic chemicals are dumped into the sewage treatment system by households and industries. Once in the water, these pollutants can cycle into other compartments of the environment - into air, sediment and animal tissues (Metro Toronto Remedial Action Plan Office, 1991). Industrial activities can increase concentrations of metals and toxic chemicals in the water. This can have a negative impact on the aquatic ecosystem and make water unsuitable for established or potential uses (Environment Canada, 1993).

The addition of pollutants can be in an indirect form, such as run-off of insecticides and herbicides applied to the land. Toxic chemicals can be used directly on freshwater communities to eliminate undesirable fauna or organisms. Herbicides are used to control fauna considered to be interfering with human use of freshwaters. Unfortunately, other organisms may be directly poisoned or more indirectly affected as the loss of plants in their community adversely alters their niche. Humans, who are at the top of the food chain, may suffer potential hazards from eating larger fish species. Scientists do not have enough information at present to assess reliably the long-term hazards from these trace substances (Great Lakes Basin Commission, 1977; Environment Canada, 1993).

Many other substances introduced into the Great Lakes by human industrial processes may create potential hazards to human health or aquatic life. Toxic substances such as mercury, arsenic, chromium, copper, zinc, lead, cadmium, and selenium, can be toxic to humans (Great Lakes Basin Commission, 1977). Among the most toxic are certain pesticides, petroleum products, phenols, chloroform, cyanide compounds, and PCBs. Some of these substances, especially PCBs and certain pesticides, assimilate and persist in the Great Lakes food chain (Great Lakes Basin Commission, 1977).

In 1985, the International Joint Commission (IJC) identified eleven of the most persistent and widespread toxic contaminants as critical Great Lakes pollutants. They include PCBs (Figure 8), DDT and its metabolites, dieldrin, toxaphene, dioxin (2,3,7,8.-TCDD), furan (2,3,7,8,TCDF), mirex, hexachlorobenzene (HCB), mercury, alkylated lead, and benzo(a)pyrene (BaP). Of these eleven pollutants, eight are organochlorines. These compounds are potentially life threatening in their chemical compositions and toxicity. Organochlorines are fat soluble and persistent in the environment and many have been used as pesticides or industrial chemicals. Other sources have been noted in industrial wastes, combustion of wastes or fuels and impurities in pesticides.

Figure 8. Lake Erie Surface Sediment PCB Levels in the Early 1970's



All of the critical pollutants identified are widely distributed, tend to bioaccumulate in organisms, biomagnify in food webs, and despite regulatory controls, persist at levels that exceed the guidelines in some areas of the ecosystem. Comparatively minor transformations occur in the environment with pesticides. An example of this is when aldrin is converted to dieldrin and DDT to DDE (dichlorodiphenylethane). These transformed products are still highly toxic yet transformed. With chlorinated hydrocarbons, including PCBs, they remain a significant pollutant since they are very persistent.

Chemicals are deliberately applied to watercourses to control undesirable animals and plants. Although these poisons are designed to be very specific, the majority directly affect many more organisms than the target species, while resultant changes in the structure of food webs have larger ramifications. Watercourses that receive domestic industrial or agricultural effluents are also subjected to a large variety of pollutants. Effluents are often complex mixtures of contaminants. An effluent comprised of two or more contaminants may have many effects. A combined reaction may occur (additive), they may combat each other (antagonistic), or they could have a greater effect together than alone on an organism (synergistic). Even if a chemical is not considered harmful on its own, combined with another chemical it could be harmful. Many of these synergistic effects are not well understood (IJC, 1984).

Environmental factors can also modify the acute toxic effect of these pollutants. Temperature is important because of its influences on the metabolic activity and behaviour of organisms. This in turn may affect their exposure to a pollutant, but may also alter the physical and chemical state of the pollutant. In general, toxicity increases with temperature, as is the case for phenol and metals (Smith and Heath, 1979; Felts and Heath, 1984). Acidity and hardness varies the toxic effect of pollutants. Hydrogen cyanide, is especially toxic in the molecular form. Consequently a change in pH reduces the degree of dissociation, increasing the toxicity of the solution without any change in total concentration of cyanide. Ammonia's toxicity is also affected by pH (Smart, 1981).

Pollutants, such as lead, copper and zinc, are generally more toxic in soft waters (Mason, 1991). This straight forward relationship may be complicated by pollutants such as lead being precipitated in hard water conditions thus forming soluble complexes. The toxicity of zinc actually decreases as the inorganic suspended solids increases. This is due to the fact that the metal is absorbed by or adsorbed on the suspended particles. The effects of various factors on the toxicity of 410 chemicals (75 per cent of them pesticides) in nearly 5000 toxicity tests with various species of invertebrates and fish were conducted by Mayer and Ellersieck (1988). Twenty percent of the chemicals showed a change in toxicity with pH causing the greatest change in toxicity of any other factor. It was determined from these tests that hardness had little effect on the toxicity of organic chemicals and temperature generally increased toxicity. The most sensitive are insects, followed by crustaceans, fish and amphibians.

Some toxic substances can enter a food web and be transferred through it. The uptake of any environmental substance by an organism is called bioconcentration. Although nutrients taken up through this process are usually converted into proteins or excreted as waste, many toxic compounds accumulate in the fat of certain organs (e.g., liver) of animals. As contaminated organisms are eaten by others, the toxic substances are transferred up the levels in the food web and become more concentrated, sometimes to harmful levels. This process is called biomagnification. The species at the top level of the food web, including humans, are often subjected to higher concentrations of toxic substances than those at the bottom. Toxic substances reaching harmful levels are a sign that the aquatic ecosystem is unhealthy (Environment Canada, 1993).

If these chemicals are used on the fields, the water that runs off agricultural fields carries with it herbicides and pesticides and can enter rivers, lakes and groundwater supplies (Environment

Canada, 1993). This process can have a negative impact on the aquatic ecosystem and make water unsuitable for established or potential uses (Environment Canada, 1993). Urban runoff on the other hand, containing storm water from city streets and adjacent domestic or commercial properties, may carry pollutants of various kinds into the sewer systems and receiving waters (Environment Canada, 1993). For example, urban runoff can collect debris littering the streets and take it to the receiving stream or water body. Furthermore, urban runoff worsens the water quality in rivers and lakes by increasing the concentrations of such substances as petroleum products and road salts (Environment Canada, 1993).

Heavy metals and organic chemicals are also dumped into the sewage treatment system by households and industries. Most sewage treatment facilities are not capable of removing toxic substances. Sewage treatment plants are designed to treat human wastes and phosphorus from detergents, not chemicals and metals. As a result, a significant portion of these toxic contaminants passes through the treatment plants, ending up in the water or in bottom sediments near the outflow pipes of the plants (Metro Toronto Remedial Action Plan Office, 1991). In addition substances entering the storm sewers often go directly to the receiving lake or river completely untreated (Environment Canada, 1993). Once in the water, these pollutants can cycle into other compartments of the environment - into air, sediment and animal tissues (Metro Toronto Remedial Action Plan Office, 1991). Most of the toxic contaminants introduced into the aquatic environment enter in a liquid form or dissolved solids in discharge water and are released through pipes into waterbodies. If one were to sample the effluent coming from such pipes, one could measure the concentrations of lead or copper or phenols or toluene which are being deposited into the water.

A sample site in Lake Erie showed the effects of metals and essential elements on Herring Gulls (Struger et. al, 1987). Eagle eggs from Lake Erie contain concentrations of PCBs which are 25 million times higher than the concentrations in the water (Metro Toronto Remedial Action Plan Office, 1991). Contaminant levels in sport fish have been measured since the 1960s, and the Ontario Ministry of the Environment (with the Ministry of Natural Resources) has published results in the "Guide to Eating Ontario Sport Fish" since 1976. The contamination of fish with toxic chemicals and the associated restrictions on fish consumption by humans are early warning signs of the potential dangers for this solution (Ontario Ministry of Environment and Energy, 1993). Because the various life stages of an organism may be affected differentially by a toxic chemical it is necessary to study the species over its lifetime to find the weak link in its response to pollution. Long-term experiments are essential in order to discover any carcinogenic or mutagenic effects of pollutants, or any teratogenic effects causing developmental abnormalities.

Few chemical substances have specific regulatory measures because many thousands are in use in the Great Lakes basin, with new ones being introduced all the time (IJC, 1984). The Canadian Environmental Protection Act is meant to be a "cradle-to-grave" management approach. This involves controlling toxic chemicals throughout their life-cycle, from their development, manufacture, transport, distribution, use, and storage, to their ultimate disposal, and to cover both new and existing chemicals. New chemicals would have to be tested and their environmental and human health effects minimized before introduction into the Canadian marketplace. Existing chemicals would have more stringent controls applied to them as a result of more detailed testing and evaluation (Environment Canada, 1991). The goal of the governments of Canada and the Province of Ontario is to virtually eliminate all toxic discharges into the Great Lakes Basin ecosystem.

Under the government of Canada's Green Plan, Environment Canada has developed a Pollution Prevention Initiative to help virtually eliminate toxic pollutants in the Great Lakes Basin by the year 2000. Part of this initiative is to address hazardous waste generated by small quantity producers (Environment Canada, 1991). Many materials that have been traditionally used by industry may be substituted with safe alternatives which are either non-toxic, less hazardous or recyclable. For example, solvent-based paints and inks can be substituted with vegetable- or water-based products. Material substitution is a good waste management method since it directly eliminates or reduces the quantity of hazardous waste generated (Environment Canada, 1991)

Organic Pollution

The input of organic matter is a normal feature of streams and rivers. Energy is derived from it and the organisms inhabitating streams and the sediment communities of slow-flowing rivers are dependent on it for their survival. There is a main difference however between natural organic input and pollution by organic matter. Natural organic input is present in large 'packets', such as leaves which has a low surface to volume ratio, or is refractory when finely divided. In contrast, pollution by organic matter is very soluble or finely divided and very unstable. Organic pollutants contain proteins, carbohydrates, fats and nucleic acids in multiple combinations. Organic wastes from humans and animals may also be rich in disease-causing (pathogenic) organisms. As a result, the bacteria that immediately colonize it need much oxygen to decompose it. Consequently, organically-polluted water rapidly becomes deoxygenated. In rivers, most invertebrates and fish can be lost to this occurrence of events.

As the organic matter decomposes, this pollution community may slowly be replaced by filamentous algae like *Cladophora*. This would be the result of ammonium and phosphate being released after decomposition. Larvae would thrive in these environmental circumstances and create a nuisance for emergent flies. Muddy stream bottoms would support worms and organisms which in turn consume the bacteria. As oxygen levels begin to rise again, a crustacean, *Asellus*, and other moderately tolerant invertebrates would become abundant. Thus, as the water again becomes fully oxygenated the 'clean water fauna', with a high species diversity, are able to return (Moss, 1988).

The greatest source of organic materials that is released into freshwater is sewage effluent. Run-off from houses, factories and roads in urban areas is becoming more of a common concern. This run-off can result in severe pollution, especially in storm conditions after periods of dry weather. In such a situation, urban run-off may be routed through the sewage works, within a combined sewage system, thus contaminating released treated water. It is also possible that this sudden surge could create its own direct sewerage flow and enter the river or stream directly. Most modern cities are built with two separate sewer systems - one for human wastes (sanitary sewage) and one for rainfall (stormwater) (Metro Toronto Remedial Action Plan Office, 1991). Conventional wastewater treatment plants remove suspended solids and some of the organic matter. More advanced plants also remove phosphorus and nitrogen. Both of these nutrients are present in human sewage as well as in runoff from agricultural practices (Environment Canada, 1993).

Industrial Effluents

Industrial effluents may be routed via the sewage treatment system or released with or without treatment directly into a watercourse. Substantial amounts of organic wastes are contained in the effluents of the following industries: food processing and brewing industries, dairies, abattoirs and tanneries, and textile and paper-making factories. The effluents may very well be effectively treated by mixing with domestic sewage, but some can inhibit microbiological activity in the treatment works, therefore allowing for poor quality effluent. Consequently, these must be treated on the industrial site.

Compounds released into watercourses can be transformed within the environment, resulting in more toxic substances. Inorganic mercury (Hg_2^+) is converted to methyl (CH_3Hg^+) and dimethyl

mercury in aquatic environments, resulting from bacterial and fungal activity. Methyl mercury is exceptionally toxic to many animals. In addition, many non-biological transformations of mercury can occur, depending on the environmental conditions. Organochlorines have been shown to biomagnify along the food chain, but biomagnification is the exception for metals (Mance, 1987). There is the occurrence of biomagnification of toxic pollutants at very high levels that are concentrated in organisms from very low levels in water. An example of this is the snail *Lymnaea palustris* wherein a bioconcentration factor of lead of 300 000 has been reported (Say et. al, 1981).

Pollutants can also be absorbed by bottom-dwelling invertebrates such as freshwater clams and worms. When a chemical or metal is found in the tissues of a plant or animal at concentrations greater than in the surrounding sediment, it is said to have been "bioconcentrated" (Metro Toronto Remedial Action Plan Office, 1991). As one moves up the food chain from the invertebrates on the bottom rung to the top predators (such as gulls or humans), the concentrations of toxic contaminants in tissues increase. This can differ from chemical to chemical (Metro Toronto and Region Remedial Action Plan Office, 1991).

Spill events, such as oil spills, or tanker accidents are possible in Long Point Bay due to the intensity of the shipping industry. An extensive system of oil and wells, pipelines and additional infrastructure are in place on the bottom of the Inner Bay. Regardless of precautions taken, if shipping is introduced into a system, the risk of spills is present in the water system. One is reminded of the Exxon Valdez spill or the Shetland Island accident where one of the world's most pristine water ecosystems was rigorously protected through precautionary measures and still fell to the hands of human error. Environment Canada (Great Lakes Office, Toronto) is currently completing oils spill contingency mapping for Lake Erie to be completed in 1994-95. The public beach at Long Point Provincial Park was closed in July 1993 when medical waste including syringes was found. Recently, thousands of abandoned tires have been washing up along the beaches on the lakeside of Long Point, causing some concern for contamination *(Port Rowan Good News*, June 1994).

Air Pollution

Substances present in the air affect rainfall which in turn affects water quality. Dust, volcanic gases and natural gases in the air such as carbon dioxide, oxygen and nitrogen are all dissolved or entrapped in moisture. When other substances such as sulphur dioxide, toxic chemicals or lead are in the air, they are also collected in the rain as it falls to the ground (Environment Canada, 1993). For example, emissions of sulphur and nitrogen oxides from various human activities such as industry and fossil fuel emissions, enter the atmosphere as substances which can produce acids. The most common acids formed in this manner are sulfuric acid and nitric acid. When mixed with rain, these acids fall as wet deposition called acid rain. In the absence of rain, the particulate matter slowly settles to the ground as dry deposition. Together, wet and dry deposition of acidic substances is known as acid precipitation (Environment Canada, 1993).

The extent of chemical alteration resulting from acidic deposition depends largely on the type and quantity of the soils and the nature of the bedrock material in the watershed, as well as the amount and duration of the precipitation. Watersheds with soils and bedrock containing substantial quantities of carbonate-containing materials, such as limestone and calcite, are not as affected by acidic deposition because of the high acid neutralizing capacity derived from the dissolution of this carbonate material.

The effects of acid deposition on water quality, although complicated and variable, have been well documented (IJC, 1988). If the acid rain lands on the land, the interactions of acid deposition with the terrestrial ecosystem, including vegetation, soil and bedrock, result in chemical alterations of the waters draining these watersheds, eventually altering conditions in the lakes downstream. Pollutants can fall out from the air as dry particles, or as wet (in rain). That portion which falls onto land gets picked up by stormwater and then becomes part of the non-point source problem. The portion which falls out directly onto water may also affect water quality. Unfortunately, little is known about the magnitude or importance of fallout of toxic contaminants onto water. In order to fully appreciate and assess the impact of acid precipitation on water quality in the Great Lakes, the Ontario Ministry of the Environment has initiated a Great Lakes Basin-wide initiative to gather information on the atmospheric fallout of toxic compounds (Metro Toronto Remedial Action Plan Office, 1991).

WATER QUALITY MONITORING

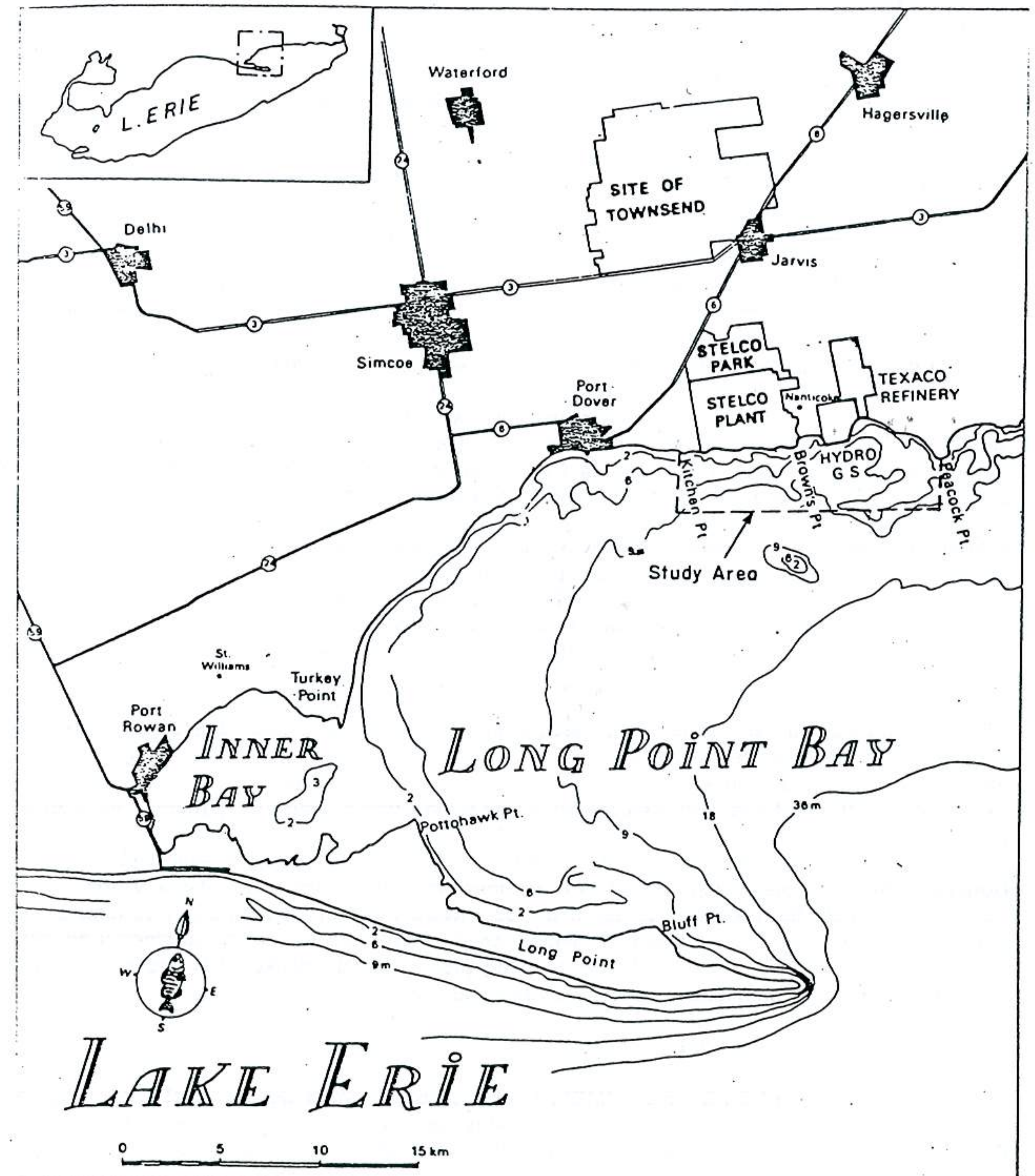
Monitoring of the water quality of Long Point Bay has been conducted by several agencies for over twenty years. The focus on concern for water contamination began in earnest with the proposal development of the Nanticoke Industrial Complex in the 1960's (Serafin, 1989). An active and comprehensive monitoring program was established by the industries and the Ontario Ministry of Environment which continued for over fifteen years. The focus of the program was on air quality monitoring; however extensive sampling of fish species, aquatic organisms and vegetation, and studies of baseline water quality parameters was conducted. The majority of this research was concluded in the early 1980's. Recent initiatives under the provincial MISA (Municipal Industrial Strategic Abatement) program, Drinking Water Survellience Program, and upgrading of local wastewater treatment facilities, have led to increased water quality monitoring within the Bay.

Nanticoke Environmental Committee

The Nanticoke Environmental Committee (including the Ministry of the Environment, Ministry of Natural Resources, Imperial Oil-Esso Canada Inc., Stelco Inc., Ontario Hydro and Environment Canada) studied the influence of industrialization on the Bay's aquatic environment from 1968-1983 (Haymes and Dunstall, 1989). The Nanticoke industrial development includes Ontario Hydro's Nanticoke Thermal Generating Station (commissioned between 1973-1978), Stelco Inc. steel mill (constructed from 1974-1981) and Texaco Canada Inc. oil refinery (operating since 1978) (Figure 9). The purpose of this monitoring program was to ensure that the integrity of the aquatic ecosystem was being maintained (Serafin, 1989). The parameters monitored included the following: water movements and temperature, water quality, phytoplankton, zooplankton, attached algae and benthos and fish (Nanticoke Environment Committee, 1981). Measurements were taken at offshore and onshore locations of the site within the Outer Bay of Long Point.

The Nanticoke Environmental Committee's research indicated that the thermal regime of the Bay has not been altered (Haymes and Dunstall, 1989). Water temperature increases are restricted to the immediate discharge areas such as the Nanticoke Thermal Generating Station (TGS). During fall the temperature increases 1 - 2^{0} C above ambient temperatures beyond the immediate discharge area and extending to Peacock Point. During the summer, temperature increase extends even beyond Peacock Point; however the TGS has little effect on lake temperature (Haymes and Dunstall, 1989). Several fish species, such as smallmouth bass, rock bass, white bass, black crappie, carp, rainbow smelt, yellow perch, and walleye, spawn in or near the TGS discharge channel. Also, several species including yellow perch, rock bass, smallmouth bass, white bass, freshwater drum, white sucker, black crappie, quillback, alewife and gizzard shad were caught in larger numbers near the TGS discharge channel than at other locations. This could be attributed to currents, higher temperature, protection from nearshore wave action or increased food availability.

Figure 9. Nanticoke Industrial Complex and Monitoring Study Site



Several species, such as the gizzard shad, reside in the discharge over winter, but there is no evidence of abnormal mortality (Nanticoke Environment Committee, 1981). However, if the TGS shut down, these species could die off. Increased growth rates of rock bass and small mouth bass over the study period could reflect an extended growing season due to the increased temperature near the TGS thermal plume. However, TGS's once-through cooling process is related to potential reductions in value fish stocks, with yellow perch and rainbow smelt being the main species affected.

The Nanticoke study also monitored chemical contaminants (Nanticoke Environment Committee, 1981). Generally, the chemical levels increased with depth and the summer months showed the lowest chemical levels. More specifically, it was found that residue particulate, phenols, cyanide, heavy metals and organic contaminants have increased during the study period (Haymes and Dunstall, 1989). At the same time, chloride concentration, conductivity, ammonia, total nitrogen, organic nitrogen, reactive phosphorus, total phosphorus and iron have all decreased. Stelco's release of iron, copper and zinc show accumulation in algae growing near industrial discharges, but this is not expected to affect the ecosystem except areas immediately adjacent to the discharges and not the Inner Bay.

Spottail shiners from Centre Creek, where the Stelco outfall is located, have elevated levels of some organochlorines, while those from the TGS discharge location have elevated residue levels of some metals (Haymes and Dunstall, 1989). The effects of organic contaminants or other heavy metals released by the Nanticoke industries have not been determined, other than mercury and PCBs, which are within acceptable limits. However, it was concluded that it is unlikely that the species types or the size of various fish stocks in Long Point Bay were affected by the existing levels of contaminants released by the industries (Haymes and Dunstall, 1989).

Nutrient enrichment (phosphorus, nitrogen and silicon) was also monitored by the Nanticoke Environment Committee (1981). It was found that the nutrient levels increased inshore and decreased with increasing distance offshore. Overall, there was a decreasing trend in phosphorus levels over time even though industrial loadings of phosphorus have increased. However, phosphorus levels in regions of Lake Erie may have been decreasing at faster rates than in Long Point Bay.

There was no substantial long-term change in attached algae biomass near Nanticoke. Therefore little or no impact from the industries due to fouling of beaches and municipal water intakes by attached algae is expected in this area (Haymes and Dunstall, 1989). Finally, the committee recommended that industrial discharges, especially trace organics and heavy metals, need to be studied more thoroughly and that the levels of these substances should be determined for lake water, and for major components of the food chain, including valued fish species (Haymes and Dunstall, 1989). More specifically, it was recommended that Long Point Bay's yellow perch population should be monitored to see if the downward trend of its population continues. In conjunction with this, it was noted that rainbow smelt should also be monitored since it appears to be most affected by the once-through cooling process at Nanticoke TGS and it is heavily exploited by the local commercial fishery (Haymes and Dunstall, 1989).

Ontario Ministry of Environment and Energy

The Ontario Ministry of Environment (MOE) has developed a water quality monitoring program for all public operated Sewage Treatment Plants (STP's) in Ontario (Ontario Ministry of Environment, 1992). The sewage effluent quality parameters used are: Biochemical Oxygen Demand (BOD), Suspended Solids (SS) and Total Phosphorous (TP). Control engineers use BOD, SS and TP as indicators of plant performance and effluent quality and are used by the MOE to assess STP compliance.

Sewage strength is measured by the 5 day Biochemical Oxygen Demand (BOD 5) test. High BOD concentration in the effluent indicates high organic content remaining in effluent, indicating ineffective treatment of sewage. High organic content may cause oxygen depletion and other environmental impairments in receiving waters. Aesthetic problems and fish casualties, due to the clogging of respiratory passages (gills), are caused by suspended solids not being effectively removed from sewage effluent. In addition, trace contaminants such as metals and toxic organics are often associated with the solids. Eutrophication of receiving waters is caused mainly by excessive amounts of Total Phosphorous (TP) being added. Algae and weeds grow rapidly with excessive TP loading and when the plants die and decompose they use up dissolved oxygen (DO) . As a result, reductions in DO can lead to decreases in aquatic organisms.

Data available for the Port Rowan Sewage Treatment Lagoon for 1989-1990 (Figure 10) which indicates trends in BOD, SS and TP in the influent into the plant over the last two years. The data gives an indication of the nature and composition of the raw sewage water produced in the community and captured by municipal and storm sewer systems. High levels of suspended solids occur in the spring in association with increased erosion and runoff. This facility discharges into Dedrich Creek semi-annually, normally in March and October. After treatment, all indicators are below critical levels and meet provincial standards with the exception of high suspended solids in the effluent. This corresponds with current concerns for increased sediment loading directly and indirectly from separate storm sewer outfalls into the Bay during severe storm events. The Ministry also investigates all exceedances of parameters listed on the Certificate of Approval for the Port Rowan Sewage Treatment Plant.

The province has also developed a Drinking Water Surveillance Program (DWSP) for water treatment plants. Under this program raw water taken into the plants is tested for 180 water quality indicators. The Port Rowan water supply system underwent a major upgrade in 1991-1993, and as a result no annual summary report has yet been released by MOE under the program. Raw monthly sample data collected from 1991 to 1993 indicate that no known health related guidelines were exceeded, and many of the parameters are negligible or even not measured. All commercial waterworks are also checked yearly by MOE inspectors for compliance.

Data for selected parameters measured at the intake from the Bay provide some indication of the raw water quality as it is removed from the Bay for treatment (Figure 11). The results display very little monthly variation. Turbidity was high on one occasion (March 1992) indicating increased suspended matter such as clay, silt and other microparticles. Hardness of the raw water also exceeded the provincial guideline of 80-200 mg/L throughout the sample period. The pH level was also high during one sample period (September 1991).

Figure 10. Port Rowan Sewage Lagoon Influent, 1989-1990
(from Ontario Ministry of Environment, 1992)

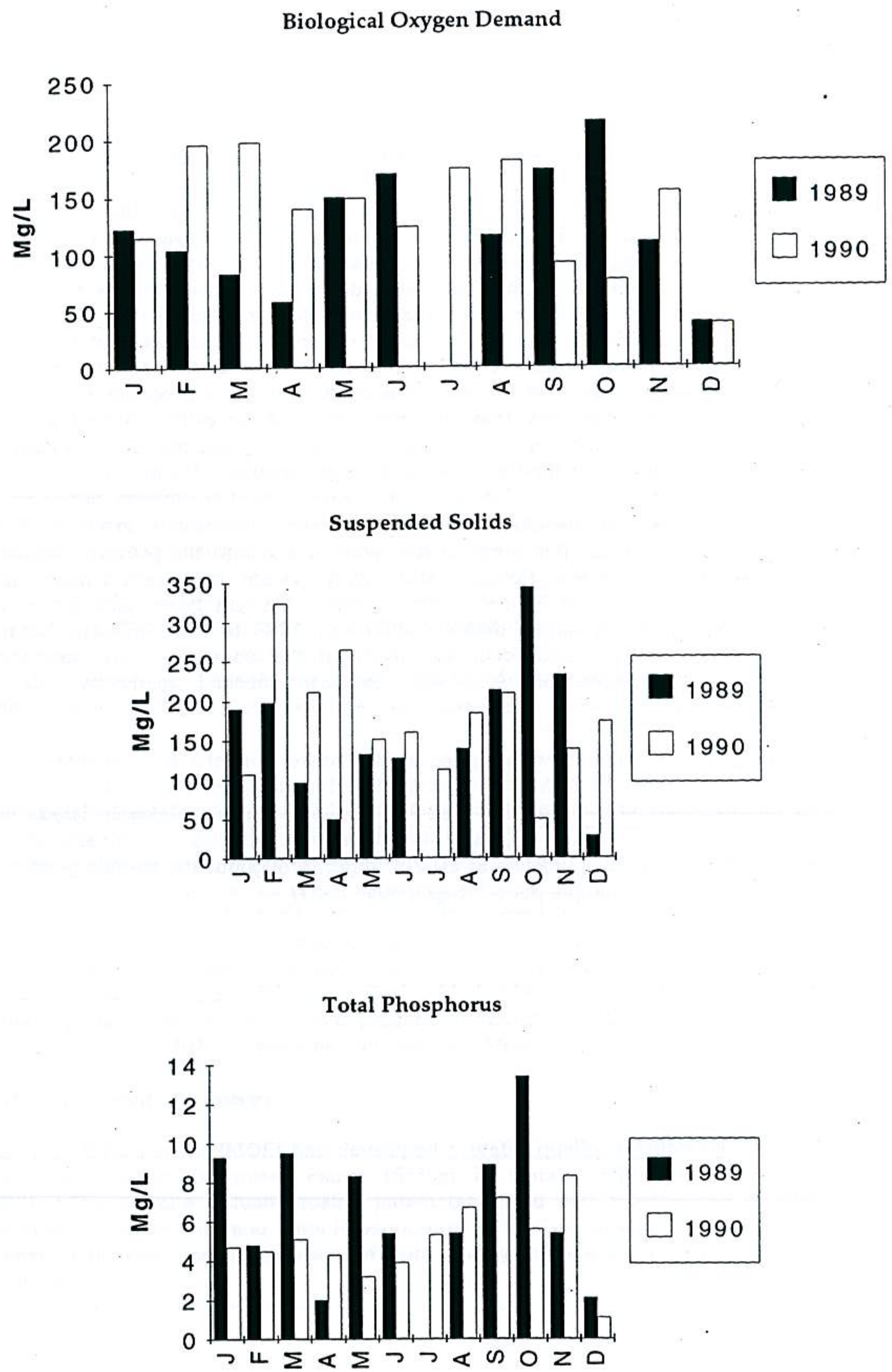


Figure 11. Port Rowan Water Treatment Plant, Raw Intake Water Parameters: 1991-93
(data provided by Ontario Ministry of Environment and Energy, West Central Region)

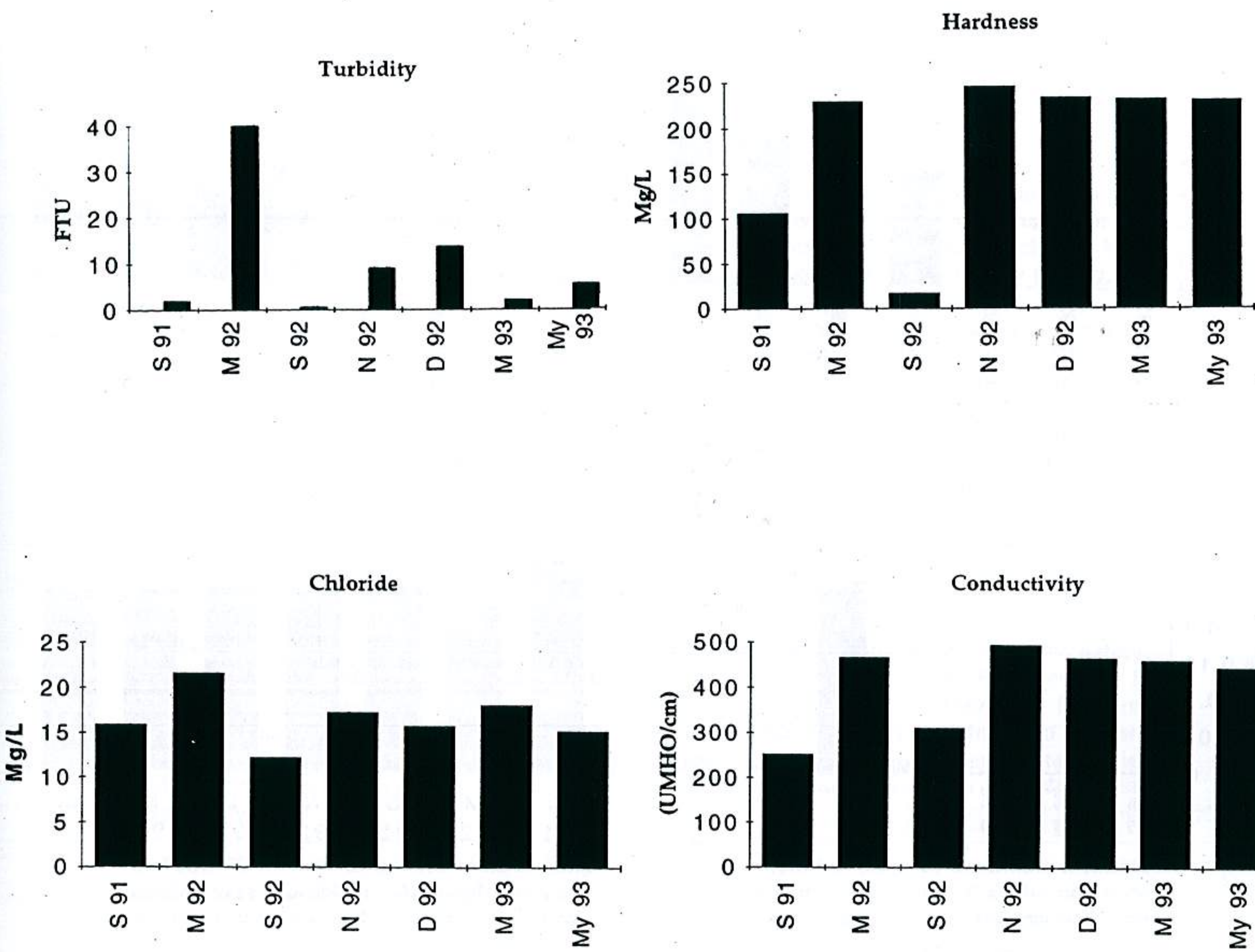
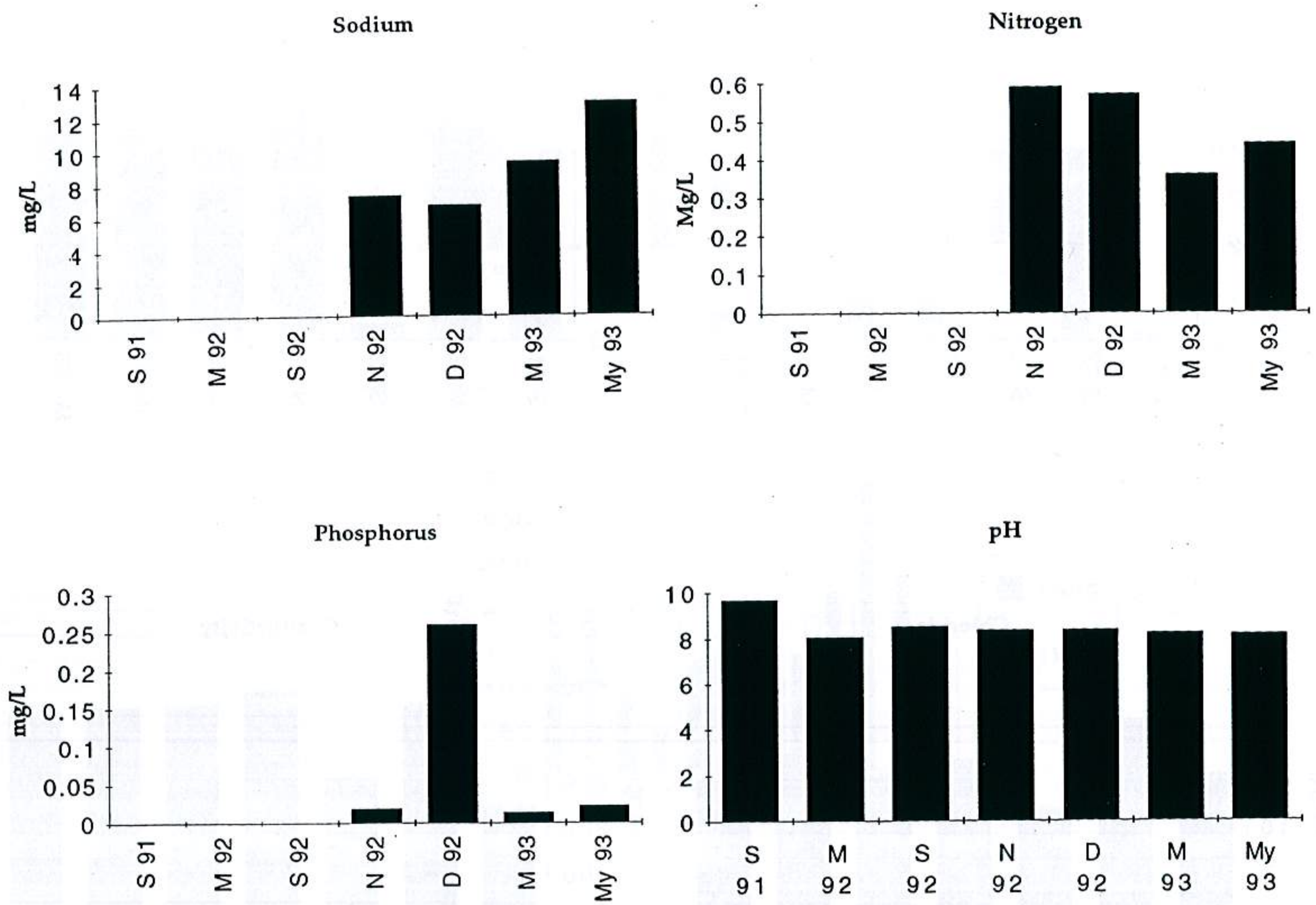


Figure 11 (continued)



The province also conducts regular monitoring of water quality of major rivers and streams (Ontario Ministry of Environment, 1991). The most recent data (1984) for Big Creek and Dedrich Creek entering Long Point Bay is presented in Table 2. The results also suggest the seasonal variations in turbidity, pH and phosphorus as indicated in the Bay raw water intake into the Port Rowan water treatment plant. Mean annual turbidity exceeds provincial guidelines for drinking water. All other parameters are quite below guidelines and several including mercury and lead are unmeasureable.

The Ministry also maintains an emergency spill response program to identify and contain a variety of chemical spills from commercial, industrial and private activities including fuel transfers, container linkage, and waste disposal. Problems of private property water pollution such as septic systems, holding tanks, illegal discharge or disposal of chemicals are dealt with on a complaint basis. No detailed studies or summary of events are currently available for the Long Point area.

Long Point Region Conservation Authority

Conservation Authorities in Ontario have been actively involved with public education and technical assistance to provide funding for improvements to existing septic systems under the Clean Up Rural Beaches Program (CURB). In association with other local agencies including MOE and the local health unit, projects have been conducted including beach water quality testing, Big Otter Creek watershed water quality testing, and a sample program of die testing of private septic systems. One main issue is the expansion of rural villages with increased demand for municipal liquid waste disposal accompanying construction of residential areas. The main concern is for increased nitrates leaching into the groundwater and affecting water quality.

At the village of Vienna defunct septic systems are suspected of discharging into Otter Creek which empties in Lake Erie at Port Burwell (*Port Rowan Good News*, April, 1994). The contaminated water can then be transported alongshore to Long Point, resulting in beach closings due to high bacterial levels. The local township is currently urging action by the Ontario Ministry of Environment to enforce water quality standards and to resolve the problem.

Haldimand-Norfolk Health Unit

The local health unit collects weekly beach samples for bacteria contamination for public safety. In the 1970's upgrades of private sewage treatment at Long Point and Turkey Point resulted in conversion from cedar boxes to holding tanks for the majority of residents (personal communication, staff, Long Point Region Conservation Authority). This had followed concern over inland flooding and high water tables resulting in contamination of adjacent water bodies and standing water from seepage out of poorly designed and in many cases over extended waste disposal systems.

In 1992-93 a study of private wells at Long Point was conducted in order to determine if nitrate loading was a problem. Although analysis is not yet complete it is suggested that the presence of small lots located on sandy substrait with a high water table allows for dilution and denitification. Future concerns is for private waste disposal from channel boathouses along the Inner Bay marshes at Long Point as many do not have proper residential services (personal communication, Glen Stein, Haldimand-Norfolk Health Unit).

Table 2. Selected Water Quality Parameters in the Vicinty of Long Point Bay (from Ontario Ministry of Environment, 1991)

		Big Creek	Dedrich Creek
TEMP(deg.C)	mean	10	9.9
	max	21(July)	22(July)
	min	1(Feb/Mar)	.5(Feb)
Turbidity	mean	14.78	17.99
(FTU)	max	56(Feb)	40(Feb)
	min	2.91 (Dec)	4.8(Mar)
Hardness	mean	265.7	N/M
(mg/L)	max	273(Jan)	N/M
	min	258(Sept)	N/M
Abient	mean	386	327
Conduct.	max	470(July)	395(July)
(UMHO/cm)	min	310(Dec)	260(dec)
Chloride	mean	12.75	12.23
(mg/L)	max	15.03(March)	21.91(Mar)
	min	5.64(Feb)	6.17(Feb)
Copper	mean	0.002	0.002
(mg/L)	max	.005(Feb)	0.004(Feb)
	min	0.001(Oct)	0.001(Jan,Sept)
Lead	mean	<0.003	<0.003
(mg/L)	max	<0.003	<0.003
	min	<0.003	<0.003
Iron	mean	0.901	1.2(Sept)
(mg/L)	max	2.700(Feb)	1.2(Sept)
	min	0.325(Nov)	1.2(Sept)
Mercury	mean	N/M	N/M
(mg/L)	max	N/M	N/M
	min	N/M	N/M
Nitrogen	mean	0.449	0.412
(mg/L)	max	0.820(Feb)	.660(Feb)
	min	0.270(Dec)	.240(Dec)
DO	mean	10.13	10.42
(mg/L)	max	13.10(Jan)	14(Jan)
	min	6.50(June)	6(July)
pH	mean	8.19	8.13
	max	8.33(Jan)	8.28(sept)
	min	7.89(Feb)	7.78(Feb)
Sodium	mean	6.44	N/M
(mg/L)	max	6.76(Sept)	N/M
	min	5.96(March)	N/M
Zinc	mean	0.003	0.004
(mg/L)	max	0.011(Feb)	0.006(Feb)
	min	0.002	0.002(Dec)
Phosphorus	mean	0.052	0.043
(mg/L)	max	0.157(FEb)	0.097(Feb)
	min	0.014(Dec)	0.014(Dec)

Environment Canada

A current study of water quality in Big Creek and and the Inner Bay is being conducted by Environment Canada, based on water and sediment samples collected during 1991-92. Water and sediment samples were collected from April to October every two weeks from stations (Figure 12). Analysis of results is underway to examine a number of current water and sediment conditions (nutrients, metals, herbicides, pesticides, PCBs, carbon, organics, phosphorus, and nitrogen) and to compare results to Leach (1981) and Berst and McCrimmon (1966). Spatial and temporal variation in the data will be assessed, along with water and sediment guideline exceedences (personal communication, John Merriman, Canada Centre for Inland Waters, Burlington).

Figure 12. Environment Canada Long Point Bay Study Sites, 1991 (provided by John Merriman, Environment Canada)

(IB = Inner Bay, BCM = Big Creek Marsh, BC = Big Creek)

CONCLUSIONS

Changes in human activities and management practices have changed the dynamics of water quality in the Bay over the last twenty years (Figure 13). Since 1963 loading of total phosphorus has declined in the eastern end of Lake Erie due to reduction in use in detergents and agricultural use. However, during the same period, the use of pesticides in the Region of Haldimand-Norfolk has greatly increased. A selection of water quality parameters for Big Creek and Dedrich Creek (see Table 2) suggests high levels of turbidity during increased river discharge and concern for entrainment, transportation and deposition of chemicals and toxins by this sediment. As a result attention in management of Lake Erie and Long Point Bay water quality needs to shift to include controls on the use of chemicals in areas where drainage and sediment conditions promote entrainment, transport and release of toxins and heavy metals into semi-enclosed, shallow, and dynamic systems like Long Point Bay.

Figure 14 is an attempt to characterize and describe the key issues and areas of concern in regards to water quality in the Long Point Bay. The issues identified represent a summary of the various point and non-point sources of pollution and related human activities highlighted during this study. The areas of concern highlight those sites where problems are chronic and are in need of management attention. In summary these areas are identified as:

Turkey Point

* cottage development, private waste systems, high water table, potential for groundwater contamination, sedimentation.

North Shore of Inner Bay

* marina developments, potential for gasoline and oil spills, boat grey water, liquid waste disposal.

Port Rowan

* surface drainage and runoff, storm sewer outfall discharge

Big Creek Watershed

* agricultural practices leading to increased sedimentation into streams, nutrient and chemical loading, rural development, groundwater contamination.

Big Creek Marsh

* importance as a buffer for deposition of nutrients and contaminants, uptake and release by aquatic vegetation and species.

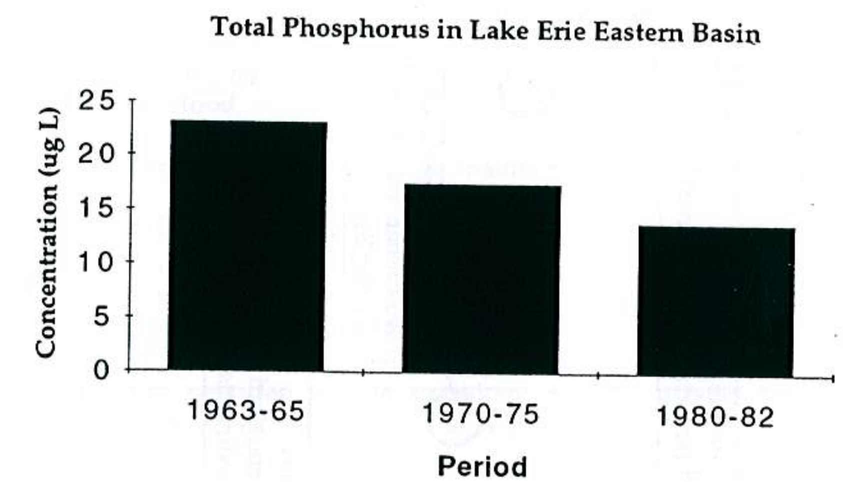
Long Point Community

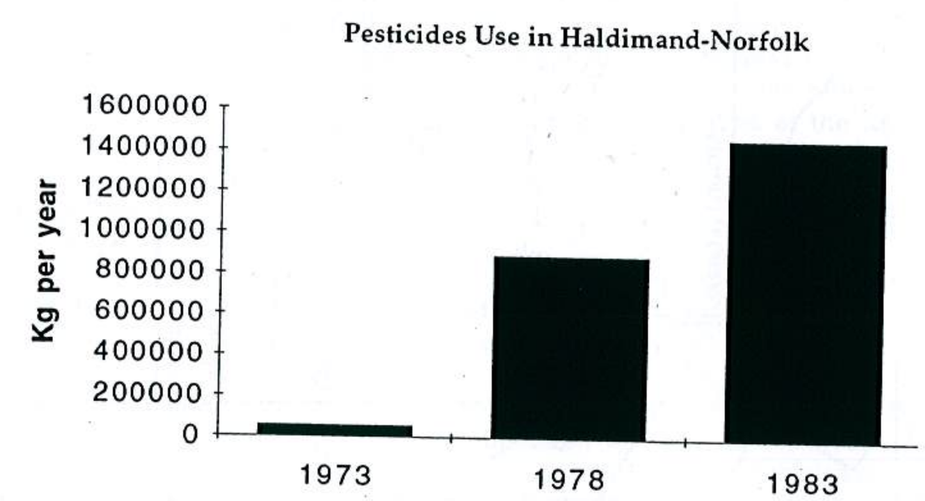
* sedimentation and nutrient loading into channels, potential for contamination from private waste systems.

Inner Bay

* deposition of toxins and heavy metals with bottom sediments, release and uptake into food chain, turbidity.

Figure 13. Chemical Loading into the Eastern Basin of Lake Erie, 1963-1983
(data provided by Mike Stone, Wilfrid Laurier University)





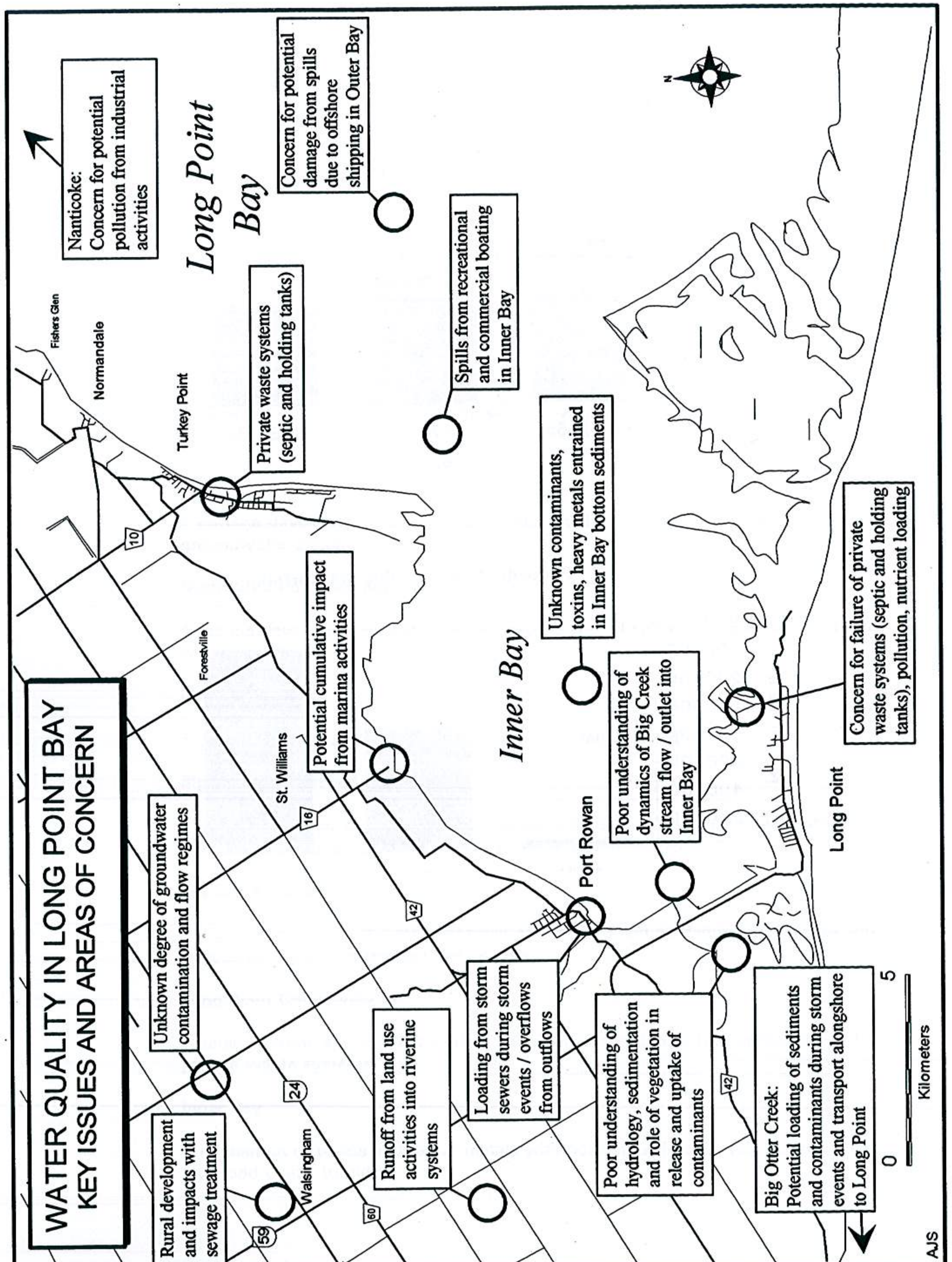


Figure 14 Water quality in Long Point Bay: Key issues and areas of concern

It is apparent that although an extensive collection of data is available concerning water quality of Lake Erie, in particular during the 1970's, more recent research focused on Long Point Bay is not complete and in a format conducive to preparing summary maps. Research has focused on the relationship between human land use activities within watersheds draining into the lake and potential for sediment transport of chemcials, toxins and heavy metals. There exists no comprehensive study of Inner Bay water and sediment quality, the variations of conditions within the bay, or any long term monitoring programs. The role of Big Creek Marsh in transport and deposition of contaminants carried by water and sediment and the discharge into the Inner Bay is poorly and incompletely understood.

One way in which to ensure that water quality is maintained is to better manage the water resource. In Canada, water management responsibilities are shared by governments at the federal, provincial and municipal levels. Due to this structure, there is no one agency responsible for the Long Point ecosystem (Whillans et. al, 1987). This results in fragmented management that may not consider the benefits or potential harm to the ecosystem in its entirety. However, whether Long Point Bay is under the responsibility of one agency or several agencies, water management strategies should focus on preventative measures. The costs of clean-up after water quality degradation has occurred can be exorbitant and the effects can be irreversible. Therefore, prevention is the only effective course of action.

As a preliminary review and assessment of the issues concerning water quality of Long Point Bay, the intention of this report has been to identify those key factors influencing the various parameters that define water quality within the study area. The focus has been on the relationship of human activities, particularly land uses within the Big Creek watershed, to changes in the concentration and distribution of chemicals, toxins, heavy metals and other contaminants. It is acknowledged that a wealth of information and studies have been completed for the Great Lakes focusing on water quality and its importance for ecosystem sustainability and health. This report is intended in the spirit of continued concern and interest in understanding those issues at the regional scale in the Long Point area for local citizens and decision makers.

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