Occasional Paper Series

UNDERSTANDING GREAT LAKES ISSUES

THREE CENTURIES OF CHANGE ON LAKE ONTARIO [1]
(1750 - 2050)

Number 90-8

GREAT LAKES PROGRAM

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Occasional Paper Sèries

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THREE CENTURIES OF CHANGE ON LAKE ONTARIO[1] (1750 - 2050)

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EXECUTIVE SUMMARY

This essay is based on material presented at a public forum jointly organized and sponsored by the International Association of Great Lakes Research and the Royal Botanical Gardens. The forum was held at the Royal Botanical Gardens Auditorium on the evening of May 2, 1989. Topics discussed are:

- physical features of the Lake Ontario Basin
- history of European settlement and industrialization
- eutrophication and toxic contaminants in the context of the Lake Ontario food web
- effects of eutrophication and toxic contaminants on Lake Ontario fish and on the human population of the Basin
- possible effects of global climate change on Lake Ontario
- population growth and land use in the Lake Ontario Basin
- societal stresses arising from real, perceived, or anticipated environmental degradation
- an optimistic future scenario for Lake Ontario.

The point of view of the article is consistent with the ecosystem approach to Great Lakes environmental issues. It suggests that individual attitudes and lifestyles will have to be reappraised and changed before the technical knowledge we now or might eventually possess will be effective in assisting a return to a sustainable way of life. The essay is written so as to be comprehensible to high school students.

The authors would like to acknowledge the ideas of many Canadian and U.S. scientists that have contributed to the content of this paper. In particular, this essay has benefitted from suggestions offered by C. Gray, M. Gilbertson, G.K. Rodgers, P.F. Hamblin, and M.A. Donelan.

INTRODUCTION

Today's headlines attest to a bewildering tumult of events in an era of rapid and often unwelcome change. Without being able to define linkages precisely, we are uneasily aware that curious occurrences in remote places may come to have repercussions for us as well. We may grasp intellectually the problems of overpopulation, the creation and expansion of deserts, uncontrolled urbanization, and climate change, but we have experienced them, if at all, in very mild forms here beside Lake Ontario. What can we expect in the near future?

If the Lake Ontario Basin is being spared some of the traumatic changes taking place elsewhere, it has nevertheless been substantially altered from its wilderness state of two centuries ago. The total ecosystem of the Basin, the system that includes the people living and working in it, is far from being in a state of harmonious balance. It relies on substantial imports of energy and materials, and it produces correspondingly substantial quantities of polluted wastes. Furthermore, many of the natural wetland and forest habitats that used to regulate flooding, erosion, and some biological processes in Lake Ontario have been degraded, if not destroyed.

To say that the Basin has been degraded beyond hope of recovery is to sell it short; for amid the loss there is also promise. Among other advantages, the energy, education, and wealth of the people living in the Great Lakes Basin have few equals elsewhere. But there can be little hope for less well-endowed societies in other places if this wealth, energy, and education are insufficient to establish a society here that invests adequately in its environmental future. In this essay we will be discussing the future of the Basin, but to do this we need to know something about its past and something about the processes operating in the Basin today.

THE LAKE ONTARIO BASIN

DESCRIPTION AND HISTORICAL BACKGROUND

A typical horizontal dimension or scale for Lake Ontario is 100 km, a typical depth is 100m. The lake is 1000 times wider than it is deep, roughly the width to thickness ratio of a sheet of bond typewriter paper. Lake Ontario has the largest drainage area, relative to the surface area of the lake, of all the Great Lakes, and it is also located at the lower-end of the Great Lakes system. Because of its lower-end location, it receives water-borne substances from the other lakes in addition to the burden imposed within its own basin.

The flow through Lake Ontario (principally the Niagara River inflow and the St. Lawrence River outflow) is sufficient to renew the water every eight years. However, wind-driven water motions result in circulating flows within the lake that are many times larger than the St. Lawrence outflow. Materials introduced at one point in the lake are spread throughout the lake within a few months. Like the other deep basins of the Great Lakes, Lake Ontario is thermally stratified from mid-June to early November, with a layer of warm, less dense, water floating on a cool bottom layer. Physical and biological processes within the lake are strongly modified by the presence of this thermal stratification.

Although this article deals mainly with the last few hundred years of rapid change in the Lake Ontario basin, its recent geological history over the last 500,000 years requires a brief description. The Laurentian Great Lakes, Lakes Winnipeg and Manitoba, Great Slave Lake and Great Bear Lake, and other large lakes in Canada lie along the zone of contact between the ancient Precambrian rocks of the Canadian Shield and sedimentary rocks formed in adjacent shallow coastal seas, in part from the erosion of the original Shield material. Large scale crustal deformations give an underlying structure to the region but it is the cyclical advance and retreat of glaciers over the last 500,000 years that have carved out the major basins and left much of the region blanketed with a thick overburden of glacial debris. Appropriate land use in the Lake Ontario Basin depends strongly on the quality of the glacial leavings, a fact often and unfortunately ignored in the process of settlement and development.

The Great Lakes System, as we know it today, is only 10,000 years old, and it continues to change. The drainage pattern of the Lakes' precursors has changed markedly, and with the continuing crustal rebound following the retreat of the most recent Wisconsin period of glaciation, it is possible that Lakes Erie, Huron, Michigan and Superior might one day drain south through the Mississippi Valley. No one can know for sure. A 10,000 year old lake is a young lake, containing relatively few species and short, easily disrupted food chains.

To say that the aboriginal people left no mark on the landscape is untrue. It is thought that the disappearance of some of the large animals such as the mastodon may have been hastened by overhunting by the first human arrivals. The fur trade undoubtedly introduced the distortions of the cash economy including over-exploiting a resource for immediate gain. However, compared with what was to follow, the activities of the aboriginal people were of small scale and were acted out over long periods of time.

EUROPEAN SETTLEMENT AND INDUSTRIAL DEVELOPMENT

A seventy-year lifetime centered on the year 1800 would have witnessed several pivotal events that influenced the transition of the Lake Ontario Basin from "wilderness" to a post-industrial landscape. By the mid 1700's heavy trapping of beavers and other fur-bearing animals in the Great Lakes Basin forced the main activities of the fur trade to shift to the west of the Great Lakes. The earlier reduction in the beaver population may well have had some influence on lakes in the Basin; its effects would be particularly noticeable in the tributary streams where beaver ponds regulate water flow. In the century previous to 1750, the Lake Ontario region was a dangerous buffer zone between the French with their Huron Indian allies, and the English aligned with the redoubtable Iroquois. Consequently, there were only a few strategically located European outposts, such as the ones at Kingston and Niagara.

In 1783, the formal hostilities ended between Britain and her former North American colonies, now the United States. Hostility continued, however, towards those colonists who had remained loyal to the Crown during the years of the American Revolution. In the summer of 1783, many Loyalists, as they were called, who had taken refuge in the British stronghold of New York elected to leave the United States prior to the evacuation of the British garrison. Thirty-three thousand Loyalists came to Canada. In 1784, Loyalist regiments were disbanded at Kingston and Niagara and land was allocated to Loyalist settlers in the Bay of Quinte area. In that year also, many Iroquois Indians, traditional allies of the British, were displaced from their ancestral home in the Finger Lakes area of New York State. The largest group settled near Brantford, where their descendants remain today. By 1791, when the colony of Upper Canada was formally separated from Quebec (Lower Canada), it counted 30,000 inhabitants.

In 1812, at the height of the Napoleonic conflict in Europe, the United States declared war on Britain and attacked Canada, all in response to the British naval blockade of Europe and high-handed searches of American ships. Many of the key battles of the 1812-14 war were fought in the Lake Ontario Basin. The vigorous defense of the Canadas by outnumbered forces and the subsequent guarded relation between former combatants helped to form a distinct Canadian identity.

In 1825, the Erie Canal was completed between Albany, New York, on the Hudson River, and Buffalo, on Lake Erie. Originally scoffed at as "Clinton's Folly", the commerce along the Erie Canal made New York City rich. In 1829, the first of several versions of the Welland Canal was completed under the leadership of Wm. Merritt, a St. Catharines' businessman. With the Industrial

Revolution fully underway in Europe, conditions were now right to try it out in the Great Lakes Basin.

It is important to note that the period from 1770 to 1870 was one of great political ferment in both Europe and the Americas and out of it arose a new order that celebrated the freedom of the individual and the power of reason. This freedom included a person's right to the fruits of his or her labor and enterprise while subduing Mother Nature.

By the middle of the nineteenth century, the main patterns of today's agricultural development and settlement were established with extensive clearing of the formerly abundant forests. In some areas, such as the Ganaraska watershed north of Port Hope, the loss of forests from sandy soils resulted in severe erosion from both water and wind. In 1798, a farm on Yonge Street, near the heart of downtown Toronto, was advertised for sale. The advertisement listed among the strong selling points the fact that a valuable salmon fishery was attached to the farm. By 1900 the salmon spawning streams entering Lake Ontario had been spoiled through warming, siltation, and damming and salmon consequently disappeared from the Lake. In the eighteenth century, caribou were found west of the French river on Georgian Bay, cougars lurked in the woods around Lake Ontario, and elk were common in the entire Great Lakes Basin. The passenger pigeons were so numerous that their migratory flocks were said to darken the sky. The total extinction of the passenger pigeons by 1902 can be attributed to wasteful slaughter and loss of habitat through clearing. The cleared agricultural land south of the Canadian Shield began to resemble the prairie land to the west and prairie animals such as coyotes, badgers, and killdeer moved in. Thus during the century-long phase of European settlement and agricultural development, before industrialization had fully taken hold, the distribution of habitats and species in the Great Lakes Basin changed enormously.

Developments in and around Hamilton are typical of those occurring in other industrial centers around the lake. Because of the proximity of good water power sites along the Niagara Escarpment, the Hamilton area, including Ancaster and Dundas, became a milling and transport center by 1790. The first paper mill in Canada was established in Greensville, near Dundas in 1797. In the 1820's the construction of a canal through the sandbar separating the former Lake Macassa (now Hamilton Harbor) from Lake Ontario allowed schooners and steamers to enter the sheltered water, and in the 1830's the Desjardins Canal linked the harbor with Dundas. In the 1830's and 40's, many immigrants arrived in the area from Great Britain. In the railway boom of the 1850's, Hamilton developed strong commercial ties with Toronto and the United States. Foundries manufacturing stoves and farm implements became established. A municipal water system drawing from lake Ontario was completed in 1860 replacing the myriad of private wells and ending the repeated outbreaks of water-borne diseases such as cholera and typhoid fever. From 1880 to 1913 the area experienced an industrial boom, and during this time the important steel complex was formed. By the beginning of the First World War the stage was set for the acceleration of industrial and urban development within the Basin.

LAKE ONTARIO POLLUTION

EUTROPHICATION, TOXIC CONTAMINANTS, AND THE FOOD WEB

In the foregoing discussion of the historical evolution of the Lake Ontario Basin, the Lake has been seen as a center of human activity (as a transportation corridor, a source of water for homes and factories, and as a fishery). In the next few paragraphs we examine the effects of some of this human activity on the Lake, viewing the Lake as a home not just for humans, but also for a host of interacting creatures that together constitute a basin-wide ecosystem.

While many of the trends leading to today's situation began in the late eighteenth century, it was not until the beginning of the present century that they were identified in any systematic way. Reliable data by which the trends can be measured extend at most over the last 50 - 60 years. In some cases, chemical analytical techniques of sufficient sensitivity to detect these trends are still in development stages. Two major pollution problems have been identified and have preoccupied scientists and legislators over the past 30 years. Both the clearing of land for agriculture with subsequent soil erosion, and the growing urban population discharging sewage to the Lake increased the supply of plant nutrients (notably nitrogen and phosphorus) to the waters of the Lake. The extra nutrients have fueled an increased and sometimes excessive biological productivity of the receiving waters, a process known as "cultural eutrophication". As the industrial economy took hold, many other substances found their way into the water (and into the air and the soil), substances that are toxic in both blatant and subtle ways to life in the Lake and its surroundings. The consequences of these additions of both nutrients and poisons are best studied in terms of an organizing concept of ecology known as the food web.

As in a pasture, the primary producers of biological energy in a lake are photosynthesizing plants. Unlike the pasture, most of the photosynthesis is accomplished by many different kinds of minute, freely drifting, single-celled organisms known collectively as algae or phytoplankton. In the summer months, if soluble nutrients are plentiful, the concentration of these otherwise invisible creatures may become so great as to make the water green and turbid. Most of the algae, at the end of their life-cycles, sink towards the bottom of the lake. While sinking, or on the bottom, they are consumed by bacteria, and the nutrients they contain are made available once more for actively photosynthesizing organisms. Like a pasture, some of the biological energy stored in the plants becomes food for plant-eating animals. In scale with the minute drifting plants of a lake, the grazing is accomplished by a myriad of tiny animals, many of them superficially resembling insects, but most of them visible only with the aid of a microscope. They are called zooplankton. Some zooplankton migrate both up and down through the water in order to find plentiful food and to avoid being eaten themselves, but they otherwise drift freely with the water movements. The zooplankton in turn are the food base for several species of fish, generally small ones such as herrings, alewives, smelts, and sculpins. The next tier of the food web includes fish such as pickerel, trout, salmon, and fish-eating birds such as gulls and cormorants. Humans temporarily occupy the same tier when they eat ciscoes or smelt, or the tier beyond when they eat pickerel or salmon.

Between 1923 and 1954, the annual average of algae concentrations measured at the Toronto water intake doubled. At the same time, changes occurred in the distribution of algal species in Lake Ontario such that in this respect, the water began to resemble that of the biologically more productive Lake Erie. Similar trends have now been identified in all the Great Lakes and they are a consequence of increased nutrients from sewage and from land runoff carrying chemical fertilizers and eroded soil. At first, the effects were confined to the nearshore waters adjacent to the source of the nutrients and where the mixing of the nutrients into the main body of the lake was relatively slow.

By the early 1970's the nutrient loadings and the accumulations of biologically active material in Lakes Michigan, Erie and Ontario were large enough that the eutrophication process was lakewide. In the popular press of the time, Lake Erie was written off as a "dead" lake when in fact it had never been more biologically productive. In some years, so much algae was produced in the upper layers of central Lake Erie that the bacteria decomposing the organic material in the bottom waters used up all the dissolved oxygen. Other anaerobic bacteria took over, but the cold bottom waters, depleted of oxygen, could no longer support some species of fish. The main body of Lake Ontario, by virtue of its greater depth, contained enough dissolved oxygen to cope with the bacterial decomposition without serious danger to fish (although Hamilton Harbor and other embayments may have suffered from oxygen depletion in the bottom waters for many years).

The changes observed in Lake Erie, some of them thought to be potentially irreversible, were so alarming that widespread action was taken. It was determined that the nutrient phosphorus was in short supply relative to the more available nitrogen and thus limited the amount of algae that could grow. From this observation it seemed to follow that if phosphorus inputs could be reduced, production of algae should decrease. The most effective way to reduce phosphorus loadings to the lake was to remove it from domestic sewage effluents before it entered the water, by reformulating household detergents, formerly rich in phosphates, and by constructing and upgrading sewage treatment plants throughout the Great Lakes Basin. By 1983 the amount of phosphorous entering the Great Lakes each year was less than half of the peak load of 1972, and the average concentrations of total phosphorus in offshore surface waters decreased by a similar amount.

In 1989, Lakes Michigan, Erie, and Ontario appear to be in a recovery phase with respect to the excessive eutrophication observed a decade earlier. Production of algae has decreased substantially in Lake Ontario, particularly nearshore (repeating the spatial progress of the earlier increase) where the filamentous algae, <u>Cladophora</u>, once grew so abundantly in shallow water that it carpeted the beaches in rotting masses after every storm. The decrease of the <u>Cladophora</u> has not been proportional to the reduction in phosphorus input because phosphorus concentrations have only recently been low enough to inhibit its growth. Offshore, the phytoplankton productivity has not decreased in proportion to the decrease in phosphorus loading, suggesting that (1) there may be a source of phosphorus available in the recent sediments, and (2) the phytoplakton are able to recycle the available phosphorus more quickly. Ultimately, a reduction in productivity at the base of the food chain ought to be reflected in other components. It is puzzling, however, that the impact of these changes has not been observed so far on the next link in the food chain, the zooplankton, the tiny animals that graze on the microscopic plants.

Within the food web described earlier, the old adage "you are what you eat" can take on an ominous meaning when it is applied to certain substances that are present in the water in seemingly innocuous concentrations. Some contaminants, and a good example would be 2,3,7,8-TCDD (dioxin), are poorly soluble in water but readily soluble in fats. These chemicals are often retained in living tissues rich in oils and fats at concentrations that are many times greater than those occurring in the water. Thus, the overall concentration of such a contaminant in the algae may be much larger than the concentration of the contaminant in the surrounding water. Since the molecules of the contaminant take no active part in the metabolism of the creatures that ingest them, they are retained, and accumulate over time in their tissues. Concentrations in zooplankton may then be larger than those in the algae, and for the same reasons, concentrations in fish and sea-birds may be larger still. This process is sometimes called biomagnification. Generally speaking, the longer-lived organisms farthest removed from the primary producers in the food web have the potential to accumulate the largest body burdens of contaminants. It is suspected that some of these contaminants may interfere with genetic material in cells, causing cancers or defective embryos. Herring gulls and cormorants, fish-eating birds, have some of the largest observed concentrations of 2,3,7,8 TCDD in their bodies and this compound has been identified as the probable cause of a long list of abnormalities and dysfunctions, including poor reproductive success, deformed fledglings, and liver malfunctions observed among herring gulls in Lake Ontario.

Another toxic pollutant example is the compound called mirex. This chemical was employed as an insecticide and a flame retardant from roughly 1968 until it was banned in 1978. Little is known about the effects of mirex on lake organisms but it, like the dioxin compound it resembles chemically, is retained in fats and oils and is not a welcome addition. The mirex story is particularly interesting because is serves in some ways as a model for the behavior of other similar compounds. In 1974, sensitive analyses for mirex were developed and it was discovered first in fish and later in the water and the sediments of Lake Ontario. The distribution of the contaminant in the sediments was consistent with what is known about the mean circulation of the Lake and indicated probable sources in the Niagara and Oswego Rivers. The suspected sources were confirmed, although both the production and use of the material had ceased some time before. The source of continuing contamination of Lake Ontario by mirex is now understood to be river and harbor sediments near the sites of the original manufacture. Mirex, like many other organic contaminants, binds preferentially to sediment particles, a feature that hastens initial removal of the material from the water column, but which ensures a long-lived supply of the material to the water as the sediments are resuspended and transported during storms. Significant quantities of mirex may be present for as long as 50 years, until all the mirex is buried by fresh sediments to a depth where it will no longer be disturbed. A removal time of this order is expected for other contaminants.

EFFECTS OF EUTROPHICATION AND TOXIC CONTAMINANTS ON FISH

Along with salmon, other "commercial" species such as lake trout, whitefish, and ciscoes, were greatly reduced through loss of habitat, and overfishing. Eutrophication further stressed the fish population via changes it induced in the relative abundance of species of plankton and via changes in water quality (lower dissolved oxygen levels in some places). During this same period, a number of non-native fish species were introduced and began to thrive in the Lake. These included rainbow smelt, lampreys, carp, and alewives, and more recently, thanks to vigorous stocking programs, Pacific Salmon. The Lake Ontario food web, first reliably described in the 1920's, but even then greatly altered from that of the previous century, has undergone significant changes in the intervening 60 years as a result of human activity.

At the same time that efforts were being made to reduce the primary biological productivity of Lake Ontario, by limiting the nutrient supply, fish stocking programs sought to increase the productivity elsewhere in the food web. Preying on the numerous smelts and alewives, the salmon prospered, making possible the parallel growth of a profitable sport fishing industry. It is estimated that the sport fishing industry generates 2.6 billion dollars' worth of economic activity each year within the Great Lakes Basin, a very large portion of it derived from the salmon fishery. The stocking programs were initially implemented independently of the nutrient abatement efforts, one of the consequences of the fragmented but overlapping management responsibilities of the many jurisdictions now in place. A more integrated view of the lake is clearly required since an assessment of the biological energy flow in the Lake Ontario food web suggests that with the present nutrient supply, Lake Ontario can barely carry the number of salmon it now contains. No one really knows whether this manufactured ecosystem can be managed stably over long periods of time. It is quite possible that unwelcome boom-and-bust cycles of predator and prey may result. Since most of the changes have been inadvertent to some degree, and even the deliberate ones undertaken with a very limited knowledge of how the food web actually works, it is fair to ask whether we have the best possible system in place.

Fish exposed to toxic contaminants in some restricted and grossly polluted areas of the Lake are frequently afflicted with tumors, among other problems, and it seems clear that there is a link between such lesions and environmental stresses, among them high levels of contaminants. Over most of the Lake however, the concentrations of toxic contaminants in water meet or exceed the most conservative standards in place today. While concentrations of contaminants such as mirex and PCB's in the salmonid predators of the open lake are significant, it is not known if the fish are impaired by them. Despite a vigorous stocking of lake trout in Lake Michigan, very few young trout are to be found in the lake, indicating poor spawning success. A study of the hatching of lake trout eggs from Lake Michigan, Lake Huron, and Lake

Superior fish revealed a very poor hatching success for the Lake Michigan eggs and that the cause of this failure was associated with the eggs and sperm, not directly with the surrounding water. Analysis of the egg, fingerlings and parent fish showed the highest levels of polychlorinated biphenyls (PCB) and other contaminants in the Lake Michigan material. This evidence is not conclusive but it is consistent with the possibility that contaminants such as PCB's accumulated in the fish are a cause of the poor reproduction of lake trout in Lake Michigan. At the next level in the food web, which includes fish-eating birds and fish-eating people, however, the dangers of contaminants cannot be ignored.

DIRECT EFFECTS OF EUTROPHICATION AND TOXIC CONTAMINANTS ON PEOPLE

Sewage disposal in nearshore waters with the associated problem of eutrophication, directly affects the human inhabitants of the Lake Ontario Basin through taste and odor problems in domestic water plus additional higher costs of filtration and purification. It has also decreased the recreational use of the nearshore zone, when, for example, beaches are closed by public health officials, when nuisance mats of Cladophora befoul the shoreline, or when fish species decline.

The presence of toxic contaminants in drinking water is most unwelcome, even at low levels, but as it turns out, most people ingest more toxic contaminants from their food than from the water they drink (85% from food, 10% from water, 5% from air, on the average). Broad averages taken across the whole population conceal the fact that certain sub-groups are much more exposed to contaminants than others. Employees of chemical industries, persons living in the vicinity of chemical waste dumps, and persons who regularly consume predator species of Lake Ontario fish would be among the high-exposure groups in the Lake Ontario Basin. Evidence is accumulating from studies in Michigan that mothers who regularly eat Great Lakes salmon transfer damaging burdens of contaminants to their babies, both during pregnancy and by nursing. Here, the critical organisms are the fetus and the infant. These infants as a group tend to have lower birth weights, smaller head circumferences, and a higher incidence of neurological disorders. There is no comparable study of Lake Ontario fish-eaters, the only known group to have been exposed to 2,3,7,8-TCDD as well as PCB's. For advice on eating Great Lakes fish the reader is referred to The Guide to Eating Ontario Sports Fish, 13th Edition, 1989, published by the Ontario Ministry of Natural Resources and the Ontario Ministry of the Environment.

OTHER IMPACTS ON LAKE ONTARIO

THE POSSIBLE EFFECTS OF GLOBAL CLIMATE WARMING

The causes and remedies of eutrophication are primarily local, at the scale of regional drainage basins. While most toxic contaminants enter Lake Ontario from local sources, some of the load is carried in the air from distant regions by winds to be deposited on both the land and water. On the other hand, the so-called greenhouse effect is truly a global phenomenon. Our concern is that the accumulation of carbon dioxide and other gases that absorb infrared radiation in the upper atmosphere may result in a warming of the mean surface temperature of the earth, (3 - 4 °C if the present CO_2 concentration is doubled) although, as we shall see, exactly how this anticipated warming would be distributed around the globe is difficult to predict. It is generally assumed that the patterns of fossil fuel consumption, mainly responsible for the increase in carbon dioxide, will not change rapidly and that an eventual doubling of the average CO_2 concentration in the atmosphere is very likely. Present estimates suggest that this increase in CO_2 will result in a very significant 3 - 4 °C rise in the mean surface temperature of the earth. Climatologists have therefore set themselves the task of anticipating the consequences of a climate change of this magnitude.

The chief predictive tool of climatologists is a "Global Climate Model (GCM)". This is a complicated computer program that simulates weather patterns on the surface of the earth. Inputs to the model include such information as the quantity of solar radiation arriving at the top of the atmosphere, the composition of the atmosphere which controls the passage of radiation through it, and the distribution of water and land over the earth's surface. The outputs are time and space varying estimates of key climate parameters such as the distributions of air temperature at the earth's surface, evaporation, precipitation, and wind speed. In order to make these computations, it is assumed that the major processes can be described by mathematical equations. The mathematical models are tested against available observations. While there appears to be general agreement among the well-established GCM's as to potential changes in average values of air temperature, there is considerable disagreement for changes in other parameters such as precipitation, and also as to how these changes will be distributed regionally. A more conservative approach, based on data alone, is to examine the records collected during an abnormally "hot" year on the assumption that the global warming trend, at least initially, will not produce totally new situations but will increase the frequency of occurrence of the warm weather that we already experience from time to time. It is also thought that our climate, while becoming warmer on the average, may also become significantly more variable.

Globally, the 1980's included some of the warmest years of the century. For example, the summer of 1983 was characterized by less-than-average wind speeds, reduced cloudiness, high atmospheric pressures, and air temperatures

2 - 4 °C above normal. Ice cover was reduced in both extent and duration. In the lower Great Lakes, the transition between winter conditions (cool, near uniform temperatures from top to bottom) and summer conditions (warm surface layer, cool lower layer) occurred several weeks earlier than usual. Although the warmed surface layer of the Lake was thinner, a greater quantity of heat was stored in Lake Ontario and near-surface water temperatures were higher.

Assuming a doubling of present day atmospheric carbon dioxide, Global Climate Models have been used to prepare estimates of changes in various hydrological parameters over the Great Lakes. Some of the predicted consequences of climate change include a smaller net water supply to the lakes. As a result, flows through the system would be reduced and lake levels would drop. The predicted decrease in the level of Lake Ontario is several meters, however this change could be lessened by controlling the outflow of the Lake to the St. Lawrence River.

We could expect several consequences of these changes to be noticeable by the year 2050. More active dredging would be needed to maintain shipping channels. Less electric power would be available from the Niagara and St. Lawrence rivers. The demand for exports of water from the Basin could be large, but less water, if any, would be available. Species distribution of fish and other organisms would change to accommodate the higher near-surface temperatures and also reduced vertical mixing of subsurface waters. The internal recycling of nutrients in the warm upper layers offshore would be reduced with a possible accompanying reduction in the Lake's carrying capacity for large predator fish such as salmon. An unbroken series of "warm" years could result in reduced oxygen concentrations in the deep waters of Lake Ontario, making it less comfortable for salmon and trout. Not only could the reduced mixing and inflow slow the elimination of toxic materials from the deep waters of Lake Ontario, but they could also lead to a deterioration of water quality close to shore. For example, the summer of 1983 is also remembered for its widespread beach closures.

Although we cannot honestly say that ALL the changes to Lake Ontario resulting from global warming will be harmful, some of them at least may work against trends we have come to welcome as signs of recovery from a dangerous phase of local pollution. Increasingly, people are turning to the Great Lakes for recreational opportunities (sport fishing, swimming, and boating). As we suggest below, it is very important that these opportunities be maintained and even enhanced.

POPULATION PRESSURE AND LAND USE

Climate change due to the greenhouse effect is an indirect consequence of growing world population, but we shall not escape the direct effects of larger local populations in the Great Lakes region. For example, the doubling of present road traffic in the Toronto area is anticipated by the year 2020. Compared with the problems facing the poorer nations as a result of growing populations, we in the Great Lakes Basin are not yet so hard-pressed that we have run out of room to manoeuvre. However, the infrastructure we consider necessary to support an individual in this region (housing, transportation, water, waste disposal, education, energy) is enormous compared to its counterpart elsewhere, and we have been discussing some of the harmful effects of this lifestyle on Lake Ontario. At this particular time we do not lack the technical ability to provide a decent level of accommodation and services to a much larger population while respecting environmental quality. Such a happy outcome, however, depends on our retaining a certain latitude for adjustment in the face of the uncertainties arising from potential climate change. In managing public affairs such as the many services we have come to expect, we must become farsighted, disciplined, and we must avoid foreclosing useful options for future generations.

Most people would agree that our success in coping with the demands of a growing industrial society depends on the wise use of that primordial resource, the land that supports us in so many ways. Yet recent trends in land "development" seem to be foreclosing at least two important options; first, that of growing food, and second, that of providing liveable situations for a much higher population density.

That much of our food is more cheaply produced outside the region is the result of an industrialized agriculture that relies heavily on chemicals amid other energy inputs, cheap labor and transportation, and above all, present soil and climate conditions. The productivity of the North American "breadbasket" on the rich farmland of the central plains has underwritten much of our material prosperity in the last half-century. Some climatologists think that particularly favorable and unusual climate conditions are as much responsible as the good soils. There are many reasons to think that the continuity of the present situation cannot be assumed in whole or in part.

As our cities become more congested, many people have moved to the adjacent countryside. Housing developments and shopping malls skirt the towns. If you are unconvinced, take a Sunday afternoon drive to the countryside over a route you have not travelled for a year and note the changes. While enlightened planners decry it, existing legislation frequently permits strip development, the leading edge of an ad hoc urbanization that has not generally been subject to public debate concerning its long range implications. The government of Ontario has assigned the responsibility for land use zoning to the regions and municipalities where the potential tax revenue from growth and development looms large in the planning process. Attempts to protect recreation values in a coordinated way, such as the Niagara Escarpment Commission are sometimes viewed as obstacles, not safeguards. Furthermore, uncoordinated, widespread developments are attractive only by virtue of their continued and convenient accessibility by private automobile, a form of travel that imposes its own considerable environmental costs and that cannot be taken for granted in the long term either.

Thus, rural spaces adjacent to cities that are valuable both for their agricultural production and for the accessible enjoyment of city dwellers are disappearing. Within our cities themselves, redevelopment has usually favored short term commercial interests over public "liveability". Although Toronto is by no means the only place where such things happen, the lack of affordable housing in that city and the condominium-dominated Toronto harborfront development are two examples that have been widely reported. These trends will continue as long as land transactions are conducted solely on the basis of the prices and conditions offered by today's short term, speculative, free market economy.

INDIRECT EFFECTS OF LOCAL POLLUTION, GLOBAL CLIMATE CHANGE, & POPULATION GROWTH ON THE PEOPLE

In 1986 the Calgary Institute for the Humanities organized a Conference entitled "Civilization and Rapid Climate Change" in order to bring together the knowledge of climatologists, social scientists, and humanists on the threat to civilization posed by rapid climate change. A summary of their proceedings was published under the title, "Thinking the Unthinkable: Civilization and Rapid Climate Change". It deserves to be widely read. From archeological evidence and historical records, a pattern emerges concerning the response of human cultures to sudden changes in their environment (droughts, fires, volcanic eruptions, etc.). Generally speaking, the most resilient culture is the one that has served us longest, the hunter-gatherer society. Such a society has a simple, flexible organization; leadership is based on demonstrated competence, and each individual possesses a substantial portion of the required survival skills and knowledge. Such people travel lightly, and in the days when they constituted the prevailing human culture, there was some place to flee.

The hunter-gatherer mode has long since ceased to be a viable option for all but a few very isolated indigenous peoples. At the other end of the scale, our modern industrial society, despite its enormous technological prowess and its demonstrated ability to solve some major environmental problems, is perhaps the most vulnerable of all to sudden change. While the creativity and productivity of an industrial society are large and contain intellectual, material and cultural wealth accumulated over many centuries of civilization, they are achieved by the organization of people with many different, but highly specialized skills. Where a dozen people might constitute a viable band of hunter-gatherers, a self-contained industrial society would require something like a hundred thousand people. The wisdom of today sets a high value on the economies of scale made possible by regional specialization and world trade. Such specialization, advantageous as it may be in terms of current projections, may further reduce the resilience of a local society to changes. Important skills and products may be continents away. Needless to say, the option of rapid migration and dispersal available in earlier times to hunter-gatherer societies is no longer available to us.

A major weakness of our society, we believe, lies not in the range of technical knowledge and skill it can bring to bear on a problem, but rather in its ability to pull together as a society in stressful times. One of the major stresses on today's society arises from both the real and the perceived consequences of environmental degradation.

The issue of toxic contaminants is particularly stressful. We readily embrace the comfort, convenience, and efficiency of industrial products but we do not readily accept their costs in terms of the associated health risks from contamination. If we knew, for example, how many cancers, impaired infants, etc. per year could be attributed to a total reliance on nuclear power generation, bearing in mind the possibility of future "Chernobyls" and "Three Mile Islands", can this be offset by the immense liberation of human creativity made possible by plentiful electrical energy? In the past we have accepted the concept of tolerable concentrations of contaminants (a little won't hurt you) but we now know that a tolerable level for some contaminants, given what we have learned or now suspect about their pathways and effects, is zero, none. Where action against polluters in the past has always involved compromises such as reduction schedules, living up to the responsibility of zero discharge means severe dislocation for some industries, and its adoption and enforcement calls for unprecedented political courage. So much is at stake in coping with these issues that misinformation is abundant, and in the ensuing climate of fear and uncertainty, the interpretation of our limited data can become wildly distorted. Economic disparities, such as the fact that affluent people can afford expensive air conditioning and water filtration systems while the non-affluent do without, are additional sources of tension.

Public access to rural spaces through the provision of greenbelts, public acquisition of land for parks, and decent, affordable, city housing, are all urgently needed throughout the Lake Ontario region not only to meet present demands, but also as an investment to alleviate the tensions of a more crowded future. All too often forward-looking municipal plans are eroded by piecemeal rezoning and it sometimes seems that land development in southern Ontario is almost totally in thrall to speculative and short term interests. A dangerous byproduct of this condition has been the real or suspected linkages between politicians and developers, a situation that undermines the credibility and effectiveness of political leadership at a time when we need it most.

Rapid climate change will also increase the stresses on our society. To bring this home to the Lake Ontario Basin, consider the hypothetical story of the air-conditioning police. As global climate warming progresses, the Basin experiences summers where unpleasant "heat waves", previously endurable because of their rarity and brevity, are now weeks and months long. Much was written about the nasty summer of 1988, fortunately not repeated in 1989. A logical but perhaps unthinking response to hotter and more humid summers is to invest heavily in air-conditioning. Never mind that an air-conditioning unit's large energy requirement actually contributes to the conditions leading to a shift in climate.

The demand for electrical energy in the peak summer months soon outstrips the generating capacity. Now on hazy and shimmering August afternoons, the workers struggling home from an overcrowded city core are apt to be greeted by wilted, cantankerous, and non air-conditioned families because of a power brown-out and failure occurring earlier in the day. Going to the beach is pointless because of the traffic congestion and the high probability that the beach will be closed to swimming anyway. On days like this, the widely promoted affluence everyone is working so hard to attain seems rather pointless.

The energy problem quickly becomes political as first utility companies and then the government are accused of ineptitude. Having no other short term options, the government institutes some form of energy rationing, voluntary at first, but as this proves to be ineffective, a more stringent form is imposed, this time backed up by the air-conditioning police. It is an unfortunate move, given the widespread irritation and disappointment at the failure of "traditional" solutions. In the riots and upheaval that follow, only brigands and bullies are able to seize a fleeting advantage. Martial law and winter restore order somewhat, but the essential confidence and trust in public institutions and leadership is seriously eroded, leaving the political field clear for manipulative demagogues.

CONCLUSIONS

As the present century closes, we find Lake Ontario and its environs in an unresolved state, poised between promises and threats. While the cumulative results of almost two centuries of environmental insults have greatly altered the structure of the Lake's biological community, it is now in a recovery phase from two major insults, excessive nutrients (eutrophication) and the introduction of toxic contaminants. This recovery can continue provided, with regards to the latter problem, that we learn from our past mistakes and do not allow "new" dangerous chemicals to enter the ecosystem. The next phase of recovery calls for the restoration of the critical forest zones along the tributaries and the reestablishment of wetlands at the mouths of tributaries and at other favorable locations along the shore. The limitations of what has been an era of generally uncoordinated and piecemeal "management" are becoming obvious, particularly in the matter of finding the optimum balance between the apparently conflicting programs of nutrient abatement and fish stocking.

The large efforts made so far to remedy the effects of eutrophication and to curtail the introductions of toxic contaminants alone demonstrate that we possess the technical ability to intervene at the scale of the Lake. Environmental stresses operating at global scales are beyond our direct control, but for the moment at least, action at the basin scale will yield positive results. Almost two decades have elapsed from the lowest ebb of Lake Ontario's fortunes. There has been progress, but much more remains to be done. It would be unrealistic not to expect some further unpleasant surprises and possible setbacks, but it would be even more unrealistic, and ultimately irresponsible to our heirs, to "give up" at this time.

Technical matters notwithstanding, continued recovery of Lake Ontario is contingent upon a widespread public desire for a sustainable and liveable environment, a desire that is supported by action starting at the individual level and extending to all groups. This desire may stem in part from a realization that a healthy environment is inseparable from personal health, and it also depends on a hopeful outlook that it is not too late to correct past mistakes. Many environmentalists think that the short term and selfish interests that seem to drive modern industrial societies are the result of assumptions and mind sets viewed as liberating at the time of their introduction in Europe 500 years ago, but which are dangerously out of touch with today's realities. In other words, some of our most fundamental attitudes and values are challenged and may have to be changed.

We must therefore encourage in every way possible the vigorous communication and discussion of the scientific, political, aesthetic, and ethical sides of environmental issues. There are indications that this discussion is underway and one positive sign is the change in tone of environmental reporting from the sensationalism and scare-mongering of the 60's and 70's to reporting that is now both better-informed and better-balanced. Another positive sign is the maturity of non-governmental organizations such as Greenpeace and Pollution Probe. By virtue of solid research and skilled public advocacy, these organizations have become effective in developing and defending a positive environmental agenda. Their pronouncements are taken seriously now by governments, and they provide a valuable challenge to narrow partisan interests.

The looming problem of rapid climate change condemns us to a period of great social tension, no matter what we do about it. The tension is increased, if anything, by the uncertainties of the climate change scenarios. If at one extreme, we individually pursue narrow self interests and beggar our neighbors, we can count on a speedy increase in both material and social discomfort, with or without climate change. History has demonstrated that societies weakened by fear, greed, deteriorating living conditions, and eroded confidence in leadership (not able to provide viable alternatives), will not tolerate the stresses for long.

Alternatively, the potential severity of the worst consequences of environmental stresses such as "rapid" climate change could possibly be avoided (or at least ameliorated) by implementing environmentally sound actions right now: with the realization of course that slightly increased stresses now may reduce the inevitable crunch later. Many positive changes in lifestyle can be imagined that would improve environmental conditions both locally (recycling) and globally (reductions in the use of energy and noxious/toxic chemicals). Initiating and encouraging change is all the more difficult because humans do not usually alter behavior which is "pleasurable" unless absolutely necessary: and then they frequently revert to the old ways when the emergency seems over.

For example, one of the major contributors to environmental degradation (especially in overcrowded metropolitan areas) is the automobile. While the automobile confers enormous personal liberty, it exhales chemicals that are unhealthy and that contribute significantly to atmospheric warming through the "greenhouse" effect. Weighing the pros and cons while marooned in a car on congested streets and highways, it is easy to conclude that "something" must be better. Technological partial remedies include the introduction of catalytic converters and downsizing of vehicles. Reorganizing our patterns of settlement, employment, communication, and transportation in order to minimize vehicle use would be much more effective.

Among the effective solutions would be a dense public transit network. Such a system has a large initial cost and its acceptance is therefore a test of public will (although it is certainly true that the "weaning" of individuals from one habit to another is much easier if the alternative is palatable). For some the sacrifice of any comfort and convenience in exchange for reduced environmental stress may be asking too much. The proper education of our children may be our best investment in the future.

The success of these and other painful but hopeful options do not depend directly on any scientific or technical breakthroughs, useful as these might be, but rather on our collective conviction that individual sacrifice is essential for something we can't own as individuals, our shared and rightful place in the Great Lakes Ecosystem.

Many writers, some with insight and imagination, have produced vivid descriptions of post-cataclysmic modern societies (Margaret Atwood, Hugh MacLennan, Wayland Drew, etc.). Consider here a more optimistic scenario for life in the Lake Ontario Basin perhaps in the year 2050 when our grandchildren are in their primes. Assume that global climate warming is a reality, but due to timely action taken in the period of the 1990's here and elsewhere, Lake Ontario will remain more or less within current established ranges. Climatic outlook may be poor for local skiers, but more encouraging for cyclists and golfers.

Let us explore some possible economic and social developments within a more environmentally conscious society of the future.

1. Industrial and Entrepreneurial Modifications:

Assume no major technological breakthroughs such as unlimited energy supplies promised by "cold fusion", but rather expect a steady accretion of small engineering improvements and a much greater emphasis on small scale, environmentally sustainable technologies. We predict a trend away from economic monocultures to dispersed and small-scale centers of production. This will arise in part from efficient recycling of materials. Waste products will be retained at the original site of manufacture and either deactivated there or else sent to a central facility, not a land-fill. Processes that risk releasing "zero-discharge" contaminants will not be undertaken. Large, centralized steel mills, for example, will be replaced to some extent by smaller local mills running on locally gathered scrap. A downsizing of the primary steel industry is not a welcome prospect in Hamilton today. Indeed Hamilton is a good example of the vulnerability occasioned by industrial concentration. However, the need for special alloys and technically demanding fabrication could offset some of the decline in bulk production. The entrepreneurial drive for growth and profit will be balanced by the satisfactions of running an outfit that pays its way, treats both its employees and customers well, and treads as lightly as possible on the environment.

2. Contaminant-Free Food-Stuffs:

As a consequence of the growing concern with a healthy diet, and more importantly, a reassessment of the dangerously short-term market forces driving land speculation, the future should see the demise of the mass-produced, imported, "truck-proof tomato" and "pharmaceutical beef". Encouraged by demand, local suppliers of organically grown produce and more "natural" animal husbandry will capture a larger share of the market. Whether the future will again see farmland close to cities valued for what it can grow rather than what can be built on it is uncertain, but this too, is a reflection of our will. Might we see the time when the presence of dirt, blemishes and the occasional worm will be viewed as indicators of high quality, contaminant-free produce?

3. Increased Energy Efficiency:

The anticipated problems of the "greenhouse effect" and the depletion of the ozone layer may have a positive result in forcing us to become much more energy efficient, some time in advance we hope, of the inevitable exhaustion of fossil fuels.

What are the possibilities? Although not an exhaustive list by any means and considered "Utopian" by some, we look forward to these options:

a) Rapid, fuel-efficient rail transportation will replace a large fraction of today's long-distance road and air transportation of goods and people.

b) Thanks to communication linkages such as facsimile machines and computers, white collar workers will require fewer visits to the office, thus decreasing pressure on transportation routes and yielding substantial savings in energy consumption while producing the same work output.

c) A more widespread implementation of a "cottage industry" type of employment where certain fabrication and assembly tasks are performed in decentralized workshops on the premise that it is more efficient to move a weekly boxcar load of product than to have employees make five round trips per week.

d) Given the reinstatement of efficient public transportation systems and a general acceptance of this mode of travel, the private automobile will return to what it was in the beginning, a vehicle of pleasure for occasional use. Such vehicles need not be powerful or fast.

e) Creative engineering talent will take up the challenge of making our tools and appliances more efficient, safer, and environmentally benign. They will cost more, but they will last longer and work better. The urgency of reducing the demand for non-renewable energy will override concerns of rapid amortization for investment.

4. Relaxed, less fragmented lifestyle; more liveable neighborhoods:
Frequent vacation travel, including weekend pilgrimages to distant cottages, will be replaced by fewer, but longer visits, again made possible in some cases by improved electronic communication. This will go hand in hand with a much greater emphasis on the liveability of neighborhoods and these may take on some of the positive aspects of village life in earlier times. The concept of home as an air-conditioned refuge for the viewing of video flicks will be superseded by a more inclusive outlook that includes recreation centers, parks, libraries, and in the particular circumstances of this essay, Lake Ontario and its environs.

5. Greater emphasis on values, ethics, and esthetics:

We also assume that the groundswell of public interest in health and environmental matters will carry us beyond an obsession with individual islands of comfort, to a collective reexamination of the fundamental questions of who we are, why we are here, and what we ought to be doing about it. These questions have always been the basis for the quest for spiritual enlightenment. A renewal of this important and creative phase of human endeavour, in an atmosphere of tolerance, would be welcome. It may be that it is an essential component of our full recovery from the abuses of the past three centuries.

As for Lake Ontario itself, three centuries of environmental insult will not be wiped away in one or two generations of repentance. Grateful for a narrow escape from a much worse fate, we will be content to watch and assist where possible, a slow but sure recovery. Assuming that the optimistic scenario also includes an appropriate investment of public funds for both the mitigation of the effects of climate change and for the integrated "management" of our collective impact on the Lake, we will at last have taken responsibility for a resource that is in fact an important component of our broadened concept of home.

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