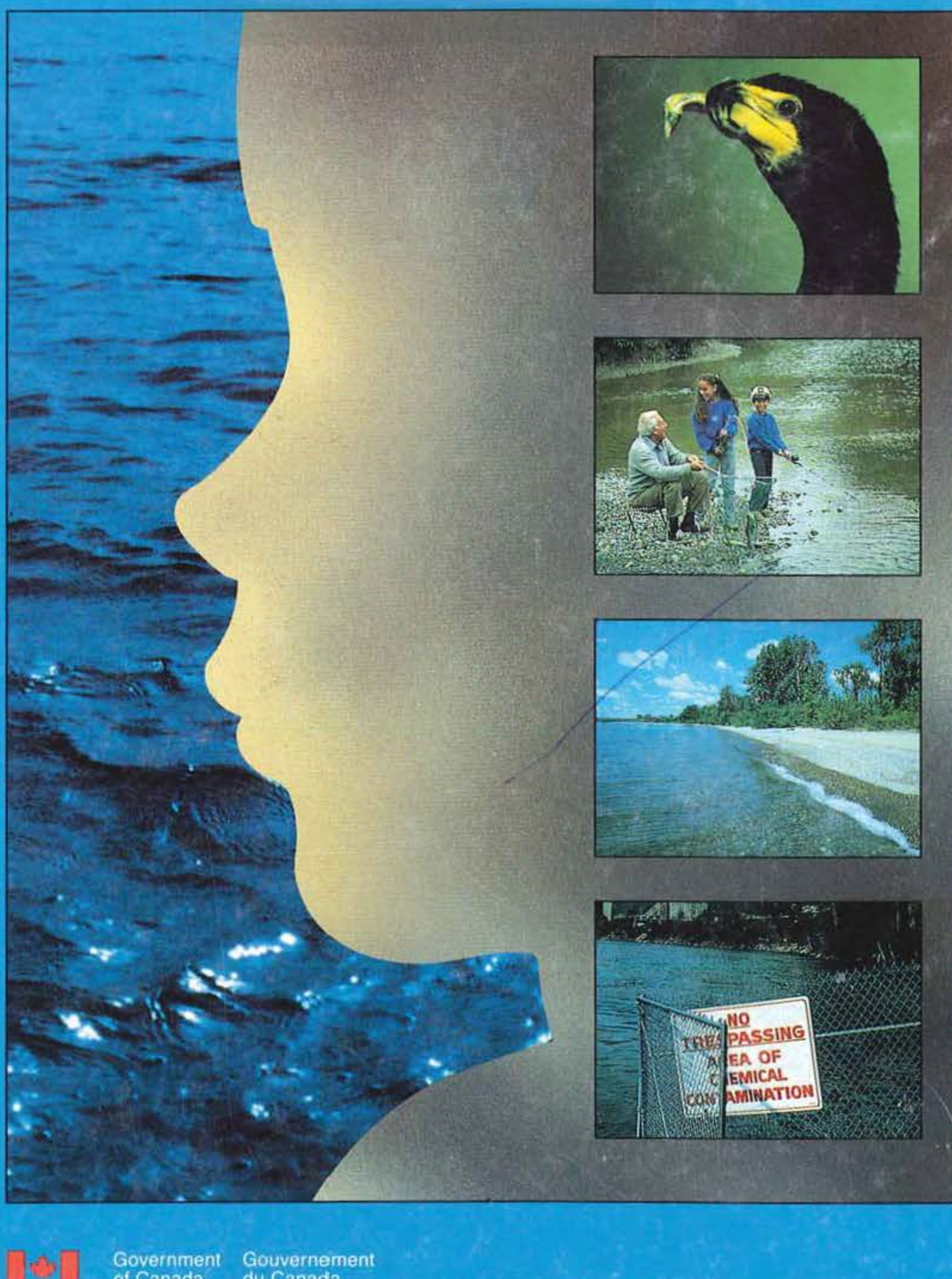
Toxic Chemicals in the Great Lakes and Associated Effects

SYNOPSIS



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Synopsis

March 1991

Environment Canada   Department of Fisheries and Oceans   Health and Welfare Canada

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Summary of Significant Findings

The increased commercial production and widespread use of synthetic chemicals and metals since the 1940s have resulted in the contamination of the environment. While the presence of persistent toxic chemicals in the Great Lakes has been known for some time, concerns have been directed in recent years towards possible human health effects of these chemicals.

This report summarizes what is currently known about the levels and the effects of toxic chemicals in the water, sediments, fish, wildlife and human residents of the Great Lakes basin. A complete account of all the findings is provided in the two technical volumes of this report. The following are the most significant findings.

1. The concentrations of toxic chemicals in the open waters of the Great Lakes (in the low parts per trillion range) are within the objectives of the Canada-U.S. Great Lakes Water Quality Agreement (GLWQA). These objectives are set to protect the most sensitive user (aquatic biota), and are well below Canadian and international drinking water standards. In nearshore areas such as harbours, connecting channels and bays, concentrations may exceed GLWQA objectives.

2. Analyses of lake bottom sediments indicate that the peak inputs of synthetic organic chemicals and heavy metals to the lakes occurred in the 1960s and 1970s followed by declines in the 1980s. These declines reflect the increased regulation of the uses of organochlorine pesticides, PCBs and mercury in the early 1970s.

3. Levels of contaminants in Great Lakes fish and aquatic birds have decreased substantially from the high values reported in the 1970s. Since the early 1980s contaminant levels in wildlife have remained essentially constant. Contaminant levels in fish have not remained constant but have fluctuated around a lower level. Stabilized contaminant levels indicate continued chemical input to the Great Lakes basin.

4. The Great Lakes support the largest freshwater fishery in the world. Commercial fishery closures resulting from toxic contaminants first occurred in Lake St. Clair and Lake Erie in the early 1970s. Since then, a number of commercial fisheries have been closed in all of the Great Lakes. In the early 1980s some of the closed fisheries were reopened, most notably the walleye fishery in western Lake Erie and Lake St. Clair. Contaminant-related restrictions on harvest are still in place for many commercial fish species.

5. Fish consumption advisories have been issued in 36 of the 42 highly contaminated Areas of Concern. These advisories occur most frequently in long-lived top predators, such as lake trout, salmon and walleye, and for fish such as carp that inhabit contaminated nearshore environments. There are advisories for lake trout in all of the Great Lakes except Lake Erie. Lake trout consumption advisories are in effect at all sites tested in Lake Ontario. For lake trout the number of fish advisories issued in Lakes Ontario and Superior has not changed since 1983.

6. Multimedia analyses of national and Great Lakes regional data indicate that 80% to 90% of human exposure to persistent chlorinated organics comes from food, 5% to 10% from air and less than 1% from water. Municipal treated drinking water drawn from the Great Lakes contains minute quantities of organochlorines but the amounts rarely exceed current guidelines for Canadian drinking water quality.

7. The effects of contaminants on Great Lakes fish populations and fish communities are difficult to separate from the effects of overfishing, habitat loss and the introduction of exotic species. There is good circumstantial evidence that contaminants were involved in the mass mortality of developing lake trout embryos in Lake Michigan during the early 1980s.

8. There is convincing evidence from laboratory data that toxic chemicals ultimately affect the survival, growth and reproduction of some fish species in the Great Lakes. Many of the sublethal responses to chemical exposure, such as elevated enzyme activity, deformed fins and the occurrence of tumours, indicate that fish are metabolizing toxic substances. Bottom-dwelling species such as brown bullhead and white sucker are

closely associated with contaminated sediments and have been used to monitor the prevalence of tumours in fish throughout the Great Lakes. Both species exhibit liver and epidermal tumours. Epidermal tumours appear to be associated with non-chemical factors. However, the geographic distribution of liver tumours combined with laboratory studies strongly suggests that these tumours are caused by environmental chemicals.

9. Eleven wildlife species (two mammals, eight birds and one reptile) in the Great Lakes basin have experienced reproductive and other problems attributable to chemical contaminants. All are long-lived fish-eating species. In the last decade there have been significant recoveries in reproductive success and increases in population for most of the affected bird species. Serious problems are now confined to a few highly contaminated areas. For example reproductive problems and birth defects are still occurring in cormorants and in terns in Lakes Michigan and Huron and in snapping turtles in Hamilton Harbour, Lake Ontario. Despite improved reproductive success, several biological indicators — vitamin A levels, thyroid function, heme biosynthesis and activities of detoxifying enzymes — remain abnormal in herring gulls over considerable areas of the Great Lakes basin.

10. The population increases of two species, the cormorant and ring-billed gull, have been outside the range of variation normally recorded for vertebrate species. The populations are now 20- to 40-fold greater than any recorded historically. These unprecedented increases indicate that some fundamental alterations in the Great Lakes ecosystem have occurred.

11. Although there has been some improvement, the number of bald eagles on the lower Great Lakes is only a small fraction of what it used to be. Pairs nesting along the shores of Lakes Michigan and Huron continue to reproduce poorly and no nesting has occurred on Lake Ontario since 1951. Lack of suitable habitat may limit this species' recovery in some areas.

12. Birth defects in young fish-eating birds have been recorded in ten species in the Great Lakes basin. The prevalence of crossed bills in cormorant chicks in Green Bay is 22 to 87 times higher than normal. Although rates of occurrence have decreased, chicks of both cormorants and terns have been found with birth defects in Lake Ontario as recently as 1988. A higher percentage of snapping turtles from the shorelines of Lakes Ontario and Erie have considerably higher numbers of unhatched eggs and deformed embryos than those from inland populations.

13. Wildlife studies have shown that developmental and reproductive effects can occur in a wide range of species including birds, reptiles, fish and mammals exposed to mixtures of contaminants in the Great Lakes basin. While differences exist in behaviour and exposure between humans and wildlife, research findings suggest that studies of human populations should focus on these subtle health effects.

14. The limited number of published studies available indicates that rates of cancer incidence and mortality and adverse reproductive outcomes in the Great Lakes basin are no higher than would be expected in any highly industrialized area of the country. Some epidemiological studies do show an association between maternal consumption of contaminated fish and adverse effects in developing children. Clearly some subpopulations (nursing infants and heavy consumers of contaminated fish and wildlife) in the Great Lakes basin and elsewhere in Canada have higher exposure to contaminants and are at greater risk. Others such as the elderly, the fetus or those who are already ill are also at greater risk because they may be more sensitive to the effects of pollutants. These subpopulations have not yet been adequately studied.

15. The limited human tissue residue data available indicate that the general population residing in the Great Lakes basin is probably not exposed to higher levels of the most persistent pollutants than people residing elsewhere in North America. However, individuals consuming large amounts of contaminated fish and wildlife, especially native peoples and sportsmen, have greater exposure to several persistent pollutants. Elevated levels of contaminants in the Great Lakes basin

(and elsewhere) do pose a threat to health but the precise nature and extent of the threat is unclear. Residents of the basin consuming large quantities of contaminated fish and wildlife should be aware of these concerns and reduce their intake of sport fish and wildlife in accordance with current advisories.

16. If the overall contamination of the Great Lakes is to be significantly reduced further, it will be necessary to address such problems as the remobilization of toxic chemicals from contaminated bottom sediments into the food web, long range atmospheric transport of toxics to the lakes, the slow leaching of contaminants from hazardous waste sites, the transfer of contaminants by tributaries to the lakes and continued input from point sources not yet adequately controlled.

Preamble

This report is a summary of the current scientific knowledge of concentrations of toxic chemicals in the Great Lakes and the associated effects on the fish, wildlife and humans living in the basin.

During the past two and a half years, Environment Canada, the Department of Fisheries and Oceans and Health and Welfare Canada have worked together to compile information on the levels, trends and effects of persistent toxic chemicals in the Great Lakes basin. This has resulted in a two-volume technical report entitled "Toxic Chemicals in the Great Lakes and Associated Effects". Volume I documents levels of toxic chemicals in water, sediments, fish, wildlife and humans. Volume II reviews what is known about the effects of these contaminants on fish, wildlife and people and contains a synthesis which is a scientific consensus on the significance of the technical data in both volumes. The material presented in this synopsis has been drawn from these two volumes.

Much has been written, spoken and conveyed through images about the levels of toxic chemicals circulating throughout the biosphere. Less has been written on the effects these chemicals have on individual species. There are comparatively fewer studies examining human health effects that are accepted by scientists and health professionals as authoritative or complete.

Based on our knowledge of chemicals and their toxicology, a pattern is emerging that suggests that persistent chemicals in the environment have a significant effect on wildlife species. We still know very little about the effects of a person's lifetime exposure to toxic organic chemicals and metals. Despite some uncertainties, it is clear that toxic chemicals are a threat to the entire ecosystem. As a result, the principle of "virtual elimination" of persistent toxic substances from the lakes has been adopted in the Canada-U.S. Great Lakes Water Quality Agreement. The national governments of both countries, together with the province of Ontario, the eight Great Lakes states and the large municipalities, are moving towards this goal using the regulatory processes, pollution prevention strategies and public education. In the meantime, government programs continue to monitor the health of the ecosystem, assess the extent to which it is impaired by toxic chemicals and develop means to reduce the impact of exposures.

The terms contaminants, persistent toxic substances and toxic chemicals are used interchangeably throughout this report. A number of persistent toxic substances are metals but the majority are organic chemicals. The terms organochlorines, organochlorine pesticides and chlorinated organic chemicals are used in the text. A glossary at the end provides definitions of the technical terms used in this report.

FIGURE 1. The Great Lakes Basin

Note: The 42 Areas of Concern are identified.

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Introduction

The Laurentian Great Lakes are collectively the largest body of freshwater on this planet. They contain the astounding volume of 22,000 cubic kilometres of water or 21% of the surface freshwater on earth. Outflows from the Great Lakes are relatively small in comparison to the total volume of water. On an annual basis, less than 1% of this immense volume flows into the St. Lawrence River.

The most recent census figures estimate that 8 million Canadians and 28 million Americans live within the drainage basin (Table 1). There are 28 cities with populations of more than 50,000 people and 13,400 manufacturing and industrial plants located within the basin. We use the lakes, tributaries and connecting channels for our water supplies, recreation, transportation of goods, industrial processes and disposal of chemical and biological wastes. The production and release of chemicals associated with high densities of population and industry in the Great Lakes basin led to widespread concern over the impact of human activity on the ecosystem and the implications of a contaminated ecosystem for health. More recently, the importance of atmospheric deposition of chemicals from outside the basin and contaminants in food have also been recognized as contributing significantly to human exposure.

TABLE 1
Population and Land Use in the Great Lakes Basin

	Superior	Michigan	Huron	Erie	Ontario
Population					
Canada (1986)	176,365	—	1,053,115	1,705,470	4,867,880
U.S. (1986)	487,100	12,051,200	1,408,000	10,827,300	2,507,400
Total	663,465	12,051,200	2,461,115	12,532,770	7,375,280
Basin Land Use (Percentage)					
Agricultural					
Canada	0.5	—	21	80	44
U.S.	6.0	44	40	63	33
Total	3.0	44	27	67	39
Shoreline Use (Percentage)					
Agricultural					
Canada	N/A	—	4	21	30
U.S.	N/A	20	15	14	33
Residential and Commercial					
Canada	N/A	—	69	49	43
U.S.	N/A	51	74	57	48
Recreational and Other					
Canada	N/A	—	27	30	27
U.S.	N/A	29	11	29	19

Sources: *The Great Lakes: An Environmental Atlas and Resource Book*, 1987.
Population data: Statistics Canada.

Historical Overview

The modern transformation of the Great Lakes basin ecosystem began with the arrival of European immigrants in the late 18th century. Initially, changes to the landscape and aquatic ecosystem were caused by settlements, forestry and agricultural practices. These were followed by bacteriological problems associated with urban sewage. Human activities in the 20th century have been responsible for a depletion of the fish populations from overfishing, a drastic restructuring of the shorelines from intensive waterfront activities and the excessive eutrophication of Lake Erie. As more synthetic chemicals were manufactured and used and more industrial and domestic wastes were generated, the lakes became increasingly used for the disposal of wastes. As a result, they became progressively more contaminated. For example:

- As early as 1963, studies of the herring gull in Lake Michigan revealed poor reproductive success and high levels of DDT/DDE.
- In 1968 high concentrations of mercury were found in the sediments of Lakes Ontario and Huron. At that time, industries using the chlor-alkali process were discharging mercury directly into rivers and lakes. In 1970 mercury was found in fish from Lake Huron, Lake St. Clair, western Lake Erie, eastern Lake Ontario and the St. Lawrence River, resulting in the closure of some commercial fisheries on the lakes.
- In 1971 a wildlife biologist visiting a colony of common terns in Hamilton Harbour observed eggs containing dead embryos and a young chick with a crossed-bill deformity. These problems were later linked to the presence of PCBs, DDT/DDE and hexachlorobenzene in the eggs.
- In 1971, as a result of finding PCB residues in fish, the Michigan Public Health Department issued the first advisory in the Great Lakes limiting the consumption of lake trout and salmon from Lake Michigan.
- In 1974 mirex was discovered in fish in the Bay of Quinte. The only known sources were a manufacturing plant on the Niagara River and another on Lake Ontario.
- In 1976 Ontario introduced the *Guide to Eating Ontario Sport Fish*. The 1990 edition provides consumption guidelines for fish caught by anglers from nearly 2000 locations on the Great Lakes and their connecting channels as well as inland lakes and rivers.
- In 1978 the Love Canal near Niagara Falls, New York, was declared a health emergency and 238 households were evacuated. A soup of industrial solvents, pesticides and process sludge long abandoned in an unused disposal canal had seeped its way into residents' backyards. One thousand and thirty households were eventually evacuated.

Critical Pollutants

In 1985, eleven of the most persistent and widespread toxic contaminants were identified as critical Great Lakes pollutants by the International Joint Commission (IJC). They are PCBs, 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 (B[a]P). Eight of these critical pollutants are organochlorine compounds and are potentially harmful to life due to their chemical characteristics and their demonstrated toxicity. They are fat soluble and persistent in the environment and many have been used as pesticides or industrial chemicals. They are also found in industrial wastes, the combustion of wastes or fuels and as impurities in pesticides.

All of these eleven chemicals are widely distributed, tend to bioaccumulate in organisms, biomagnify in food webs, and despite some regulatory controls, persist at levels that exceed guidelines in some areas of the ecosystem. In 1985, nearly 1,000 compounds were identified in a chemical inventory conducted for the IJC. Three hundred and sixty-two chemicals were verified to have been measured at least once in the basin. Toxicity profiles have now been prepared for approximately 200 of these. Profiles are developed through a review of scientific literature covering acute, subchronic and chronic toxicity, carcinogenicity, mutagenicity and reproductive effects. Reproductive effects include teratogenicity (developmental toxicity), immuno- and neurotoxicity and behavioural effects.

Appendix I contains more information on each of the 11 critical pollutants.

Many of the chemicals found in the Great Lakes are classified as volatile organic compounds and tend to evaporate from lake water. These chemicals degrade fairly rapidly (non-persistent); however, they are widespread and some are highly toxic. Although this report focuses on persistent toxic substances, volatile organic chemicals are of concern.

- During the late 1970s, the word dioxin entered the lexicon as the name of the most toxic chemical found in the Great Lakes ecosystem.
- Today, public opinion polls have repeatedly indicated that Canadians are concerned about how exposure to toxic chemicals may be affecting their health. They would like to see strong governmental intervention to address their concerns.

Governments have acted to counter the progressive contamination of the Great Lakes. For example:

- In 1978 the Canada-U.S. Great Lakes Water Quality Agreement (GLWQA) was revised to address contamination by persistent toxic substances. The philosophy adopted for control of input of these chemicals to the Great Lakes was zero discharge.
- In 1976 federal legislation to control chemicals which pose a significant danger to human health and the environment came into force (Environmental Contaminants Act).
- In 1980, the use of PCBs in Canada was restricted to the existing electrical and mechanical equipment. The import or manufacture of any PCB-filled equipment was prohibited.
- In 1987 the GLWQA was amended. The governments of Canada and the United States, together with the province of Ontario and the eight Great Lakes states, committed to the cleanup of 42 severely polluted sites in the Great Lakes basin. (These Areas of Concern are shown in Figure 1.)
- In 1987 a declaration of intent was signed by the two countries to reduce the discharge of specific toxic chemicals in the Niagara River by at least 50% by 1996.
- In 1988 the Canadian Environmental Protection Act (CEPA) was proclaimed. It provides a framework to establish and apply controls to toxic substances throughout their life cycle.
- New regulations under CEPA to control dioxins and furans in pulp and paper mill discharge will require modifications to the chlorine bleaching process (used in ten Great Lakes mills). This reform will lead to the virtual elimination of dioxins and furans in the effluent by 1996.
- In 1990 Canada and the United States agreed to develop a Pollution Prevention Strategy for the Great Lakes. An agenda for action by all sectors of society to meet the goal of virtual elimination will be drawn up.

The Behaviour of Toxic Chemicals in the Ecosystem

The pathways and fate of toxic chemicals in lakes are governed by physical, chemical and biological laws. A molecule of a chemical present in the water can enter into chemical reactions that change its structure and increase or decrease its toxicity. It may be taken up by biota, be deposited in the sediments at the bottom of the lake, or be vaporized into the atmosphere. Industrial solvents found in the water tend to evaporate and may degrade in the atmosphere or be re-precipitated. There is evidence that chlorinated organic chemicals deposited in the past are "evaporating" from the lakes. This mechanism contributes to the detoxification of the lakes but also enables these chemicals to be redistributed globally. In the shipping channels and in the shallow lakes and bays such as Lakes Erie and St. Clair, Saginaw Bay and the Bay of Quinte, sediments can be disturbed and the resuspended materials, including toxic chemicals, may enter biological systems. A proportion of the toxic chemicals in the water and sediments, whether they are dissolved or insoluble, will inevitably enter the aquatic food web.

A substance is bioaccumulated when it is concentrated in an organism faster than it is being excreted. Predatory organisms effectively biomagnify the concentration in their own bodies by eating large numbers of contaminated prey. For example, fish-eating aquatic birds, such as herring gulls, are found to have higher concentrations in their bodies than the fish they eat.

Removal of toxic chemicals also takes place in lakes by chemical and biological processes. Living systems in the lakes rely on the primary productivity of plankton. Under enriched nutrient conditions, more plankton are produced and toxic substances which move into the food web will remain in the lower trophic levels or be buried by sedimentation. The excess plankton in effect divert chemicals from the higher trophic levels. This can be seen in Lake Erie where fish and birds have markedly lower tissue burdens of some persistent toxic chemicals.

Nature of the Problem

Environmentally persistent toxic substances enter the lakes via direct industrial discharge pipes, effluent flow from municipal sewage treatment plants and storm sewers. These are often referred to as point sources and are subject to varying degrees of government regulation. The level of treatment applied depends on the industrial sector, the city and the regulations in effect. The amounts can be enormous. For example, the city of Detroit discharges about 3.2 billion litres of wastewater (700 million gallons) every day into the Detroit River and about 73 kilograms of PCBs annually.

Toxic chemicals enter the Great Lakes by a number of other pathways, of which air deposition is one example. Chemicals present in the Great Lakes basin may have been transported through the atmosphere from thousands of miles away. Consequently, they are difficult to regulate in target areas. The large surface areas of Lakes Superior, Huron and Michigan mean that they each receive a large percentage of their contaminant load from the atmosphere (see Table 2).

Another important pathway is the run-off of organochlorine pesticides from farm land into streams and subsequently into the lakes. Contamination of this type is often referred to as non-point source pollution. In the 1960s and 1970s restrictions were placed on the use of the pesticides DDT, hexachlorobenzene and dieldrin.

A fourth source is the chemical waste stored in large quantities by industries and by municipalities in waste and landfill sites. Over time these underground storage facilities have seeped unknown quantities of hazardous chemicals into the water table. Leachate from sites along the Niagara frontier continues to migrate through the groundwater and into the Niagara River. An estimated 315 kilograms per day of toxic chemicals currently enter the river from the largest U.S. hazardous waste sites that are within three miles of the river.

With current analytical techniques, scientists are able to detect the concentration of some chemicals in water at the parts per quadrillion level. (By comparison, sensitive noses can detect the odour of fuel oil at one part per billion. A part per billion is a billion times greater than a part per quadrillion.) The International Joint Commission (IJC) has developed a working list of 362 chemicals considered to be unequivocally present in water of the Great Lakes. These measurements indicate that a compound has entered the lake ecosystem but do not reveal the source of the chemical or its eventual fate. By analyzing sediment cores taken from the lake bottoms, scientists have been able to reconstruct events. Serious chemical contamination of the Great Lakes began after World War II and continued to increase until the 1970s. The continued presence of persistent toxic chemicals in the ecosystem is confirmed by concentrations measured in lake bottom sediments and the tissue burdens of fish, birds and humans. (See box, page 5.)

TABLE 2
Chemical Loads[1] to the Great Lakes and Percentage Attributable to Atmospheric Deposition

	LAKE BASIN									
	Superior		Michigan		Huron		Erie		Ontario	
	kg/yr	%	kg/yr	%	kg/yr	%	kg/yr	%	kg/yr	%
PCBs	606	90	685	58	636	63	2520	7	2540	6
DDT	92	97	65	98	92	97	319	22	111	32
Benzo(a)pyrene	72	96	208	86	290	80	122	79	155	72
Lead	241	97	543	99	430	94	567	39	426	50

1. Data to carry out mass balance were sufficient only for these four chemicals and mirex; even for these there is a great deal of uncertainty.

Note: The upper lakes, Superior, Michigan and Huron, receive a significant fraction of their PCBs, DDT and lead directly from the atmosphere. Compared to the lower lakes, they have larger surface areas and fewer local contaminant sources. In absolute terms, total PCB inputs to the lower lakes are four times higher than to the upper lakes due to local sources.

Source: *Mass Balancing of Toxic Chemicals in the Great Lakes*, International Joint Commission 1988.

Hydrological Features

The five Great Lakes are linked by four connecting channels and are drained by the St. Lawrence River. The lakes and channels possess unique attributes that influence the behaviour of toxic chemicals that enter their waters. Table 3 shows that the water retention time varies considerably between lakes. A molecule of water entering Lake Superior in 1960 could remain there well into the 22nd century. On the other hand, water is flushed out of Lakes Erie and Ontario very rapidly through the Niagara and St. Lawrence rivers. The connecting channels move water and sediments rapidly downstream; the wastes from the high concentration of industry along the St. Clair, Detroit and Niagara rivers are loaded into the lower lakes.

TABLE 3
Hydrological Features of the Great Lakes and Connecting Channels

	Superior	Michigan	Huron	Erie	Ontario
Maximum Depth (m)	405	281	229	64	244
Lake Surface Area (km^2)	82,100	57,800	59,600	25,700	18,960
Land Drainage Area (km^2)	127,700	118,000	134,100	78,000	64,030
Total (km^2)	209,800	175,800	193,700	103,700	82,990
Volume (km^3)	12,230	4,920	3,540	480	1,640
Residence Time[1] (years)	191	99	22	2.6	6

	St. Marys River	St. Clair River	Lake St. Clair	Detroit River	Niagara River	St. Lawrence River
Length (kilometres)	101-121	64	1115 km^2 (area)	51	59	240
Average Flow (m^3/sec.)	2,200	5,200	—	5,300	5,800	7,200
Flushing Time[2]	2 days	21 hrs.	2-9 days	21 hrs.	n/c	n/c
Time of Travel of Surface Water (hours)	<24	6	—	5	16	240

n/c = not calculated

1. The residence time of water in a lake is the time that it would take to replace all of the water if it were all flushed through the outlet.
2. Flushing time of water in a river is the time taken to replace all of the water.

Note: The residence time of any particular toxic chemical in a lake is shorter than for water due to factors such as burial in bottom sediments, evaporation and whether the chemical is biodegradable.

Source: Environment Canada.

2

Contaminants in Water and Sediments

Water

In recent years, sensitive analytical techniques have been developed to measure very low concentrations of contaminants. Until 1980 there were few reliable data on concentrations of toxic metals and organic chemicals in Great Lakes water. Improvements now permit the reliable detection of metals, pesticides and industrial organic chemicals in parts per trillion and in some cases parts per quadrillion.

Synthetic chemicals in the open waters of the Great Lakes occur in the parts per trillion range or lower. The open water is generally less polluted than the nearshore water. In the nearshore areas, harbours, stream mouths, embayments and the connecting channels, water quality guidelines for specific chemicals are often exceeded. The guidelines themselves are set in the parts per billion range or lower (Table 4).

Based on an overall appraisal of toxic chemical concentration in water, suspended sediments and bottom sediments, Lakes Ontario, Michigan and Erie have the highest concentrations of toxic and persistent chemicals. Lakes Superior and Huron are the least contaminated, with the exception of some local areas. Concentrations of chemicals in the open waters of the lakes are below Great Lakes Water Quality Agreement specific objectives.

To detect the presence of toxic organic chemicals, large volumes of water are collected; however, this procedure is costly and time consuming. Recent programs have focused attention on detecting chemicals in the 42 Areas of Concern including the international connecting channels (the Niagara, Detroit, St. Clair and St. Marys rivers) where there are known sources of priority chemicals.

Earlier measurements of toxic metals (lead, mercury, cadmium and arsenic) in water were likely distorted by the presence of these ubiquitous metals as dust in sampling equipment and in the laboratory. True water concentrations in the 1960s and 1970s were likely far lower than previously thought. Special laboratory procedures have since corrected this problem. Scientists have difficulty in comparing historic with recent data; statements about long-term trends for metal concentrations in water, therefore, are questionable. Present concentrations of metals dissolved in water are in the parts per trillion range.

The detection and measurement of extremely low concentrations of toxic chemicals in the water may help scientists to relate the presence of a contaminant in samples of water to the higher levels found in plankton, fish and wildlife. Unfortunately, there is probably no simple relationship between the concentration of a chemical in water or the sediments and that found in aquatic organisms. Environment Canada and other agencies measure chemicals in water to assess whether water quality guidelines are being met. For diagnostic purposes these ambient water quality measurements are imprecise. The concentrations in the connecting channels and nearshore can vary considerably with the rapid movement of water, seasonal variations, and resuspension of sediments following storms. These variations in natural conditions make it difficult to establish time trends for water concentrations with any certainty. Biological communities which act as long-term integrators of these fluxes provide data showing that contaminant levels in Great Lakes fish and birds have decreased. Over the past 15 years, industrial and agricultural loadings have been regulated to some extent, thus it is reasonable to assume that concentrations in water have also decreased.

Sediments

Sediments in lakes and rivers are composed of inorganic (mineral) and organic matter. Due to their physico-chemical properties, PCBs and the organochlorine

TABLE 4
Persistent Toxic Substances in the Great Lakes

Substance	Water Quality Objective[1] (parts per billion)
Persistent Organic Chemicals[2]	
Aldrin/dieldrin	0.001
Benzo[a]pyrene	0.01
Chlordane	0.06
DDT (total)	0.003
Endrin	0.002
Heptachlor (total)	0.001
Lindane	0.01
Methoxychlor	0.04
Mirex	0.005[4]
PCP (pentachlorophenol)	0.4
DEHP (Di-2-ethylhexylphthalate)	0.6
PCBs (polychlorinated biphenyls)	0.001 (proposed)
Toxaphene	0.008
2,3,7,8-TCDD (a dioxin congener)	0.00001 (detection limit)
Metals	
Arsenic	50
Cadmium	0.2
Chromium	50
Copper	5
Lead[3]	10.0 – 25.0
Mercury	0.2
Selenium	10
Zinc	30

1. As stated in the 1978 Great Lakes Quality Agreement or subsequently proposed. Levels are set to protect the most sensitive user (not always humans).
2. For persistent, toxic organic contaminants for which objectives have not been defined, the concentrations of such compounds in water or aquatic organisms should be less than detection levels as determined by the best scientific methodology available. No guidelines have been established for OCS (octachlorostyrene), HCB (hexachlorobenzene), BHC (benzene hexachloride), TCDF (tetrachlorodibenzofuran) and HCBD (hexachlorobutadiene).
3. Concentration depends on the lake. Lower objectives were set for Lakes Superior and Huron.
4. Objective for mirex is "substantially absent" or below the level of detection as determined by the best methodology (presently 0.005 ppb).

Note: Objectives for fish are discussed in chapter 3.

pesticides and metals adsorb to the suspended particulate sediment phase in water. The suspended sediments are also partially composed of plankton which can bioaccumulate metals and toxic organic chemicals. As a result, suspended sediment concentrations of PCBs can be 1000 times higher than in water. Eventually, suspended sediments are either propelled downstream or are deposited on the lake bottom in depositional or sedimentary basins. For example, the surficial layers of the sediments of Lake St. Clair have elevated mercury concentrations as a result of loading from the St. Clair River.

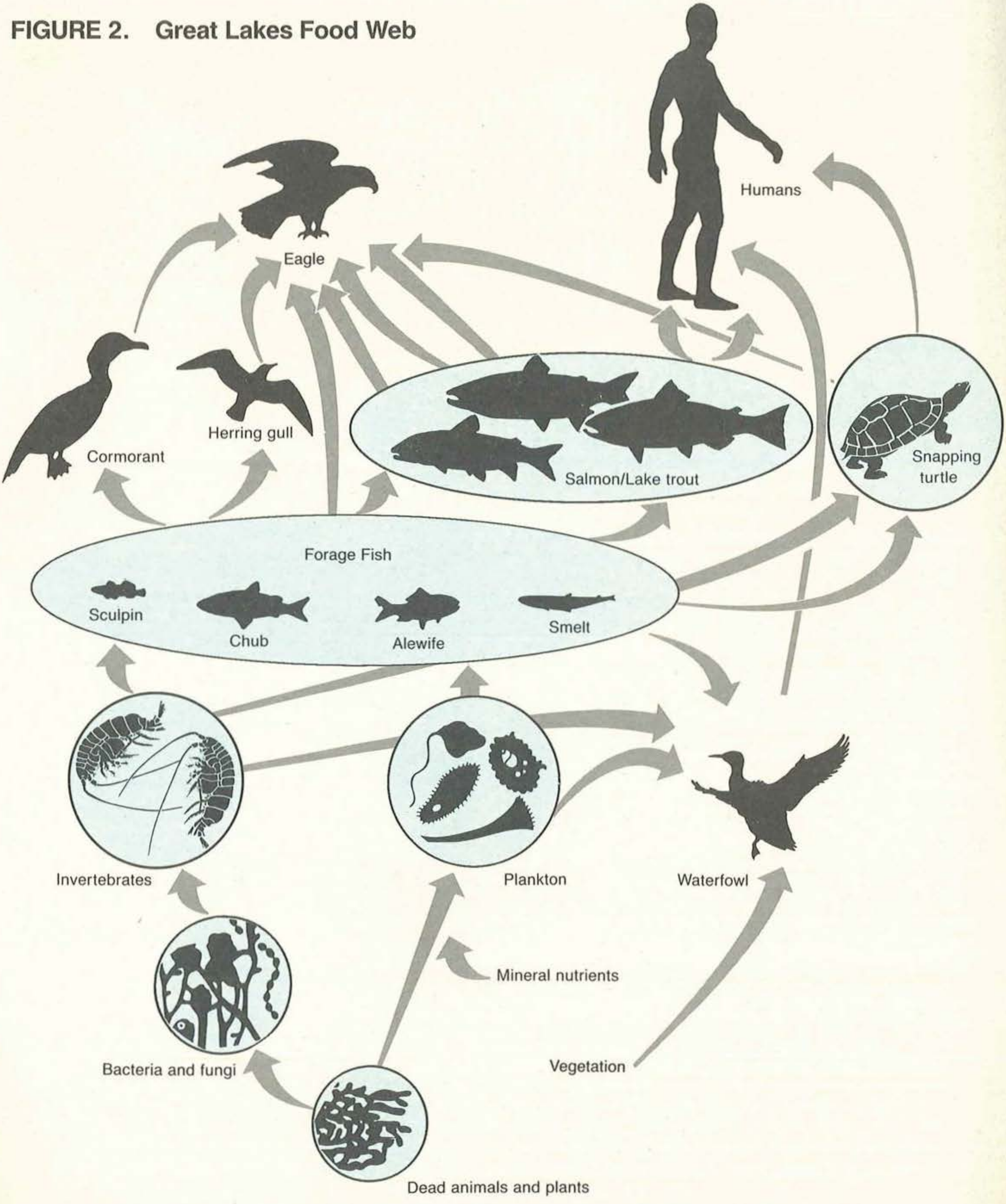
The collection of sediment cores from the bottom of the lakes is a useful method of determining historical trends of chemical inputs to the lakes. Sections of these cores are analyzed in relation to depth, and this gives a profile of deposition over time. Through radioactive dating of the sediment core material, scientists can record pre-industrial levels of a synthetic chemical (zero) or a metal, track its increases and decreases over the past 40 years and determine the changes resulting from regulations or discontinued use.

The historical trends for most contaminants indicate that the loadings of nearly all persistent toxic chemicals peaked in the 1960s and 1970s. These peak inputs were followed by decreases reflecting control actions for organochlorine pesticides, PCBs, lead and mercury. Even so, in the Niagara, Detroit and St. Clair rivers, levels of mercury in bottom sediments remain above guideline levels for the disposal of dredged material.

Sediment cores taken from Lakes Huron and Erie show that dioxins and furans continue to be deposited to the sediments at the same rate as in the 1960s, although there has been a slight decline in Lake Erie since the mid-1970s. Continued atmospheric inputs of these combustion by-products are likely the reason. Lead in sediment cores in Lakes Superior and Michigan are at 1970 levels or slightly below. As controls on automobile emissions become more stringent and gasoline containing lead is phased out in Canada (1991), the rate of lead deposition should begin to decline again.

The pesticide mirex was manufactured in a plant situated on the Niagara River from the 1950s until 1976, and the record of the sediment cores taken from the delta area of the river in 1980 tracks this industrial activity. But in 1981, analysis of sedimentary basins on the south shore of Lake Ontario showed that deposition of this chemical was still occurring. Remobilization of contaminated Niagara River sediments is suspected. Sediment core records of the deposition of PCBs in the Niagara River delta show that the highest concentrations correspond to the early 1960s. Levels have now plateaued at levels equivalent to those for the 1950s. As with mirex, PCBs have been flushed into Lake Ontario from the Niagara River. Mapping of Lake Ontario bottom sediments show a PCB plume extending out from the mouth of the Niagara River.

FIGURE 2. Great Lakes Food Web



NOTE: This is a simplified representation of the food web showing the main pathways. Food (energy) moves in the direction of the arrows. The driving force is sunlight. Depictions of the various organisms are not to scale.

3

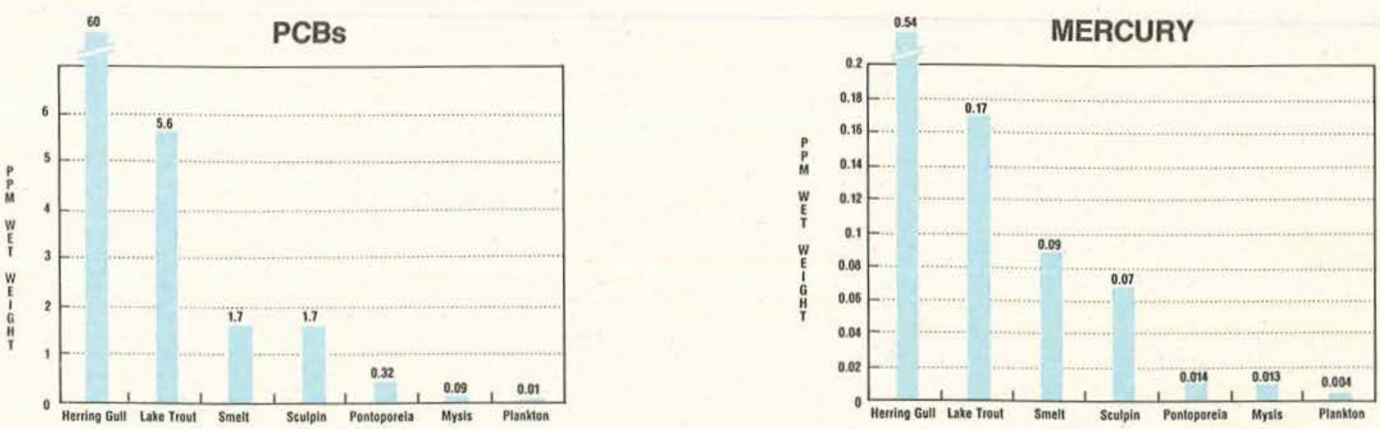
Toxic Contaminants: Levels and Effects in the Great Lakes Food Web

All species have evolved the ability to selectively absorb essential chemical elements and natural compounds from their environment. The physical and chemical properties of heavy metals and many synthetic chemicals allow them to gain entry into organisms, resist being metabolized or excreted, and thus bioaccumulate. If the organism continues to be exposed to chemicals in its environment that it cannot adequately excrete or detoxify, concentrations can increase to toxic levels. Some of the critical pollutants can cause carcinogenic, reproductive and developmental effects even at relatively low concentrations. In the Great Lakes, the levels of contaminants found in fish and wildlife species depend on a variety of factors including habitat, body size, selection of prey, energy requirements, position in the food web, ability to metabolize contaminants and, in the case of organochlorine chemicals, fat levels in tissues.

The biomagnification of chemicals such as PCBs, dioxins and organochlorine pesticides from the lowest trophic levels (phytoplankton) through to top predators (fish-eating birds and humans) has been observed in the Great Lakes food web (Figure 2). Since organochlorines are much more soluble in fat than in water, they are absorbed from the water by phytoplankton (microscopic plants and algae) into their fats. These small organisms are eaten by larger ones, passing the contaminants up the food web to fish and eventually to the aquatic birds and mammals. Since many smaller organisms are eaten by a single predator, the total amount of contaminant ingested is higher than in its prey. Taken together with the fact that aquatic animals excrete organochlorine chemicals very slowly (or not at all), these contaminants build up to higher concentrations at each step in the food web (Figure 3).

In another pathway, contaminants are absorbed from the sediments by bottom-dwelling animals such as tubificid worms, insect larvae, molluscs or crayfish and accumulate in ducks, turtles and bottom-feeding fish such as white suckers, brown bullheads and carp.

FIGURE 3. Biomagnification of PCBs and Mercury in the Lake Ontario Food Web, 1982



Source: Environment Canada and Department of Fisheries and Oceans

Note: The pathway from plankton through to herring gull was selected from the food web.
The year 1982 was used since this was the most recent year when plankton, *Mysis* and *Pontoporeia* data were available. The concentration of PCBs in the open waters of Lake Ontario was measured at 5 ppt in 1986; thus, there is a bioconcentration factor of 10 million from water to herring gull eggs.

In addition, fish also absorb toxic chemicals directly from the large amount of water flowing across their gills as part of their normal respiration.

Ascending the food web, the factors of biomagnification become quite large. For example, PCBs in Great Lakes water are present in concentrations in the low parts per trillion range; PCBs in the eggs of eagles at the top of the Lake Erie food web have been measured at greater than 25 parts per million as recently as 1988. This corresponds to a biomagnification factor of 25 million. Biomagnification factors for mercury and PAHs are less spectacular (usually 1000).

Contaminant Residues

Regulatory actions implemented by governments in the 1970s to restrict the use of organochlorine pesticides and PCBs have led to substantial decreases in contaminant concentrations in Great Lakes fish and wildlife. Data sets for PCBs, DDT, mirex and hexachlorobenzene in lake trout and herring gulls illustrate this trend. Contaminant levels in fish and fish-eating birds have now reached a plateau. This is because some of the chemicals are extremely persistent and some inputs have yet to be controlled.

Fish

Concentration levels of contaminants in fish are influenced by position in the food web, portion of the fish analyzed and the age and fat content of the individual. In order to standardize these factors, and thus be able to make comparisons between lakes and discern time trends, top predator species are collected, chemical analyses are made using whole fish and data

Biomonitoring

Birds

By the early 1960s, it was evident that the bald eagle and other birds were suffering reproductive problems linked to exposure to the pesticide DDT and other industrial chemicals. In the late 1960s field biologists began observing declines in the populations of fish-eating birds in the Great Lakes basin. Scientists studying populations of these species from Lakes Ontario and Michigan found that they were among the most contaminated in the world. In 1974 the Canadian Wildlife Service established a monitoring program to measure organochlorine contaminant residues in herring gull eggs at 13 colonies throughout the Great Lakes basin on an annual basis.

Fish-eating birds and predatory fish are at the top of the Great Lakes food web and measurements of their tissue burdens serve as indicators of ecosystem contamination. The herring gull was chosen as a Great Lakes biomonitor in 1974 since gull populations were not as severely affected as cormorants and terns, and gulls continued to lay eggs. Herring gulls are found throughout the basin, they remain year-round and their diet is mainly fish. Bird eggs were chosen as monitors because this is the least disruptive way of measuring levels in the food web. Females will replace eggs lost early in the season and no adults need to be killed in order to measure pollution levels. Within each lake, herring gulls remain in the vicinity of their colony for much of the year and thus function as an integrator of contaminants on a regional basis.

Fish

There are four programs involving Canadian agencies which monitor fish contaminant levels in the Great Lakes.

(1) The Open Lake Fish Contaminant Program is conducted jointly by the Department of Fisheries and Oceans and the U.S. Environmental Protection Agency and the U.S. Fish and Wildlife Service. Since 1977, the program annually measures concentrations of persistent toxic chemicals in top predator fish (lake trout and walleye) and forage fish (rainbow smelt and bloater chub). Since contaminants accumulated by fish concentrate in all tissues, the program analyzes whole fish.

(2) The Ontario Ministry of the Environment (MOE) collects young-of-the-year spottail shiners from the connecting channels and tributary mouth locations on the Great Lakes. As shiners (a minnow) are non-migratory, and only young-of-the-year are selected, this reflects local contaminant levels and indicates recent loadings.

(3) Sport fish are collected by the Ontario MOE and the Ministry of Natural Resources (MNR) and the lean, dorsal muscle tissue is analyzed. The *Guide to Eating Ontario Sport Fish* gives results on an annual basis.

(4) The Department of Fisheries and Oceans collects and analyzes fish fillets prepared for sale by commercial fishermen in the Great Lakes.

Other Species

Net plankton, *Mysis* (a large zooplankton) and *Pontoporeia* (bottom dwellers) were selected as biomonitors under the Great Lakes Water Quality Agreement. These organisms were selected to quantify pollution gradients as they bioaccumulate residues and to predict food chain biomagnification since they compose major diet items of fish.

are reported for specific age classes. The lake trout serves as the top predator species for Lakes Ontario, Huron, Michigan and Superior, and the walleye is used for Lake Erie.

Lake-wide Trends

Fish from Lakes Ontario and Michigan generally have higher contaminant burdens than those from the other lakes based on the most recent data sets (1988) for organochlorine pesticides, PCBs and dioxin. Among the Canadian Great Lakes, lake trout from Lake Ontario have the highest levels of PCBs, DDT, mirex, dieldrin and dioxins, while lake trout from Lake Superior have the highest toxaphene levels. Lake St. Clair walleye have the highest mercury levels. Annual data show that since the late 1970s, the largest declines have occurred in Lakes Ontario and Michigan, while the most consistent decrease across the range of chemicals has occurred in fish from Lake Erie. This lake has the shortest residence time of the five large lakes and it is thought that contaminants adsorbed to particles are effectively flushed from the lake and down the Niagara River. It also has the most biomass and thus the amount of contaminant in an individual is proportionately less.

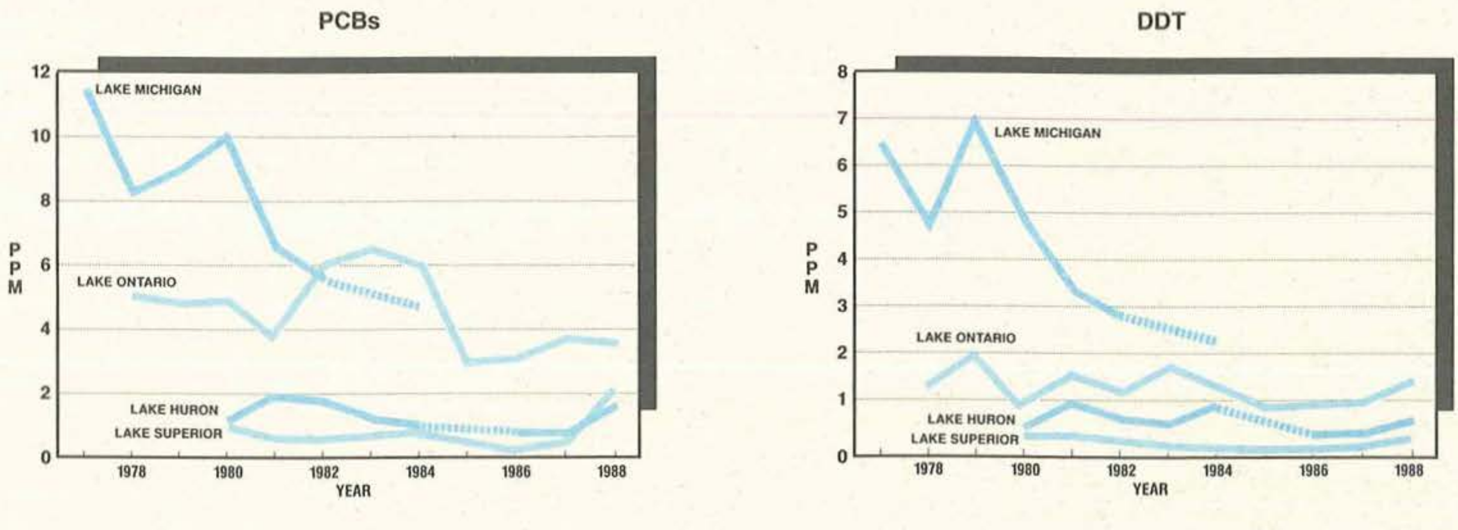
Since the 1970s, levels of PCBs and DDT in lake trout have shown a declining trend followed by a levelling off in Lakes Ontario and Michigan with the most dramatic drop occurring in Lake Michigan (Figure 4). There do not appear to be consistent trends for these compounds in lake trout from Lakes Superior and Huron. Atmospheric deposition to these two lakes is likely responsible.

Great Lakes Water Quality Agreement Specific Objectives

Under the Canada-U.S. Great Lakes Water Quality Agreement (GLWQA), specific objectives have been set for a number of persistent toxic substances in water and whole fish to protect the health of humans and fish-eating birds and to maintain the integrity of the ecosystem. There are objectives for all organochlorines discussed in this report except dioxins, furans, hexachlorobenzene and octachlorostyrene.

The most recent data for lake trout indicate that concentrations of PCBs in whole fish remain above the GLWQA objective of 0.1 ppm in all of the Great Lakes and connecting channels including the St. Lawrence River. DDT/DDE levels in lake trout are below the objective of 1 ppm in all lakes except Ontario and Michigan. The GLWQA objective for mirex is "substantially absent" in water or fish but it continues to be detected in spottail shiners, lake trout and rainbow smelt from Lake Ontario. Mirex residues were also detected in spottail shiners collected in the early 1980s from the Niagara and St. Lawrence rivers. Mercury concentrations in Lake St. Clair walleye have recently dropped below the objective of 0.5 ppm; how-

FIGURE 4. Concentrations of Contaminants in Lake Trout from the Great Lakes, 1977–1988



Note: These are the average annual concentrations in parts per million wet weight of total PCBs and DDT in whole lake trout. Fish from the Canadian lakes are 4 years of age; fish from Lake Michigan are between 620 and 640 mm in length.
The pesticide DDT is metabolized by biological systems to several other compounds. Total DDT refers to the complex of DDT and its metabolites.

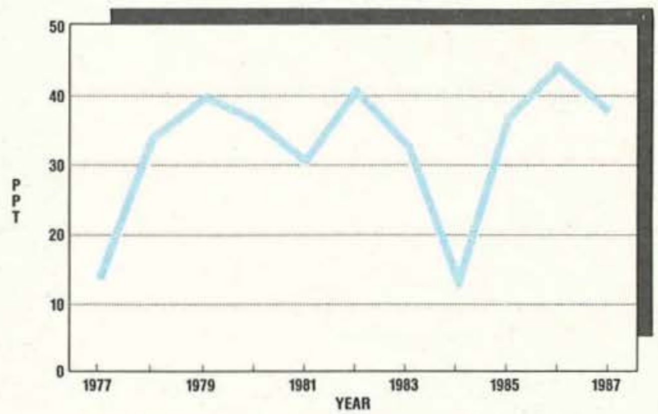
Source: Department of Fisheries and Oceans and the U.S. Environmental Protection Agency.

Lake Ontario Case Study

Lake Ontario is situated "downstream" from the other Great Lakes and the connecting channels. It is subject to several chronic sources of contamination. As a result, there has been little recent change in the residue levels (PCBs, DDE, dioxin, dieldrin, hexachlorobenzene, mirex) found in lake trout and herring gull eggs. The largest single source of persistent toxic chemicals to the lake is the Niagara River drainage basin where an estimated 1.2 million tons of contaminated material have been stored in the 66 largest waste sites over the past 50 years. These sites are leaching or have the potential to leach toxic chemicals into the fast-flowing river and to be transported downstream to Lake Ontario. The Niagara River is the principal source of dioxin found in Lake Ontario fish. There are no obvious trends of dioxin in lake trout (Figure 5). The high dioxin levels in eggs from Lake Ontario gull colonies (Figure 6) are attributable to a chemical plant on the Niagara River that used to manufacture trichlorophenol for the production of pesticides. Dioxin (2,3,7,8-TCDD) can be formed in the production of this chemical and the wastewater could have entered the Niagara River and subsequently Lake Ontario. Production of the pesticide was discontinued in the mid-1970s and levels recorded in eggs from the Scotch Bonnet Island colony dropped. Residues measured in the 1980s show that levels in Lake Ontario colonies remain substantially higher than in the other lakes. A similar phenomenon has occurred in Saginaw Bay, Lake Huron, where the same chemical was manufactured nearby.

Contaminated bottom sediments are another ongoing source. Although mirex has not been manufactured

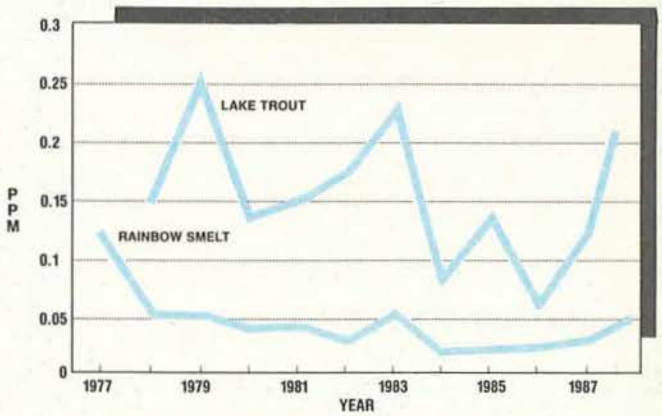
FIGURE 5. Dioxin Concentrations in Lake Trout from Lake Ontario, 1977–1988 (2,3,7,8-TCDD)



Average concentrations of the most toxic dioxin congener (2,3,7,8-TCDD) measured in parts per trillion wet weight in whole lake trout.

Source: Department of Fisheries and Oceans.

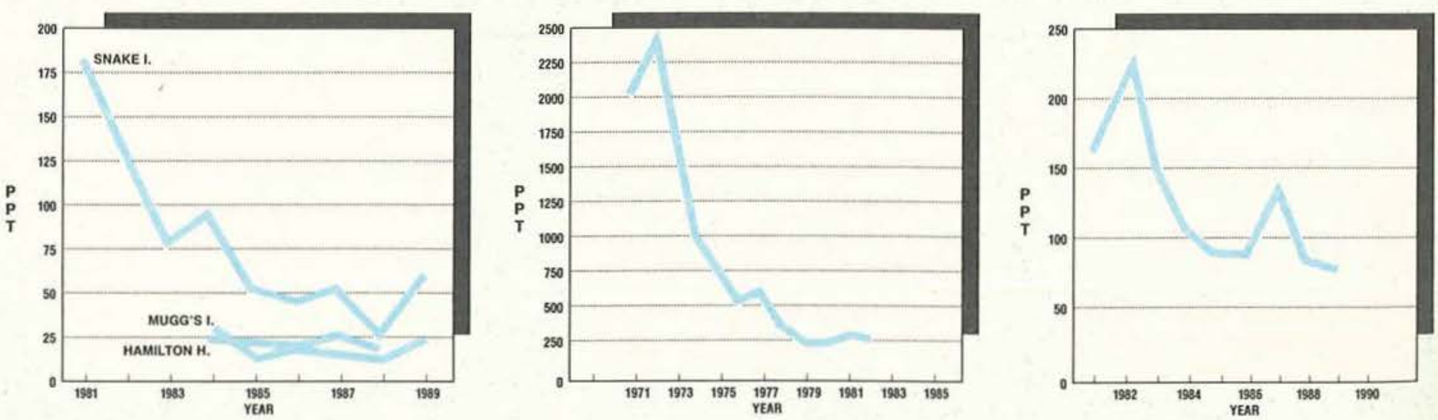
FIGURE 7. Mirex Concentrations in Lake Ontario Fish, 1977–1988



Average concentrations of the insecticide mirex measured in parts per million wet weight in whole fish.

Source: Department of Fisheries and Oceans.

FIGURE 6. Dioxin (2,3,7,8-TCDD) Concentrations in Herring Gull Eggs



HAMILTON H., MUGG'S I., SNAKE I.

SCOTCH BONNET ISLAND

CHANNEL/SHELTER ISLAND (Saginaw Bay)

Measured in parts per trillion wet weight.

Scotch Bonnet and Snake Islands are at the eastern end of Lake Ontario, Mugg's Island is at Toronto.

Source: Canadian Wildlife Service, Environment Canada.

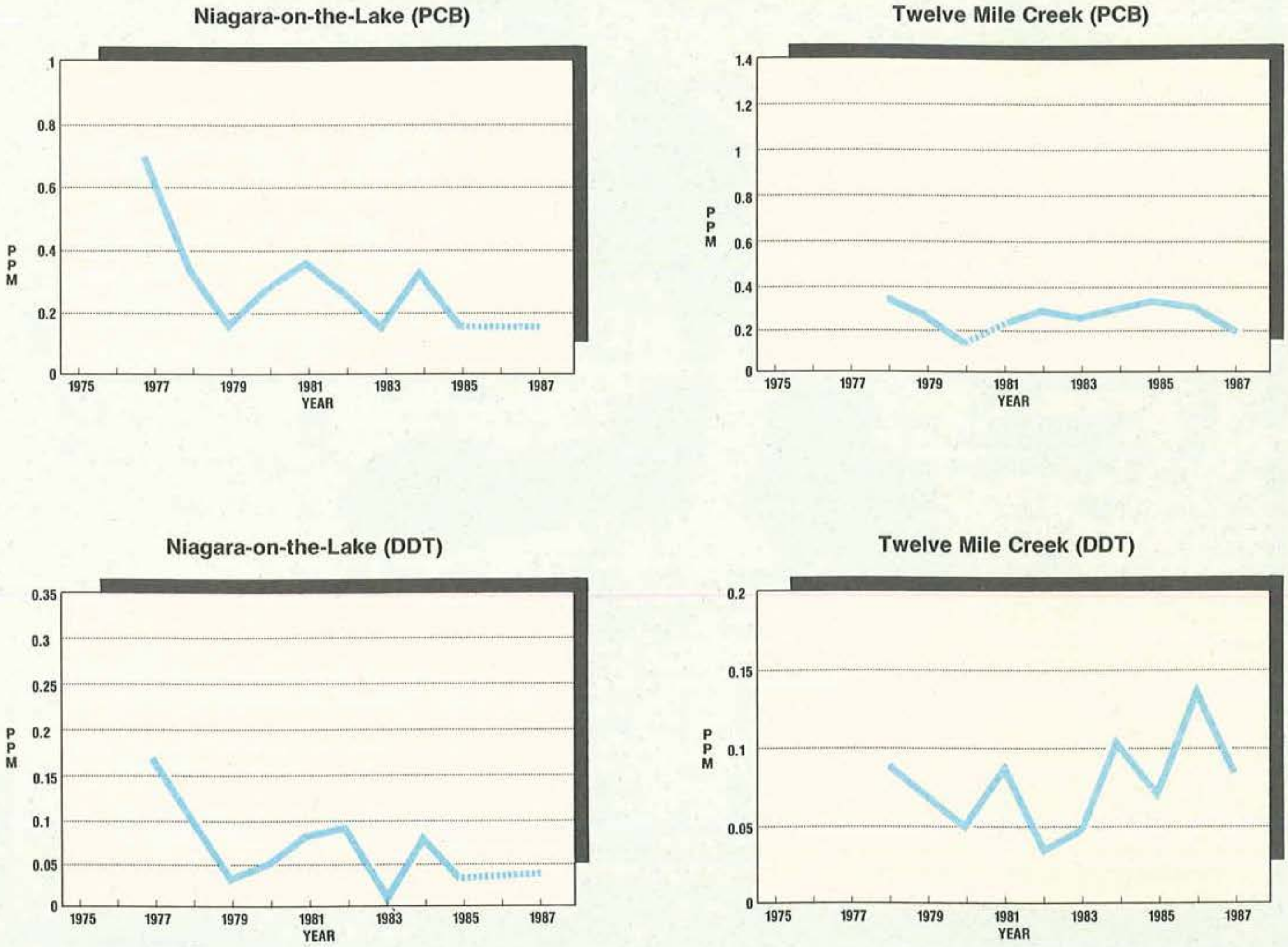
since 1976, it is still entering the food web through the resuspension of sediments. Levels of mirex in Lake Ontario fish, although lower today than during the late 1970s, are maintained almost entirely by the sediment pathway (Figure 7). Lake Ontario herring gull eggs also have the highest mirex levels compared to the other lakes by a factor of 10. Sediment resuspension also maintains the levels of other organochlorine pesticides in the Lake Ontario food web, even though their manufacture and use were restricted or banned in the 1970s.

Atmospheric deposition contributes to the contaminant burdens of fish. For example, pesticides applied to crops by aerial spraying can remain airborne for a number of days. Toxaphene, an organochlorine pesticide which was used very little in Canada after 1970 and was last used in Ontario in 1980, is still present in lake trout. This is because it is atmospherically transported from the southern United States, where it was applied in large amounts to cotton crops. Although data for this chemical are limited, levels have decreased since the U.S. manufacture of this chemical was banned in 1982.

It is suspected that chemicals previously applied to crops may still be present in agricultural soils. Volatilization from soils is another pathway through which chemicals can be mobilized in the ecosystem.

Finally, present day urban, rural and industrial effluents contribute PCBs, organochlorine pesticides and toxic metals to the lake. Measurements in young-of-the-year spottail shiners provide an indication of the distribution of these sources on the Canadian side of the lake. A number of examples are given in Figure 8.

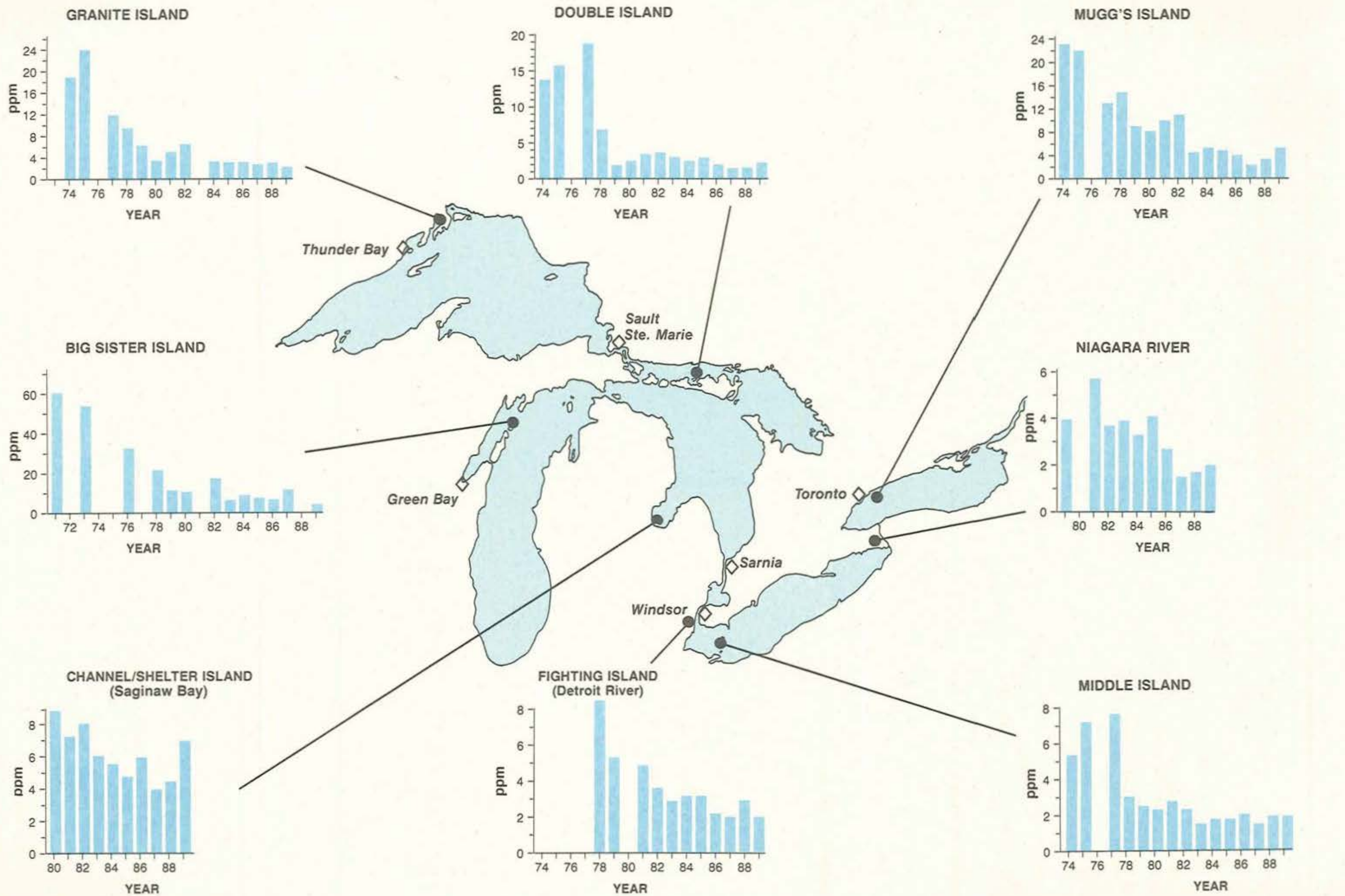
FIGURE 8. PCB and DDT Residues in Spottail Shiners Collected from Locations on Lake Ontario, 1975–1987



Average PCB and DDT residues measured in parts per million wet weight in Lake Ontario young-of-the-year spottail shiners collected at Niagara-on-the-Lake and Twelve Mile Creek.

Source: Ontario Ministry of the Environment.

FIGURE 9. Trends in DDE Concentrations in Great Lakes Herring Gull Eggs



Source: Canadian Wildlife Service, Environment Canada.

Note: The scale for each bar chart is different.

ever, levels in St. Lawrence River walleye collected from Lake St. Francis remain above the objective.

On a lake-wide basis, concentrations of persistent toxic substances in lake trout from Lakes Erie, Huron and Superior meet GLWQA objectives (for all compounds for which there are objectives) except PCBs.

Wildlife

A number of species of birds, including the bald eagle, osprey and most colonial nesting birds, aquatic mammals and turtles in the Great Lakes ecosystem rely on fish as their primary source of food. Through the process of bioaccumulation and biomagnification, these long-lived top predators have the highest levels of organochlorine chemicals in their tissues.

Herring Gull

The herring gull was selected as the principal wildlife indicator species for levels of contaminants in the Great Lakes ecosystem.

Since 1974 herring gull eggs have been collected from colonies and analyzed for residues of organochlorine compounds every year. It is likely that the highest levels of organochlorine contamination occurred in Great Lakes aquatic birds before this program began. With the exception of the pesticide dieldrin, organochlorine residues in herring gull eggs decreased from 1974 to the early 1980s. Since then, levels have remained essentially constant. These trends are in parallel with the lake trout. This is not surprising since they both eat smelt and alewife. Figure 9 shows this phenomenon for DDE at eight herring gull colonies on the Great Lakes.

TABLE 5
Organochlorine Contaminant Concentrations in Herring Gull Eggs[1] from Colonies on the Great Lakes, 1989

	CONTAMINANT[2]						
	PCB congeners[3]	DDE	MIREX	HCB	DIELDRIN	DIOXIN	%LIPID[4]
Lake Ontario							
Snake I.	14	5.2	1.1	0.07	0.14	91	8.6
Mugg's I.	16	5.3	1.2	0.06	0.12	55	8.6
Niagara River							
Island Above Falls	9	2.1	0.24	0.04	0.13	18	8.4
Lake Erie							
Port Colborne	17	3.1	0.33	0.05	0.23	19	10
Middle I.	21	2.3	0.03	0.05	0.11	16	8.8
Detroit River							
Fighting I.	27	2.2	0.04	0.05	0.06	13	7.5
Lake Huron							
Chantry I.	3.1	0.77	0.05	0.03	0.15	12	8.7
Double I.	7.1	2.4	0.14	0.04	0.25	18	8.8
Channel/Shelter I.	28	7.0	0.09	0.08	0.15	78	8.2
Lake Superior							
Granite I.	7.2	2.4	0.05	0.06	0.34	16	7.6
Agawa Rock	6.8	2.6	0.09	0.04	0.33	19	7.5
Lake Michigan							
Big Sister I.	9.9	4.7	0.03	0.04	0.58	10	8.7
Gull I.	9.4	5.0	0.04	0.05	0.53	11	8.8

1. Data are mean values based on individual analyses of a 10-egg pool for each colony.
2. All values are in parts per million except dioxin (2,3,7,8-TCDD) which is in parts per trillion.
3. PCB mixtures are made up of as many as 209 congeners. PCB congeners refers to the total of 41 different individual PCB congeners analyzed separately. This gives a more accurate measurement and can be used by researchers to note the presence of the most toxic congeners.
4. The percentage lipid content of each egg is used as a way to standardize concentrations of these lipophilic contaminants.

Source: Canadian Wildlife Service, Environment Canada.

Eggs from other species of birds have not been collected as systematically as the herring gull. Limited data for the double-crested cormorant, black-crowned night-heron and caspian tern also suggest a general decrease in organochlorine residue levels in eggs collected between 1971 and 1989.

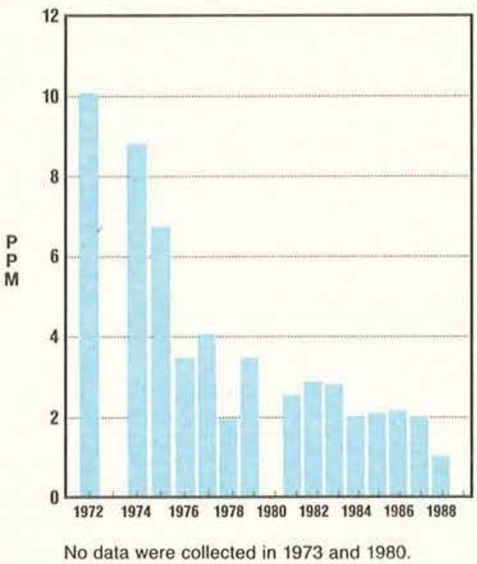
Table 5 shows contaminant levels from the 13 herring gull colonies in 1989. Data from eggs analyzed reveal that a number of organochlorines are distributed throughout the entire basin. Eggs taken from colonies on Saginaw Bay, Lake Huron, the Detroit River and Lake Erie have the highest levels of PCBs. Eggs from Lake Ontario and Saginaw Bay have the highest dioxin residues. Levels of dioxin (10–20 ppt) in eggs from the other colonies in the basin are maintained by atmospheric deposition. Combustion is the most likely source of these "background levels". The declines in levels of pesticides witnessed during the 1970s are mainly due to the restrictions of their use in Ontario and the American states in the Great Lakes basin. Between 1969 and 1974 uses of DDT, aldrin, dieldrin and hexachlorobenzene were severely restricted. In 1976, mirex releases from production and distribution plants on the Niagara and Oswego rivers respectively ended with the restriction of the commercial use of this chemical. Regulations restricting PCB use and manufacture began in 1977.

Levels of contaminants in herring gull eggs will likely remain constant well into the 1990s. Continued atmospheric deposition from sources often outside the basin, resuspension of sediments, leachate from waste dumps, and the remaining sources of direct discharge of toxic chemicals account for the levelling off of the downward trends witnessed for the organochlorine chemicals in the 1980s.

Fish Consumption Criteria

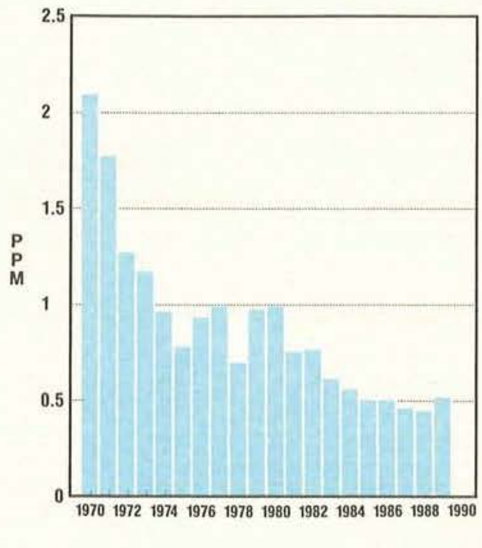
The biomagnification of contaminants through successive levels of the food web can make fish unsuitable for human or wildlife consumption. There is a direct relationship between the lipid (fat) content of a fish species and the concentration of organochlorine contaminants in its tissues. Salmon, trout, carp and catfish have relatively higher levels of organochlorine contaminants than low lipid species such as walleye, northern pike and yellow perch. Older fish also have a longer exposure to contaminants (eight-year-old fish are common in Lake Ontario). In addition, the lipid content of a fish increases with age. Accordingly, organochlorine contaminant concentrations found in a fish are a function of its age and the lipid content of its tissues.

FIGURE 10. Average PCB Concentrations in Lake Ontario Coho Salmon Collected from the Credit River, 1972–1988



No data were collected in 1973 and 1980.

FIGURE 11. Average Mercury Concentrations in Walleye Collected from Lake St. Clair, 1970–1989



Note: Data for Figures 10 and 11 were obtained through the sport fish monitoring program and are useful in assessing overall trends in contaminants. The numerical values are the average contaminant concentration of fish of various ages and should not be used to compare individual years.

Source: Ontario Ministry of the Environment.

Source: Ontario Ministry of the Environment.

Under the Sport Fish Testing Program of the Ontario government, fish have been collected and analyzed since 1976 for toxic contaminants. Laboratory analyses are carried out on lean, skinless dorsal muscle tissue samples. Similar programs are conducted by the eight Great Lakes states, however, the skin is retained in samples used for analyses in some states. The province issues an annual summary of these data in diagrammatical form for anglers in its *Guide to Eating Ontario Sport Fish*. A variety of fish species are selected from a large number of locations on a rotation basis in Ontario. In the 1990 edition, nearly 200 locations in the Great Lakes are listed and advice on the frequency of consumption is given based on the species and its length. The guide makes more stringent recommendations for children and women of childbearing age. As part of the program a few locations are sampled every year. Figures 10 and 11 show PCB and mercury concentrations in fillets of coho salmon from Lake Ontario and walleye from Lake St. Clair over two decades.

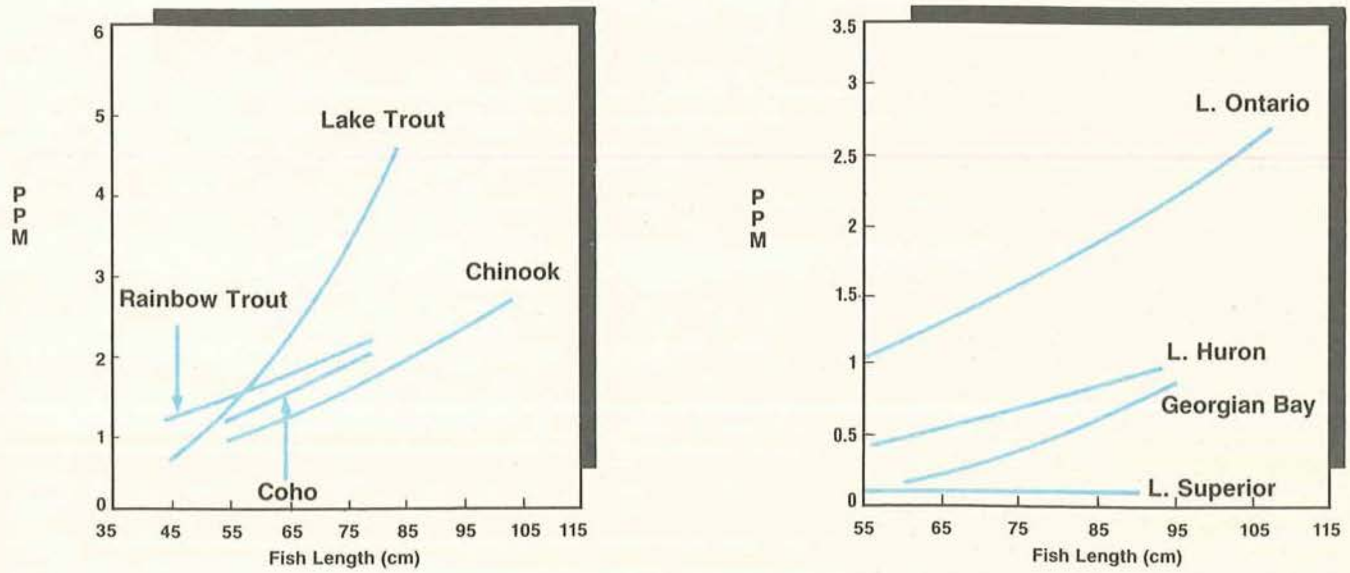
While recent "averaged" concentrations are now slightly below the guidelines set for these persistent toxic substances, older fish are found to have higher concentrations of these contaminants. Figure 12 (a) shows the relationship between fish length and PCB concentrations found in four salmonid species from the Credit River which enters Lake Ontario. The variation in contaminant levels is accounted for by the age of the fish. Lake trout have a slower growth rate than the other species and have been exposed for a longer period of time than other species of fish of the same length. Figure 12 (b) shows that chinook salmon from Lake Ontario have higher concentrations of PCBs than fish of the same length taken from other Great Lakes locations.

In 1985 more than 4 million people fished in the Great Lakes basin. The economic value of the sport fishery is estimated at $4 billion.

FIGURE 12. PCB Concentrations in Great Lakes Sport Fish of Different Lengths

(a) Four Salmonid Species from the Credit River, Lake Ontario

(b) Chinook Salmon from the Great Lakes



Note: These simplified representations are presented to show that concentrations of chemicals in fish vary between species and between locations. As in the previous figure, the numerical values should not be used to make individual comparisons.

Source: Ontario Ministry of the Environment.

Table 6 lists fish consumption criteria developed in the 1960s by the Canadian and U.S. federal health agencies for the protection of consumers of fish. In Canada, the Department of Fisheries and Oceans fish inspection program ensures that contaminant levels in fish species caught commercially in the Great Lakes and processed in registered fish processing facilities do not exceed guidelines set by Health and Welfare Canada.

A fish fillet is used as the basis to calculate a person's ingestion of contaminants. In Canada, fish consumption advisories are developed by determining the Tolerable Daily Intake (TDI) or the quantity of a chemical that could be consumed on a daily basis, for a lifetime, with reasonable assurance that health will not be threatened. The TDI is based on all available animal and human toxicology data and the application of safety factors. The next step is to determine the Probable Daily Intake (PDI) of the chemical contaminant. The PDI is based on a person's exposure to the chemical from all sources. All foods that may contain the substance are identified and those that may contribute more of the contaminant than others (e.g., fish) are carefully evaluated. The PDI values take account of average and high consumption rates; they also consider the potential exposure of more sensitive sub-groups of the population (such as children or the elderly). A fish consumption guideline may be proposed if the Probable Daily Intake of a chemical is greater than the Tolerable Daily Intake.

Safety factors are included when fish consumption guidelines are established because of uncertainties about the relationship between exposures and effects. There are differences among Great Lakes jurisdic-

TABLE 6
Fish Consumption Criteria[1]
(parts per million, wet weight except dioxin, parts per trillion wet weight)

Parameter	Great Lakes Water Quality Agreement Specific Objective[2]	Health & Welfare Canada Regulatory Limit[3]	U.S. FDA Action Level[4]	Ontario Sport Fish Consumption Guideline[5]
Aldrin/Dieldrin	0.3	0.1	0.3	—
DDT (total)	1.0[6]	5.0	5.0	5.0
Dioxin (2,3,7,8-TCDD)	—	20 (ppt)	25[7] (ppt)	20 (ppt)
Endrin	0.3	0.1	0.3	—
Heptachlor/Heptachlor Epoxide	0.3	0.1	0.3	—
Hexachlorobenzene (HCB)	—	0.1	0.3	—
Kepone	—	0.1	0.3	—
Lead	—	—	—	1.0
Lindane	0.3	0.1	0.3	—
Mercury	0.5[6]	0.5	1.0	0.5[8]
Mirex	Substantially absent[6]	0.1	0.1	0.1
PCBs	0.1[6]	2.0	2.0	2.0
Toxaphene	—	0.1	5.0	—

1. Criteria based on skinless fillet unless otherwise footnoted.
2. Based on the protection of the most sensitive species, which accounts for lower values for some compounds.
3. HWC regulatory limits apply to fish in commerce only. The Province of Ontario applies these as guidelines to sport fish consumption.
4. U.S. Food and Drug Administration (FDA) action levels based on fillet with skin on.
5. Ontario guidelines refer to restricted frequency of consumption of fish: If level of a single contaminant in a skinless dorsal fillet is below the guideline then unrestricted consumption is allowed; if the level exceeds the guideline then restriction in frequency of fish meals is advised. For women of child-bearing age and children under 15 years, restrictions apply below the guideline levels and no consumption is recommended for levels that exceed the guideline.
6. Criteria based on whole fish.
7. No consumption where TCDD levels exceed 50 ppt.
8. No consumption is recommended if the level for mercury exceeds 1.5 ppm.

A number of studies have shown that reduction of fat in fish flesh can decrease the amount of fat-soluble contaminants in the portions of fish consumed. Fats in fish flesh can be reduced by trimming fatty areas, puncturing or removing skin prior to cooking, cooking so that fats are drained (e.g., baked, broiled or grilled on a rack), or deep frying. These methods do not reduce the mercury content in fish flesh since this chemical is stored primarily in muscle tissue (fillet).

tions in the guideline levels set for fish consumption advisories. This has caused confusion. In response to a public demand for clarification, there is at present an exercise under way to standardize fish consumption guidelines among U.S. states.

Depending on contaminant levels found, fish sampling at the same location in Ontario is done every three years or less. Although not statistically rigorous, the presence or absence of an advisory on a lake-wide basis is revealing. The percentage of sampling locations on Lakes Ontario and Superior with advisories for lake trout have remained constant since 1983; but there has been a decline in the percentage on Lake Huron. In 1989 all Lake Ontario sampling locations for lake trout and chinook salmon had consumption advisories. These fish all have a high lipid content and are top predators. On Lake Superior, 100 percent of the sites for siscowet, a subspecies of lake trout, and walleye had advisories. Many of the Lake Superior advisories are for mercury which is a natural contaminant of this watershed. For yellow perch the percentage of locations with advisories is lower on all lakes but declining in only Lakes Erie and Ontario. Yellow perch have lower lipid levels and are lower in the food web than trout.

A Catalogue of Effects

Earlier in this chapter, information was provided showing that specific organochlorine chemicals have accumulated in the plankton, fish and eggs of birds in the food web of the Great Lakes. While a great deal is known about the trends of persistent toxic chemicals and their distribution in the Great Lakes basin, the full biological significance of their presence in the ecosystem remains the subject of ongoing research.

To date, there is published scientific evidence that 11 wildlife species, all top predators, have exhibited population declines, reproductive effects and/or other physiological problems related to persistent toxic substances since the 1960s. These effects are summarized in Table 7. There are also unpublished records of effects for several other aquatic species (osprey, great blue heron, Virginia rail). It is encouraging to observe that on a lake-wide basis, the majority of bird species have experienced significant recoveries in their reproductive success. The exceptions are the bald eagle and the common and Forster's tern. Field biologists are still observing manifestations of developmental toxicity in species on Lakes Michigan, Superior, Huron and Ontario. These difficulties are

TABLE 7
Species of Fish and Wildlife Known to be Affected by Contaminants in the Great Lakes[1]

Species	Population decrease	Effects on reproduction	Eggshell thinning	Congenital malformations[1]	Behavioural changes	Biochemical changes	Mortality	Alterations in recruitment
Mink	X	X	NA	NE	NE	NE	X	?
Otter	X		NA	NE	NE	NE	?	?
Double-crested Cormorant	X	X	X	(X)		X	?	?
Black-crowned Night-Heron	X	X	X	X		X	?	?
Bald Eagle	X	X	X	NE		NE	NE	?
Herring Gull		X	X	X	X	X	X	
Ring-billed Gull				X		NE	X	
Caspian Tern		X		X	NE	NE		X
Common Tern		X	X	X		X		
Forster's Tern		X		X	X	X		
Snapping Turtle	NE	X	NA	X	NE	NE	NE	NE
Lake Trout		X	NA			X		
Brown Bullhead			NA			X		
White Sucker			NA	X		X		

X = effects documented
NA = not applicable
NE = not examined
? = suspected since population declined

1. Unpublished records of congenital malformations (gross birth defects) exist for the double-crested cormorant, great blue heron and the Virginia rail.

FIGURE 13. Birth Defects Reported in the Young of Great Lakes Fish-Eating Birds, 1971-1985

Location	Time Period	No. of Species	Number of Individuals
Lake Superior			
1. North Shore	1971-75	1	1
	1976-80	1	1
Lake Michigan			
2. Green Bay	1971-75	3	3
	1976-80	3	3
	1981-85	4	53
3. Straits of Mackinac area	1976-80	1	1
Lake Huron			
4. North Channel	1976-80	1	1
	1981-85	3	3
5. Georgian Bay	1976-80	2	2
	1981-85	1	2
6. Thunder Bay	1971-75	2	6
7. Central Basin	1976-80	1	1
Lake Erie			
8. Detroit River/Western Basin	1971-75	1	1
	1976-80	1	1
9. Eastern Basin	1971-75	1	2
Lake Ontario			
10. Western Basin	1971-75	1	8
11. Bay of Quinte	1971-75	3	5
	1976-80	4	3
	1981-85	1	1

See Table 7 for a list of affected bird species.

Source: Canadian Wildlife Service, Environment Canada.

the most severe in highly contaminated areas such as Green Bay on Lake Michigan, Saginaw Bay on Lake Huron and Hamilton Harbour on Lake Ontario.

Deformities

Congenital malformations (birth defects) provide gross visible evidence that young birds and turtles are affected during their development. Field biologists have noted that in healthy wildlife populations birth defects are uncommon. Over the past 20 years, birth defects have been reported in ten species of Great Lakes fish-eating birds (see Figure 13). If malformations were to be monitored in a systematic way, their occurrence and prevalence could serve as indicators of biologically significant levels of developmental toxins in the food web.

The reported malformations occur in locations heavily contaminated with PCBs and other organochlorine compounds. There are clusters of birth defects involving several species.

1) In Lake Ontario, defects were particularly prevalent in the early 1970s in six species which breed there.
2) In Lake Huron, deformities have been found in the North Channel, Georgian Bay and offshore from Alpena County, Michigan.
3) In Lake Michigan, deformities have been found in several species and markedly elevated rates of bill deformities have been found in young cormorants in the 1980s.

A study of Forster's terns in Green Bay found no evidence that infectious disease could account for the poor survival of embryos, birth defects in young or the abnormal physiological functioning. It was concluded that organochlorine chemicals were involved.

Tumours in Fish

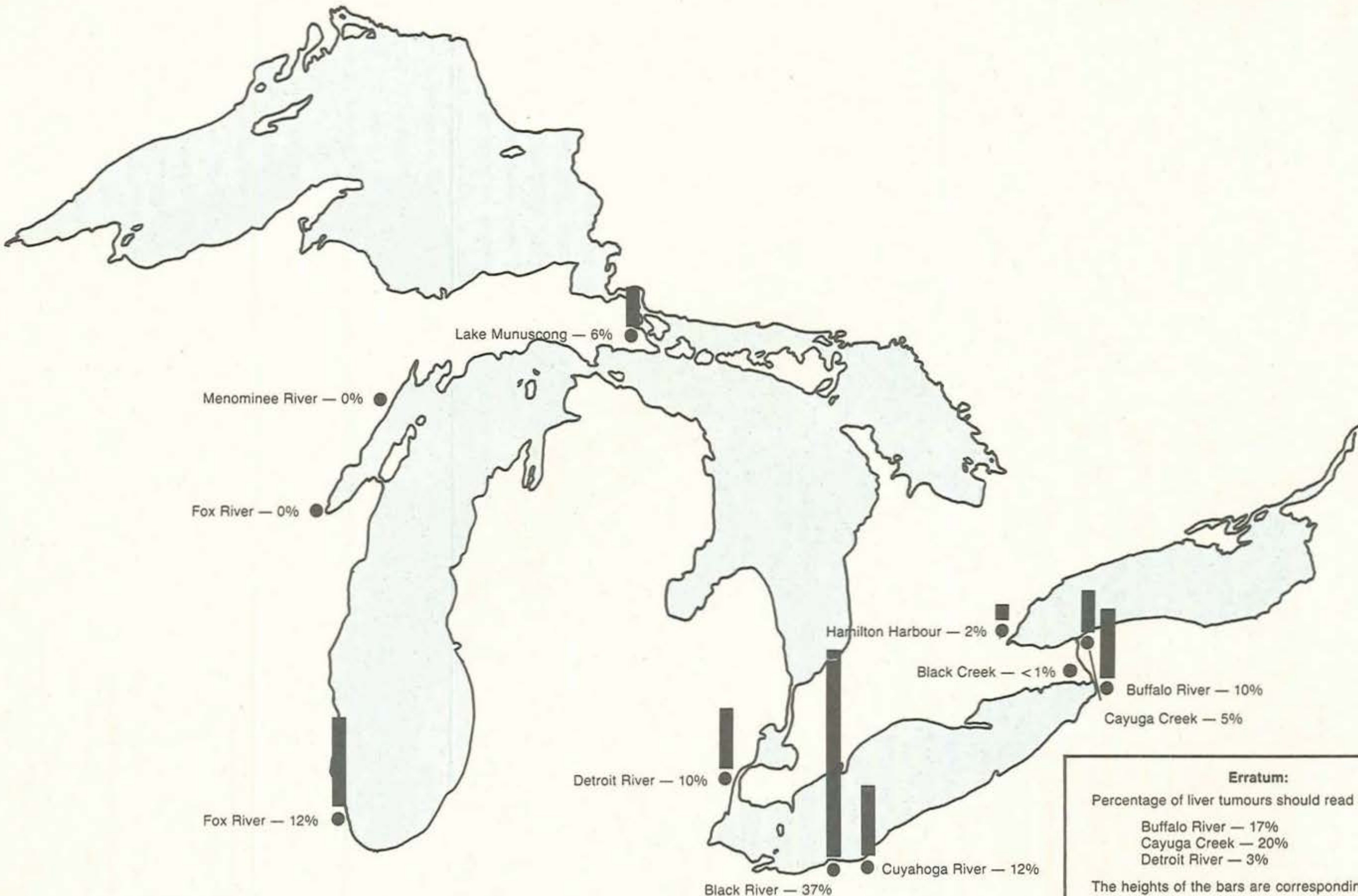
A field study conducted between 1967 and 1972 using 17 species of fish concluded that the increased prevalence of tumours in the Fox River, Illinois, was correlated with the degree of chemical pollution. In 1982 liver tumours in brown bullheads were associated with high levels of carcinogenic PAHs found in the bottom sediments of the Black River, a tributary of Lake Erie. This contamination was caused by discharges from steel and coke industries in the area. The brown bullhead is now used across the basin as an indicator of chemical carcinogens in nearshore areas and connecting channels.

Liver tumours were found in white suckers from western Lake Ontario sites surveyed between 1985 and 1987. The presence of tumours in fish in such geographically restricted areas strongly suggests a chemical cause especially since this type of tumour is often associated with chemical exposure. Figure 14 shows the occurrence of liver tumours in brown bullheads and white suckers. Given the large number of contaminants in the Great Lakes it is unlikely that carcinogenesis can be linked to a specific chemical. Despite the difficulties in "proving" that exposure to individual chemicals in the Great Lakes is responsible for tumours in fish, the circumstantial evidence is overwhelming. In the laboratory, known chemical carcinogens have caused liver tumours, and river sediment extracts have induced tumours in fish. In the Great Lakes environment, tumour frequencies are highest at locations contaminated with chemical carcinogens, and fish analyzed are found to metabolize chemicals such as B[a]P into carcinogens. It is reasonable to conclude that the same processes demonstrated in the laboratory are also occurring in the environment.

How Toxic Chemicals Affect Organisms

Toxic chemicals alter the normal biochemical and physiological functions of animals and plants. Effects can occur at the *molecular* level (e.g. enzyme activity, DNA damage), at the *cellular* level (e.g. tumour formation), at the *tissue* level (e.g. eggshell thinning, organ functions), at the *individual* level (e.g., behaviour and survival ability), at the *population* level (e.g., mortality, abundance and distribution), and at the *community* level (e.g., number of species and their interactions). These levels are not independent of each other. For example, when the field biologists observed the decline of bird *populations* in the 1960s and 70s, there was reduced reproductive success of *individuals* and eggshell thinning in a number of fish-eating bird species. Investigation at the *cellular* and *molecular* levels established a cause and effect relationship with the persistent organochlorine pesticide DDT/DDE and the process responsible for eggshell formation. This work was carried out interactively by laboratory experimentation and by field studies.

FIGURE 14 Percentage of Liver Tumours in Fish from Great Lakes Locations
(a) Sampling Locations for Brown Bullheads



Erratum:

Percentage of liver tumours should read as follows:

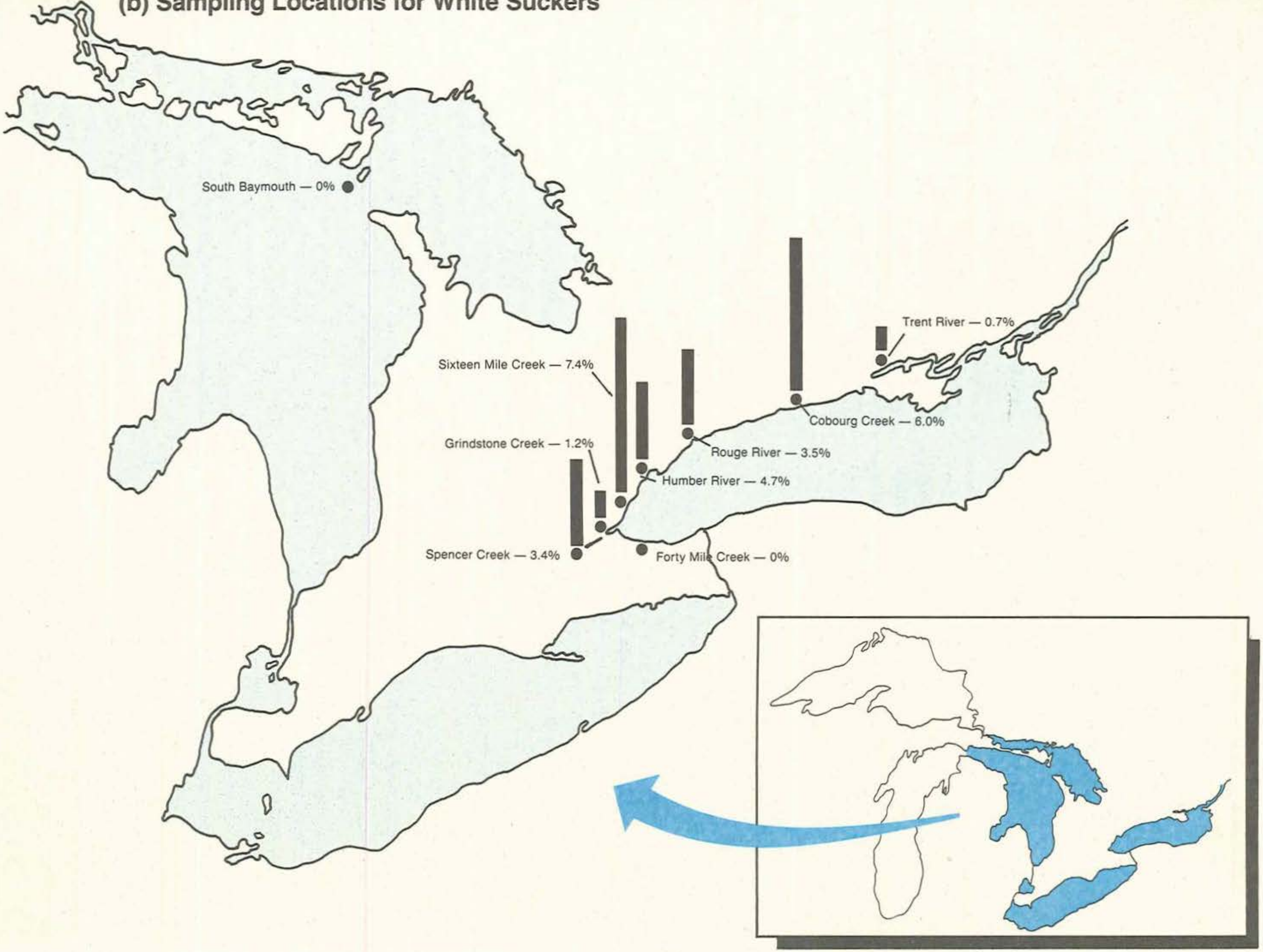
Buffalo River — 17%
Cayuga Creek — 20%
Detroit River — 3%

The heights of the bars are correspondingly higher or lower.

Note: The height of the bar graphs indicates the prevalence (as a percentage) of liver tumors in populations of brown bullheads and white suckers sampled from Great Lakes locations. These data were collected in various years during the 1980s.

Source: Department of Fisheries and Oceans

FIGURE 14 Percentage of Liver Tumours in Fish from Great Lakes Locations
(b) Sampling Locations for White Suckers



Biochemical Tests

An approach has now been developed in fish and wildlife toxicology to detect changes induced in cells as a result of exposure to chemicals in the environment. These are called "biomarkers". If normal physiological functioning of organisms is a criterion for a healthy environment, then this approach will tell the investigator whether or not the environment is healthy for the species being studied. The herring gull, cormorant and tern are Great Lakes birds presently most amenable to these types of tests. Changes in thyroid function, the activity of liver enzymes involved in detoxification, synthesis of heme in the liver and retinol (vitamin A) storage have been used. In fish, two enzymes (mixed function oxidase and amino levulinic acid dehydratase) found in all species are used to assess health.

Dioxin Equivalents

The term dioxin refers to a group of 75 similarly structured compounds known as congeners. The most toxic dioxin congener, 2,3,7,8-TCDD, activates enzyme systems associated with the detoxification of chemicals in the liver of laboratory rats. The induction of one of these enzyme systems has been strongly correlated with reduced body weight (wasting), abnormal thyroid gland function, changes to the immune system and deformities in test animals.

2,3,7,8-TCDD induces liver enzyme activity more than any other compound on a weight basis. In the algebra of dioxin equivalents, it is assigned a value of one. PCBs, furans, and other dioxin congeners are assigned values based on their toxic potential relative to 2,3,7,8-TCDD. Analysis of eggs of Great Lakes Caspian terns and double-crested cormorants have found a direct correlation between dioxin equivalents and levels of embryo mortality.

4

Accounts of Great Lakes Species

There are three fish, one reptile, eight bird and two mammal species (Table 7) for which exposure to toxic chemicals has been linked to reproductive or other physiological problems. Two of the species, brown bullheads and white suckers, are bottom-dwelling and bottom-feeding fish. All of the wildlife species are long-lived and they feed either predominantly or almost entirely on Great Lakes fish. As part of the Great Lakes food web, humans share a position atop the food web with the bald eagle (Figure 2).

The following accounts review data on the concentrations of persistent toxic chemicals and the associated effects in seven of these species.

Double-Crested Cormorant

The best estimates of the total Great Lakes population of cormorants in the early 1950s were under 1000 pairs of birds. By the 1970s, populations had crashed on all Great Lakes except Lake Erie. On Lake Ontario there was no known successful breeding of cormorants between 1954 and 1977, while on Lakes Michigan and Superior, cormorants failed to breed by the early 1960s and 1970s respectively. This reproductive failure was the result of broken eggs or the failure to lay eggs. Most of the breakage occurred due to the marked thinning (15%–20%) of the eggshells induced by the pesticide DDT. Cormorants are particularly sensitive to eggshell thinning because they incubate their eggs by standing on them. Cormorant populations have since recovered and the increase in cormorant nests after 1980 coincides with the decline of DDT/DDE concentrations in their eggs.

The cormorant story has recently taken an interesting turn. Currently there are more than 20 times the number of cormorants nesting in the basin than at any time in this century. While the cause of this population explosion is unknown, the present-day ecosystem is clearly advantageous to the cormorant's success.

Since the resumption of successful breeding, field biologists have observed a range of deformities in young cormorants. The prevalence of chicks with bill defects is a particular concern because these developmental defects are initiated when chicks are still inside the egg (see cover photograph). Markedly elevated rates of occurrence of bill defects are found in Green Bay, and overall rates are slightly higher in the Great Lakes cormorants compared to those from relatively non-contaminated environments.

These findings link a birth defect with the highly contaminated food chain of this species. PCBs and related compounds are likely responsible. Although data are limited, present PCB levels in Lake Ontario cormorant eggs appear to be unchanged from the early 1970s.

Bald Eagle

The bald eagle is a long-lived top predator species feeding on large fish, gulls, waterfowl, turtles and muskrats. By being at the top of the Great Lakes food web, the species is particularly vulnerable (see Figure 2). Bald eagles tend to occupy the same breeding areas year after year and thus are affected by local environmental contaminants. They may also migrate to polluted areas outside their breeding season.

Shortly after the widespread introduction of DDT in 1946, an amateur naturalist noted that many eagles in Florida had failed to nest and that their eggs did not hatch. Following an investigation of the remaining eagle populations, the U.S. Fish and Wildlife Service declared the southern subspecies "endangered" in 1967. The bald eagle was probably the first bird species known to be affected by the widespread use of DDT.

TABLE 8
Concentrations of Organochlorines in Eggs[1] from Bald Eagle Nests in the Great Lakes Basin, 1986-1988

Year	Site	Residue Concentration		
		PCB[2]	DDE	Dieldrin
Shoreline				
1986	Lake Michigan (Big Bay de Noc)	51-60	26-35	14-22
1986	Lake Erie (Sandusky Bay)	8.6-44	2.3-10	0.25-0.69
1986	Lake Huron (Thunder Bay)	96-119	38-44	2.2-2.4
1986	Lake Superior (Whitefish Bay)	12.9-14	2.4-9.5	0.18-0.51
Inland				
1986	Lake Michigan (Menominee River)	2-29	1.1-16	0.08-0.9
1986	Michigan (lower peninsula)	12-14	5.2-6.2	0.24-0.26
1988	Michigan/Wisconsin border	2.4-13	0.48-2.7	0.06-0.09
1988	Ohio	5.7	1.5	0.07

All values are in parts per million.

1. A total of 24 eggs were collected from 14 sites over 3 years.
2. PCB concentrations based on analysis using Aroclor mixtures and are not directly comparable to the PCB congener values for herring gulls in Table 5. For an approximate conversion multiply Aroclor values by 0.5.

Source: U.S. Fish and Wildlife Service.

In the Great Lakes region, the introduction of persistent toxic chemicals led to a drastic decline in eagle populations. Historically, there were at least 90 locations where eagles nested on the Canadian shoreline. During the 1960s and 1970s, only ten active sites were found on the lower lakes between Lake Huron and the St. Lawrence. During the 1969 and 1974 period, field data show that only nine young fledged, all on Lake Erie. Along the U.S. shoreline, fewer than 30% of eagle nesting attempts resulted in fledglings leaving the nests. Analysis of eagle eggs collected from nests during the 1970s suggested that DDE was the causative agent in eggshell thinning and the impairment of reproduction. Although no eggs were collected from the Great Lakes shoreline nests during this study, biologists have correlated the presence of DDE with the lack of reproductive success. Another pesticide, dieldrin, played a role in adult mortality.

Because of the endangered/threatened status of this species in both Canada and the United States, it has not been possible to carry out systematic egg collections. Data on contaminant levels have been obtained by analyzing eggs which have failed to hatch. Levels of PCBs, DDE and dieldrin are equal to or higher than those found in herring gull eggs in the same area. This is not surprising as bald eagles may feed on herring gulls and contaminated waterfowl as part of their diet. Data from U.S. locations collected between 1986 and 1988 are given in Table 8. An important feature of these data is that residue levels of DDE, PCBs and dieldrin are significantly higher in eggs obtained from shoreline nests than from inland sites. At present there are insufficient data to discern temporal trends but contaminant levels are high enough to cause embryo mortality.

It is encouraging that eagle populations have begun to recover in some parts of Ontario and in several U.S. states following the restriction in agricultural use of DDT; however, researchers have cautioned that since the bald eagle is a long-lived species, survival of the young to breeding age may be more important than nesting success itself. Observations during the 1980s on the U.S. side of the Great Lakes show that many pairs of eagles are now able to nest, but they are unsuccessful in producing offspring.

In recent years, there has been an expansion of eagle populations along the Canadian Lake Erie shoreline. More and more attempts to breed are successful, reflecting the lower concentrations of organochlorine pesticides in Lake Erie fish and waterfowl. On Lake Ontario, no nesting attempts have been recorded even in areas which still have suitable habitat.

Given that the bald eagle feeds on species which are also consumed by anglers, hunters and aboriginal people, its health may be a useful surrogate for humans. In addition, its position at the top of the food web and high sensitivity to toxic contaminants make it a candidate for ecosystem indicator. The return of normally reproducing eagle pairs to their former habitat and the expansion of their population should also serve as the biological definition of the "virtual elimination" of persistent toxic substances from the Great Lakes ecosystem. In relatively uncontaminated environments, individuals of this long-lived species return to the same nesting location year after year.

Herring Gull

As noted earlier, the herring gull has been routinely used as an indicator species of Great Lakes contaminant levels since 1974. The herring gull's ability to bioaccumulate persistent toxic chemicals while remaining relatively insensitive to the toxicity of these chemicals makes it valuable for the measurement of levels and trends. Wildlife biologists have also utilized this species to measure biochemical changes from contaminants. This is significant now that contaminant levels have declined somewhat and there are generally fewer observable deformities in birds. Alterations in biomarkers indicate that PCBs and other organochlorine chemicals continue to be present in sufficient quantities in Great Lakes fish to influence the physiology of the herring gull over much of the basin. The experimental use of this animal may bring us closer to establishing cause and effect relationships between toxic chemicals other than DDT and wildlife.

As early as 1964, colonies of this species on Lake Michigan suffered reproductive problems; by 1970, Lake Ontario colonies also had similar problems. In contrast to cormorants, eagles, common terns and black-crowned night-herons, herring gulls did not experience critical eggshell thinning. Instead, a different pattern emerged: there was a high embryo mortality and a high loss of eggs due to lack of attentiveness of the adults incubating the eggs.

By 1978, productivity had increased in both Lakes Ontario and Erie to levels that ensured stable populations. Currently, populations are once again thriving. Herring gulls on Lakes Huron and Superior did not experience the depressed levels of productivity observed in colonies on the other lakes. These findings are consistent with the lower contaminant levels in the food web of these lakes. The pesticide DDT and its metabolite DDE are known to mimic the female hormone estrogen and male embryos can be feminized experimentally by doses of these compounds. In a retrospective analysis, herring gull embryos that were preserved from the mid-1970s were examined. A portion of the male embryos were found to be significantly feminized, and the female embryos had enlarged oviducts. The significance of these findings is unclear.

Common Tern

There is a good deal of concern for the common tern in the Great Lakes. Recently, the Committee on the Status of Endangered Species in Canada began to review its status. While the common tern has certainly been affected by the contamination of the aquatic food web, the high lake levels of the last 20 years have forced this species to abandon its preferred nesting habitat of gravel islands. Terns are now nesting on artificial sites, but these are subject to human disturbances and wildlife predators. In 1987, common tern populations in Lake Ontario were the lowest recorded in history.

In 1970, a field biologist with Environment Canada discovered that something was fundamentally wrong with the common tern colonies in Hamilton Harbour on two of these artificial sites. While some young of varying age were found in the nests, the eggs in most had failed to hatch. On examining one of those eggs, he found that the young chick had died before it could completely crack open the shell. Several other eggs contained dead embryos. At the edge of a grass tussock, the biologist also noticed an abnormal two-week-old chick, its upper and lower bill crossing over without meeting — a deformity which would result in certain starvation. A systematic study of these and other colonies confirmed that colonies on Lakes Ontario and Erie were reproducing poorly due to contaminant toxicity to embryos. The prevalence of birth defects in the five Lake Ontario colonies between 1971 and 1973 is the highest observed in any species in any location to date. Data show that PCB and DDT levels have decreased in eggs of this species. A severely deformed common tern embryo was found in Hamilton Harbour as recently as the 1989 field season and chicks in Saginaw Bay and Green Bay continue to suffer from contaminant-related effects.

The common tern is sensitive to the reproductive effects of persistent toxic contaminants and faced with a variety of threats, its future survival on the Great Lakes remains in question.

Mink

Mink, otter and muskrat are aquatic mammals exploited by humans for the commercial value of their fur. Scientists have found that these species accumulate organochlorine chemicals in their body tissues. In the 1960s mink raised on fur farms and fed on a diet of Great Lakes fish suffered complete reproductive failure. Detailed laboratory research showed that the causative agent was PCBs in Great Lakes fish. Later research showed that individual PCB congeners with dioxin-like activities were related to the adverse effects in the adults and toxicity to the fetus. Mink are one of the species most sensitive to PCBs, HCB and dioxin poisoning.

Mink are important indicators of contaminant levels in Great Lakes wetlands since they have small home ranges and eat muskrats and other mammals, fish and birds living in the wetlands. They are sensitive to PCBs and relatively insensitive to DDT exposure. Data from five regions of Lake Ontario and five townships bordering Lake Erie show that the distance of the capture from the Great Lakes shoreline is an important factor in determining the extent of contaminant accumulation in mink. Animals captured farther away from the shore do not feed exclusively on Great Lakes fish and generally had lower organochlorine levels. Based on analyses of mink carcasses obtained from trappers, high concentrations of PCBs in the liver were observed along the St. Lawrence River and in the Whitby-Cobourg area of Lake Ontario. Mink from the shoreline had levels of PCBs high enough to suggest that adverse reproductive effects would occur, based on studies of ranch mink.

In the absence of a census of fur-bearing mammal populations along the shores of the Great Lakes and inland, trapping records have been examined to determine whether wild mink populations in high PCB risk areas have declined. The findings are inconclusive. The data from these records are confounded by at least three factors: intensity of trapping, the value of pelts and the destruction of mink in some areas by trappers in order to protect muskrats.

The harvest data of Ontario mink and muskrat (their main prey) between 1970 and 1985 have been recently examined. Two areas of Great Lakes shoreline known to be highly contaminated with PCBs were compared to harvests in two areas of comparable size, one consisting of townships one or two townships removed from the shoreline townships in the high risk group and another of two townships in central Ontario where PCB contamination would be minimal. The two high PCB risk areas had significantly smaller mink harvests than the two low risk areas in 12 out of 15 years. In contrast, muskrat harvests were different in only 7 of 15 years, and in 3 of these years it was the high risk areas that had the larger muskrat harvest.

While this evidence of mink population differences correlated against Great Lakes shoreline residence is largely circumstantial, it is consistent with the pattern observed in another aquatic mammal, the river otter. The diet of the river otter is predominantly fish. In this species, rivers where inland stretches support healthy populations in Michigan and Wisconsin become sparsely populated as they approach Lake Michigan. There is a similar pattern in the bald eagle with inland populations recovering and shoreline nesting largely unsuccessful.

Common Snapping Turtle

The common snapping turtle eats mainly fish, plants and insects, and since these foods can accumulate contaminants, the turtle itself and its eggs become contaminated. Pollutant levels can become quite high in the fat, liver and eggs of snapping turtles. This species is long-lived and restricts itself to a small area throughout the year, which makes it a useful indicator of local contamination. Snapping turtles are common throughout eastern and central Canada and the United States. This makes comparison of contaminant levels in the turtles possible among many areas.

In the 1980s, snapping turtle eggs were collected from ten locations in Ontario and two locations in Quebec and analyzed for the presence of PCBs, organochlorine pesticides, dioxins and furans during three study periods.

In each study period, Lake Ontario eggs were generally more contaminated than eggs from Lake Erie, the St. Lawrence River and Algonquin Park. In specific populations in Lake Ontario such as those in Cootes Paradise/Hamilton Harbour and Lynde Creek, eggs were substantially more contaminated with PCBs, dioxins and furans than eggs from elsewhere.

For populations which were studied in both 1984 and the 1988/1989 period, mirex and DDE contamination in snapping turtle eggs had not declined markedly at any site with the exception of Hamilton Harbour. PCB concentrations at Algonquin Park were lower in 1989 than in 1984, while levels from Lake Ontario eggs fluctuated.

Cootes Paradise/Hamilton Harbour is the only site where dioxins and furans have been measured in both 1984 and 1988. Although concentrations of the most toxic dioxin congener declined by 50% at Hamilton Harbour compared to 1984 levels, concentrations of other dioxins and furans are either remaining constant or increasing.

Contaminant levels in turtle eggs have generally not declined and in many cases have increased since 1984.

Between 1984 and 1987, 27 adult turtles from Hamilton Harbour were found in various states of poor health; 22 died from unknown causes in mid-summer, a time of relatively low stress for this species. High residues of PCBs and the pesticides HCB, chlordane and DDE were found in their tissues. Turtle eggs collected from wetlands along Lake Ontario were incubated and deformities in the embryos and hatchlings were observed. These deformities were similar to those seen in Great Lakes cormorants, gulls, terns and fish (bent tails, twisted mouth parts, deformed legs) and were associated with levels of contaminants in the tissues at some sites.

Lake Trout

Commercial harvests of lake trout in the Great Lakes decreased by over 90% between 1930 and 1960. To address this trend fisheries agencies have implemented stocking programs, sea lamprey control (an important predator), quota management and measures for the conservation of fish habitat. Presently lake trout populations in the Great Lakes are maintained by intensive stocking programs and there is evidence of poor recruitment of young fish into the breeding population. Levels of PCBs and DDT for each lake since the 1970s are given in Figure 4.

The effects of chemicals on fish populations are often masked by the effects of non-chemical stresses and the organisms may succumb before the effects of chemical exposure are observed. Mortalities of lake trout (and coho salmon) fry were first reported in Lake Michigan in 1969. Lake trout were studied for 12 years and researchers concluded that chemicals are involved in the reproductive impairment of Lake Michigan lake trout because

a) mortality was restricted to the most heavily contaminated area of the lake;
b) mortality occurred during the "swim-up" stage of life when the trout fry are the most sensitive to chemical exposure; and
c) the syndrome peaked simultaneously in lake trout and chinook salmon fry in 1981.

Subsequently chemical analyses have revealed that there were 167 organic chemicals in the flesh of these fish taken from southern Lake Michigan. Although the evidence strongly suggests chemical causality for the observed lake trout mortality, the responsible chemical or chemicals involved may never be identified.

5

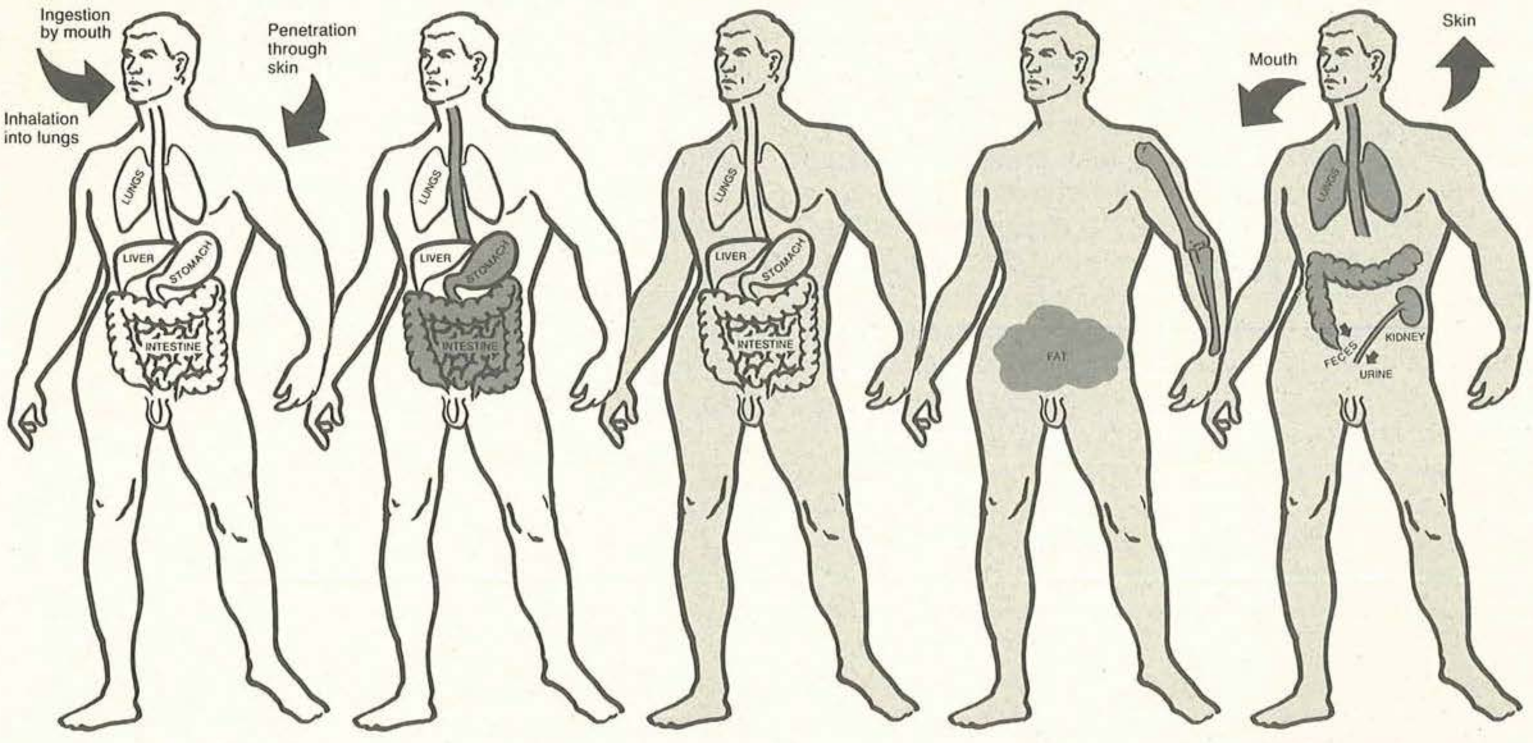
Exposure and Contaminant Levels in Humans

Humans living in the Great Lakes basin ecosystem are exposed to a wide range of organic and inorganic substances. Persistent toxic chemicals come from a number of sources including industrial processes, farms, leaking waste sites and emissions from combustion sources such as incinerators, motor vehicles and industrial activities. Only a portion of our total exposure to environmental contaminants can be attributed to sources in the drainage basin of the Great Lakes. A number of airborne contaminants arrive in the basin from remote sources. Much of the food we consume is grown outside the basin.

Exposure

The routes of exposure to environmental pollutants are from food and beverages, inhalation of air and airborne particulates, from the ingestion of water, body contact with water when bathing or swimming, from inadvertent ingestion of contaminated soil, and from skin contact with airborne particulates. The information presented here on exposure is based primarily on what is known about the intake of specific chemicals from food, drinking water, air and soil. People exposed to pollutants occupationally, including the

FIGURE 15. Intake and Elimination of Contaminants by the Human Body



Contaminants can enter the body through the skin, by mouth or by the lungs.

A chemical ingested by mouth moves through the digestive tract from which it may be absorbed into the bloodstream.

The parent compound or its metabolite may move into all organs and tissues of the body.

The chemical or its metabolite may be stored in bones and fat for long periods of time.

The chemical or its metabolite may be excreted from the body, most commonly through feces or urine, breath and sweat. Breast milk is a significant route of excretion for women.

Source: Adapted from *Toxicology for the Citizen*, Michigan State University, 1987.

handling of contaminated sediments, can accumulate higher levels of these substances than the general population. This report does not address occupational exposures or exposures from acute poisoning episodes. Exposure to persistent toxic chemicals is discussed in the following sections. This report does not discuss exposure to the broad class of volatile organic chemicals, many of which are widespread and toxic.

Food

Chemical residues of persistent toxic substances in food originate from the application of agricultural pesticides and atmospheric deposition on crops. Contamination of Great Lakes fish and wildlife can also arise from agricultural and industrial wastes that enter the waters directly. Although foodbasket studies (food items collected in the supermarket to approximate the Canadian diet) have been carried out in the Great Lakes basin, they are difficult to interpret for several reasons. There has been no agreement on which food items constitute a typical diet and on whether samples should be analyzed before preparation as food or after washing, peeling or cooking. Also, the data presentation varies between studies. The limited data show that food items contain many of the contaminants found in the Great Lakes ecosystem. Estimated dietary intake for each of these substances tends to be far below the acceptable daily intake established for each chemical by the World Health Organization.

The calculation of intake of chemical residues in food for average populations is most often based on an adult diet. These calculations do not adequately account for intakes in populations eating large amounts of sport fish and wild game (e.g., sportsmen and their families and native groups), nor do the majority of studies address the exposure of children. Several factors can increase the intake of contaminants by children and infants. Children usually consume more food per kilogram of body weight and have a higher absorption rate than adults. In addition, breast-fed infants are exposed to higher concentrations of fat-soluble contaminants than those found in adult foods. Although these exposures are for a relatively short period of time, they occur during a critical period of development.

Drinking Water

For most persistent toxic substances, calculations show that drinking water accounts for only a very small percentage of the total daily intake (e.g., less than 1% for dioxins, DDT and PCBs). Most contaminants detected in drinking water are found at very low concentrations and are well below current Canadian drinking water guidelines. In general, fewer than 1% of the samples analyzed by the province of Ontario have detectable levels of the most common environmental organic contaminants. One exception is the agricultural pesticide lindane which is present in approximately 20% of the samples analyzed, but at levels below current guidelines.

A number of non-essential metals are frequently detected in drinking water samples from cities in the Great Lakes basin but at levels below current guidelines. In urban areas there is some variability depending on the age and type of plumbing in use. For example lead can often be detected in household drinking water drawn after several hours of standing in plumbing.

The findings that contaminants are found at very low levels in drinking water are similar to the results of a comprehensive review of Great Lakes drinking water undertaken in 1986 by the Canadian Public Health Association. Contaminant levels in municipal water occasionally may exceed guidelines. This does not imply that drinking water is dangerous to health since guidelines are based on lifetime exposures and have been developed with wide margins of safety. Continued exceedances serve as an alert that there may be an uncontrolled source of a particular chemical.

Air

There are few comprehensive data sets available for levels of airborne heavy metals and organochlorine contaminants that are deposited in Great Lakes water and food. Inorganic lead and copper levels appear to have decreased since 1977 but PCB levels may have increased slightly. Many organic chemicals released into rivers and lakes are volatile and can be transported in air throughout the basin. It is estimated that in some areas of Canada, airborne exposure to furans and dioxins could account for 2% to 8% of the total daily intake of these contaminants.

Soil

Concentrations of contaminants in soil are important because adults and children can be exposed to contaminants found in soil dust. In addition young children may inadvertently ingest significant quantities of soil. Monitoring of contaminants in soil in the Great Lakes basin has not been extensive. Lead levels are highest in urban areas due to the use of leaded

fuels and in particular locations because of industrial activities (e.g., lead battery reclamation and smelting). Elevated soil concentrations are in the parts per million (ppm) range. Soil lead concentrations are likely to decrease with the phase-out of lead in gasoline.

There are few data on concentrations of volatile organics in soil. These compounds would contribute little to the total intake via soil ingestion; they would however contribute to the general airborne exposure.

Total Exposure

The "multimedia approach" is now being used to estimate human exposure from all pathways. This approach to exposure will ensure that total exposure is determined rather than exposure to chemicals in only one medium at a time. Population risk estimates calculated from multimedia exposure analysis are more realistic than risk estimates based on single media exposure.

Multimedia analyses completed thus far indicate that for people in the Great Lakes basin, the majority (80%–90%) of their intake of chlorinated organic chemicals comes from food, a lesser amount from air (5%–10%) and minute amounts from water (less than 1%). Most of the calculations on total human exposure to chemicals in the Great Lakes basin come from the analysis of contaminant levels in drinking water and fish.

Populations Subjected to Increased Exposure

Although drinking water and air contain a wide range of environmental contaminants, these are in low concentrations and thus are not major sources of human exposure to these substances. It is not surprising that food constitutes the main exposure pathway because many persistent toxic substances are fat-soluble and bioaccumulate. There are several subpopulations that are exposed to higher levels of toxic compounds than the general population. When sportsmen and their families and native groups consume from the top of the food web by eating fish (especially in areas where advisories have been issued), waterfowl, or turtles, they are likely to be exposed to higher levels of mixtures of these contaminants. Individuals living in highly polluted locations, such as some cities or industrial areas, are also likely to be more exposed to airborne pollutants. Infants and children consume more food per kilogram of body weight than adults and thus have a relatively higher exposure. Nursing infants in particular can be exposed to far greater amounts of fat-soluble contaminants from their mothers' milk even though it is for a short period of their life. It should be emphasized that despite the presence of organochlorine chemicals in breast milk, the advantages of breast-feeding outweigh the disadvantages to the infant.

Human Tissue Data

The concentrations of a contaminant in tissue can be used as a measure of an individual's exposure. Tissue residues represent the dynamic balance between the intake and absorption of a contaminant and the body's capability to metabolize and excrete the substance (see Figure 15). Studies show that humans have been exposed to many synthetic organic chemicals and metals; a number of these are consistently present in human tissue samples.

In the Great Lakes basin, many ubiquitous contaminants bioaccumulate in resident organisms. For most chemicals this results in increasing concentrations at higher levels of the food web.

Recent improvements in analytical capability resulted in the detection of minute quantities of many chemical contaminants in the ambient environment and in biological samples. As a result, the number of samples that contain detectable levels of these chemicals has increased and a large number of previously unidentified contaminants have been detected. This does not mean that these chemicals were absent from humans and the environment before the improvements in analytical techniques.

Data on contaminant residues in adipose tissue (fat), blood and breast milk are not sufficient to draw conclusions on trends over the last 20 years, although there is a decline in concentrations of some chemicals found in breast milk. The lack of common laboratory procedures is one obstacle in comparing existing studies. The absence of a long-term monitoring program and a human tissue bank also makes it difficult to determine the extent of exposure and if the exposure is changing over time.

Adipose Tissue

Adipose tissue has been the most frequently analyzed tissue; it is the primary storage site for lipophilic (fat-soluble) contaminants. PCBs and DDE are the most prevalent contaminants and occur at the highest concentrations (usually low ppm). The pesticides dieldrin, lindane, hexacholorobenzene and chlordane occur in human adipose tissue samples throughout North America but at lower concentrations than PCBs and DDE. Dioxins have been found in the low parts per trillion (ppt) range in almost every human fat sample analyzed throughout the world.

Based on the limited data available, it appears that the levels of most contaminants found in residents of the Great Lakes basin are similar to those found in individuals residing elsewhere in North America. There also do not appear to be major differences in the residue levels of individuals from different parts of the Canadian side of the basin. Data are also insufficient to draw conclusions about trends over time in the general population. Data from different studies cannot be rigorously compared because samples have been collected and analyzed using different protocols. In addition, comparisons of human tissue data would be more meaningful if residence, exposure history and (when relevant) cause of death were known.

Blood

Blood serum contains a small amount of fat and has been used to determine concentrations of fat-soluble contaminants in the human body. Blood levels of organochlorine chemicals can be a misleading measure of total body burden because the concentration of a specific contaminant can vary significantly over a few hours. For example, PCB levels can increase dramatically within one hour after the ingestion of PCB contaminated food, reach a maximum ten hours after the meal and return to baseline values within one week as the PCBs are moved out of the blood into the tissues.

There are not adequate data to compare the concentrations of metals such as nickel, copper, cadmium and lead in blood obtained from individuals living within the basin with those of individuals living elsewhere. Factors such as local contamination (e.g., lead smelting, nickel refining), socio-economic status and proximity to urban areas can have significant effects on blood metal concentrations. Levels range from a few parts per million to a few parts per billion (ppb).

Levels of mercury in the blood of some native peoples in the Great Lakes basin have been reported in the "increasing risk" range (20–99 ppb). These levels were similar to findings among Indian residents of a number of other communities elsewhere in Canada. They did not reach the "at risk" levels (over 100 ppb) found in residents of other Ontario native communities known to be severely exposed to mercury contamination, for example, Grassy Narrows and Whitedog, nor in certain Quebec Indian communities (Mistassini and Waswasipi).

Breast Milk

Breast milk has a relatively high proportion of fat and consequently contains many fat-soluble organo-

chlorine chemicals. Three national surveys conducted between 1967 and 1982 found residues of nine organochlorine chemicals or their metabolites in most of the breast milk sampled. In Canada, concentrations of organochlorines in breast milk do not differ significantly in samples taken from different regions. PCB levels in both Canada and the United States did not change noticeably between 1962 and 1982. Levels of dioxins and furans in Canadian samples are similar to those reported in the United States and Sweden (low ppt range).

As with adipose tissue, differences in sampling and analysis protocols make it difficult to compare data between studies and to determine whether the chemical residues measured in these studies are truly representative of Canadian women and consequently the degree of exposure to infants. In addition, contaminant concentrations in breast milk during feeding, between feedings and during the lactation period may vary. For a population of lactating women, the number of previous breast-fed infants, place of residence and life history of exposure to chemicals can also cause variation among samples.

Other Tissues

Tissues such as liver, kidney, brain, muscle and gonad have been analyzed for contaminants. The data available are not adequate to allow meaningful comparisons between residents within the Great Lakes basin and elsewhere. Many metals accumulate in the kidneys. Concentrations are affected by occupational exposure, local contamination, smoking history and socio-economic status. Differences were reported in the concentrations of nine metals in liver and kidneys sampled from cadavers in Kingston and Ottawa, respectively, but donor histories were not available.

Tissue concentrations of lipophilic (fat-soluble) contaminants are largely dependent on the presence of fat in the tissue. Concentrations (on a wet weight basis) of contaminants like PCBs are highest in adipose tissue, followed by liver, kidney, gonad, and brain. Concentrations in the fat extracted from all these tissues tend to be in the same order of magnitude.

Overview of Human Tissue Information

Current data, although incomplete, do not suggest that Canadians living in the Great Lakes basin have higher contaminant levels than those in other parts of the country. Certainly, monitoring programs for contaminants in human tissue have not been comprehensive, have not used similar sampling or analytical protocols and have not taken account of the health and exposure of the donor. If temporal, geographical, gender- and age-related trends in human body burdens are to be determined, a comprehensive sampling strategy should be developed and tissues should be stored for retrospective analysis.

6

Effects of Toxic Chemicals on Human Health

Evaluating Human Health Data

Assessment of the effects of contaminants on the health of populations is complicated by several factors. Frequently, there are insufficient data to determine how much exposure has occurred. Gender, age and lifestyle can all dramatically affect how individuals respond. Humans consume a wide range of foods and beverages and nearly always consume foods grown or produced both from within their community and from elsewhere. Frequently, the types of food and the amounts consumed are seasonal and dependent on sociological and ethnic factors. Finally, humans are nearly always exposed to complex mixtures of environmental contaminants, rarely to single chemicals, and they are frequently exposed to other substances such as medications, alcohol and tobacco products, all of which may interact.

To sort through these difficulties, scientists endeavour to combine the results of studies with human populations and laboratory animals to predict toxic effects associated with exposures. Human epidemiological studies can focus on general populations, occupational groups or individuals with unusual accidental exposures. Some studies consider groups displaying similar adverse effects (e.g., cancer) and look for possible common exposures; conversely, other studies consider common population exposures (e.g., to PCBs) and look for group effects. Each type of study contributes some information but not a complete picture of exposure and effect. Studies with laboratory animals are also useful because, unlike the human studies, experimental conditions can be rigorously controlled, exposure varied through control of dose and detailed biochemical and pathological changes monitored. While most animals, including humans, have similar basic cellular mechanisms, it is important to keep in mind that different species respond in

The effects of contaminants on human populations are dependent on the toxic properties of the contaminants themselves and on the amount, route and duration of exposure. The amount absorbed (dose) is affected by the route of exposure (via mouth, lungs or skin). The magnitude of the effect is dependent on whether it is received all at once, over a long period of time, continuously, intermittently, alone, or in conjunction with other substances.

different ways to the same amount of a contaminant.

Wildlife species in the Great Lakes have been intensively studied. Metabolic, developmental, reproductive, behavioural and immunological effects have been observed across a range of species exposed to mixtures of persistent toxic substances (see Chapter 4). While differences exist in behaviour and exposure between humans and wildlife, these findings are of significance to humans.

The information in this chapter reviews the very sparse data on human populations exposed to a broad range of contaminants in the Great Lakes basin. Appendix I provides summary information on individual contaminants and their most important effects.

"Persistent toxic chemicals due to their nature (ability to cross the placenta, bioaccumulation, occurrence as mixtures, long half-lives, toxic properties) pose threats to the health of individuals within the basin."

Consensus conclusion reached by participants in an international working conference, The State University of New York at Buffalo, 1989

Studies of the General Population

National disease and mortality statistics can provide the basis for one type of assessment of population health. For all types of cancer taken together, the number of cancer cases increased across the North American continent as well as in the Great Lakes basin between 1950 and 1985. This increase is largely due to an increase in lung and skin cancer. These two cancers are associated with cigarette smoking and exposure to ultraviolet radiation. The number of cases per 100,000 population appears also to have increased slightly in North America from the mid-1970s to the mid-1980s.

Cancer is a significant cause of death in North America and the Great Lakes basin. Although the number of cancer deaths per 100,000 population due to all cancers has increased since 1950, it has actually decreased for all cancer deaths other than lung cancer. The Mortality Atlas of Canada (1980) compares cancer mortality of each county to the national average for 1966 to 1976. In the Great Lakes basin there is no obvious indication of any increase in male and female mortality rates for all cancer types when compared to national figures. There is an indication of increased rates in certain Quebec counties bordering the St. Lawrence River. These increases are associated with densely populated municipalities and could be due to several factors including lifestyle and socio-economic conditions.

There have been very few studies of cancer mortality in specific areas of the Great Lakes basin. In one study in Niagara County, an excess of liver and lung cancer was found in women between 1977 and 1981. There was no association with environmental variables and the determining factor was probably heavy cigarette smoking. There were increases and decreases in the rates of different types of cancer among men in Niagara County; however, there was no consistent pattern and there was no association with the use of Niagara River water.

There have been a few studies of reproductive health in the general population in the Great Lakes basin. Rates of various adverse reproductive outcomes (low birth weight, stillbirth, birth defects) varied in the counties adjacent to and inland from the Great Lakes, although there were no consistent increases or decreases associated with specific areas of the basin. In a study of birth outcomes in five municipalities in the Niagara region, birth outcomes were similar to province-wide results. There were significant increases and decreases in specific congenital anomaly rates, but there was no obvious pattern and no association with environmental variables.

These studies of aggregate populations cannot be used to confirm or deny that there may be adverse effects from exposure to environmental contaminants. Fluctuations in the rates of adverse outcomes (i.e., more than average or less than average) from year to year and area to area are a consistent finding in such studies. There are insufficient data to determine whether or not the incidence of these outcomes in the Great Lakes basin is different from that of other regions in Canada or the United States. There is also inadequate assessment of these effects in communities with greater exposure to Great Lakes basin contaminants through the consumption of Great Lakes fish or drinking water, agricultural or industrial practices or from airborne pollutants.

Studies of Select Populations

Studies of human populations attempt to link exposures to ill-health or death. Some focus on individuals in a group with a common exposure and then establish common health effects (see box); others focus on individuals with similar health outcomes and attempt to determine a common cause (exposure).

Numerous chemical spills which have taken place in the St. Clair River prompted a study of reproductive outcomes in women in this area. Results of this study have not given any indication of major adverse health effects, although there were a decreased number of stillbirths and perinatal deaths and an increased number of low birth weight infants. A more in-depth case-control study has now been completed for the Ontario Ministry of Health. It has concluded that exposure to drinking water from the St. Clair River was not associated with stillbirths, congenital anomalies, low birth weight or infant deaths.

The current knowledge on the health effects of air pollution in the Great Lakes basin is limited. Sulphur oxides and ozone have been linked to increased hospital admissions (for respiratory reasons) and to reduced lung function. These studies were conducted in the Great Lakes basin region but did not account for all pollutants which may affect human health (i.e., metals, organohalogens).

Studies of blood lead concentrations have been carried out in children living in Ontario. Levels reported are similar to those found elsewhere and are declining. Blood lead measures are important because neurological effects have been observed in children and newborns exposed to very low concentrations of lead.

An extensive study of the exposure of Indian residents of Akwasasne to the mix of contaminants in the St. Lawrence River (concentrating on methylmercury, PCBs and mirex as indicator contaminants) and fluoride air emissions from a nearby factory failed to reach any substantive conclusions. Blood levels of contaminants were generally in the accepted normal range or slighly elevated. However, knowledge of the degree of contamination of the fish, air and water did result in serious concern among residents of the community.

A cross-Canada survey of blood mercury levels in native peoples revealed that some individuals in the Great Lakes basin are in the "increasing risk" range. No clinical effects were found in Indian residents of the Great Lakes basin with elevated blood mercury.

Despite the limited number of human population studies to date, these investigations indicate that some groups in the Great Lakes basin have already experienced adverse health effects.

An ongoing study of the children of 242 women who consumed Lake Michigan fish over a six-year period has demonstrated the occurrence of several effects. These women had an average consumption of 6.7 kilograms of fish per year, equivalent to between two and four meals per month. The relationships between fish consumption, PCB levels in the mother's blood, PCB levels in the umbilical cord serum and the effects on the offspring were investigated. Factors other than PCB exposure were taken into account statistically; however, the control group was smaller than the exposed group and there were differences between the two groups of mothers in terms of their use of medication and consumption of alcohol and caffeine.

Initially, a statistical correlation was found between the maximum yearly consumption of Lake Michigan fish and the women's blood PCB levels. No correlation was found between the maximum yearly consumption of fish and PCB levels in the umbilical cord serum. A study of the infants in the group showed statistically significant decreases in their gestation period, birth weight and head size. Based on PCB levels in the umbilical cord, infants were more likely to show "motoric immaturity", more abnormally weak reflexes and a greater amount of "startle". The most highly exposed infants were more likely to be classified as "worrisome".

At seven months, infants were re-tested and showed a statistically significant decrease in their ability to recognize novel visual stimuli; this effect was again associated with increasing cord serum PCB levels. At the age of four, some children of the original group were found to have poorer short-term memory on both verbal and quantitative tests. A separate study of the same group of children demonstrated that PCBs were still present in the blood of over 50% of the children and that mothers' milk was the primary source of exposure. In statistical terms, prolonged breast-feeding was associated with increases in PCB burdens. While much larger quantities of PCBs are transferred to children through breast-feeding, the transfer of contaminants through the placenta seems more important in terms of the developmental effects noted.

These studies are important because they provide initial evidence of the effects of Great Lakes contaminants on human populations. An unpublished study of the offspring of women who consumed fish from Lake Michigan apparently contradicts the findings regarding weight and size of newborns, however, the available documentation does not contain many details and it is difficult to compare the results with the first group.

Given the implications of the association between environmental contaminants and birth outcomes, further research is needed to clarify the relationships between exposure, contaminant levels and developmental effects in other exposed groups and to more precisely identify the causative agents.

Possible Impacts of Specific Pollutants

"Fish and wildlife in the Great Lakes basin have been hurt by toxic chemicals and the information on human health ... indicates that people are being affected as well. The scale of effects of toxic chemicals on human health cannot be determined ... but we feel that it is significant and warrants concern."
Tom Muir and Ann Sudar

Human beings are exposed to a myriad of chemical contaminants. Information on individual chemicals is important as it enables an assessment of the potential toxic effects of human exposure and possible control of the chemical's use. Summary information on a number of toxic substances identified as critical pollutants by the Water Quality Board of the International Joint Commission is provided in Appendix I. The best possible estimates of exposures of average Canadian consumers to individual chemicals are currently below a level of concern; however, consumption of large amounts of freshwater fish containing PCBs, dioxins, furans, lead, or mercury could pose a significant risk to health. Concentrations of contaminants in Canadian drinking water are usually far below current federal guidelines and in most cases contribute only minor amounts to an individual's daily intake.

Recently, sophisticated studies have been conducted on the adverse effects on health of PCBs, lead, mercury, dioxins and furans. Although the subtle effects reported in these studies on the development of the nervous system in children have not been fully substantiated, there is enough evidence to conclude that some sustained environmental exposures may be injurious.

While there is toxicological information in the scientific literature on chemicals acting individually, there are only a few data on their effects as mixtures. Furthermore, there are only limited data on contaminant levels that can be used for estimating exposure. Assessment of the effects of individual chemicals should be complemented with a consideration of the interactive effects of simultaneous exposure to mixtures of chemicals. Despite the possibility that chemicals in the environment act synergistically (3 + 3 = 7 or more), limited scientific evidence available suggests that the mode of action of a mixture of chemicals within an organism is likely to be additive (3 + 3 = 6) or antagonistic (3 + 3 = 5 or less).

There are often similarities in toxic effects and mechanisms of action between different contaminants of similar families. For example, chlorinated organic chemicals such as PCBs, polybrominated biphenyls, mirex, hexachlorobenzene, dieldrin, DDT, dioxins, and furans all cause enzyme induction and, at sufficient dosage, liver damage. Concurrent exposures to low levels of these contaminants have caused effects in experimental animals and are associated with effects in wildlife populations.

As research tools have become more refined, several subtle effects have been observed at extremely low concentrations. Three of the most frequently described effects associated with synthetic organic contaminants are interference of cell-to-cell communication, enzyme induction and disruption of the control of endocrine hormones. These effects on cellular processes may not immediately threaten health or lead directly to disease or death. They indicate that natural regulatory mechanisms are being activated or suppressed and that some processes are being altered. While the direct implications of these effects in humans are unclear, they are undesirable and support the need to reduce our exposure to substances that cause these effects.

7

Synthesis

The Great Lakes basin is a contaminated ecosystem. Monitoring data collected since the early 1970s show that persistent toxic chemicals are present in the water and sediments, fish, wildlife and humans. These chemicals have been associated with effects observed in the fish, wildlife and the human residents of the basin.

In the 1970s and 1980s, restrictions imposed on the uses of organochlorine pesticides, PCBs and mercury in Canada and the United States led to the reduction of their input to the biosphere; however, organochlorine chemicals, toxic metals and aromatic hydrocarbons are extremely persistent. The overall contamination of the Great Lakes, though lower than in the 1970s, is being maintained at current levels due to the resuspension of contaminated sediments, the deposition of airborne toxics, the slow leaching of contaminants from hazardous waste sites and, possibly, runoff from historically contaminated agricultural land. The uncontrolled discharge from municipal sewage systems during some rainstorms and unregulated or accidental industrial releases also contribute contaminants to the ecosystem. As a result, fish, wildlife and humans in the Great Lakes basin ecosystem will continue to be exposed to contaminants for some time to come.

Laboratory and field studies of fish and wildlife have established that many of the chemicals present in the Great Lakes basin can cause adverse effects in a wide range of species. Non-chemical factors also play a role. The interaction of these factors is even more complex in humans. It is difficult to establish that exposure to a particular environmental chemical caused a particular effect in fish, wildlife or humans. It is common for researchers to confirm associations between exposure and effects. Perhaps the best-known example of a cause and effect relationship is between DDT/DDE and eggshell thinning in fish-eating birds.

Since there are biological similarities between wildlife and humans, wildlife species are useful surrogates in assessing the potential for human health effects. At present, the data suggest that neurobehavioural and developmental effects occur in both wildlife and humans exposed to similar mixtures of toxic substances.

There remains the question whether the health of people living in the Great Lakes basin ecosystem is affected by their continued exposure to persistent toxic substances. While traditional measures of human mortality and disease incidence have not indicated that the health of Canadians is affected by toxic chemicals, there is good reason to believe that exposure to persistent toxic contaminants poses a risk to human health. The precise nature and extent of that threat are at present unclear. The most thorough study of subtle adverse effects in the Great Lakes basin to date has shown that there are adverse effects in the children of women who ate contaminated fish from Lake Michigan. It is clear that there are people who are at greater risk than average because they are either more heavily exposed (e.g., nursing infants and those people who eat large amounts of contaminated fish) or are more susceptible (e.g., the developing fetus, newborns, the elderly and those who are in poor health). These "at-risk groups" must be provided with the means by which they can reduce their exposure.

Lack of full scientific understanding of the behaviour of persistent toxic chemicals in the environment and their modes of action within an organism raises the possibilities that there may yet be new means of exposure and undiscovered adverse effects. While researchers are accelerating studies investigating the relationship between exposure to toxic chemicals and human health effects, it is essential that all sectors of society move to reduce the contamination of the environment.

The goal of virtual elimination of persistent toxic substances in the Great Lakes basin can only be achieved if there is a change in attitude and behaviour on a broad scale. Changes are required in individual actions, corporate strategies, and regulatory initiatives by government agencies. Actions needed include the cleanup of contaminated areas, the prevention of further contamination through close-looped industrial processes and, more fundamentally, the substitution of substances that are less toxic and persistent than those we currently use.

The convergence of human needs with a respect for all forms of life can lead to a balanced use of the earth's resources. The co-operation of all levels of society is needed to reduce further the concentrations of contaminants in the environment.

Appendix I

Critical Pollutants

Many chemicals have been identified in the Great Lakes basin. While toxicity profiles have been prepared for nearly 200 of these, there are insufficient data on most of these to assess the extent of human exposure. This appendix contains a review of information on the 11 chemicals identified as critical pollutants in the Great Lakes basin ecosystem. Although they are treated separately, their presence as mixtures in the environment is of concern. Assessments regarding the threat to human health of each of these chemicals are based on a consideration of the Tolerable Daily Intake discussed in Chapter 3.

Chlorinated Organic Chemicals

PCBs (polychlorinated biphenyls)

PCBs are a group of chemicals used in electrical and hydraulic equipment, lubricants and in many other fluids because they are chemically stable and heat resistant. They are persistent and ubiquitous in the environment. PCBs will continue to cycle through the environment although they are no longer manufactured and new uses are restricted. It has been estimated that there are more PCBs still in use than have been released to the environment to date. PCBs are found at higher concentrations in top predator fish from the Great Lakes, and one study has found an association between maternal consumption of Great Lakes fish, levels of PCBs in maternal serum and delays in certain measures of neurobehavioural development in the infants. Further research is needed to see if these effects are caused by PCBs or by other chemicals that are often found with PCBs.

Mirex

Mirex is an extremely persistent insecticide. In sunlight, it breaks down slowly to photomirex. Both mirex and photomirex are toxic. Although mirex was never used in the Great Lakes basin for agriculture, it is present in the Lake Ontario food web because of industrial releases into the Niagara and Oswego rivers during its manufacture. All uses in Canada were banned in 1978, as was its use as an insecticide in the United States. Since the 1970s, the levels of mirex have decreased in lake trout and coho salmon; levels in herring gull eggs during this same period have not decreased appreciably. Mirex also has been identified in the tissues of people living in the Great Lakes basin. Exposure to mirex at levels currently found in Great Lakes fish is not a threat to human health provided that fish advisories are followed.

HCB (Hexachlorobenzene)

Hexachlorobenzene is a persistent chemical that was originally manufactured as a fungicide for cereal crops. Its use was restricted in Canada in 1971. It is also generated as a contaminant or by-product in the manufacture of pesticides, and it can be formed during the combustion of substances containing chlorine. This compound is ubiquitous and it is found in the tissues of fish, wildlife and humans from the Great Lakes basin. In the 1970s, levels of HCB were present at low concentrations in fish from the Great Lakes. Consumption of reasonable quantities of fish by adults still leaves a considerable margin of safety in relation to adverse health effects observed from this chemical in experimental animals. The intake per unit of body weight by nursing infants is significantly higher than that by most adults because hexachlorobenzene is often present in breast milk. Current environmental levels of hexachlorobenzene are not a threat to health.

Dieldrin

Dieldrin is a persistent toxic chemical that was used mainly as a soil insecticide. It is no longer manufactured in Canada or the United States, and its use is now restricted to applications for termite control. Levels of dieldrin in the environment have not decreased as much as levels of other pesticides. Dieldrin continues to enter the aquatic environment as leachate. Current levels of dieldrin in fish from the Great Lakes are not a hazard to human health.

DDT

DDT was introduced into North America in 1946 as an insecticide. Its use was restricted in Canada in 1974 and suspended in 1985. In 1989, the last permitted use was banned. The levels of this chemical and its principal metabolite, DDE, have decreased significantly although concentrations in wildlife and fish have now equilibrated. DDT is still used elsewhere in the hemisphere and may be entering the Great Lakes through atmospheric transportation and deposition. DDE is stored in the fatty tissues of fish, birds and mammals, including humans. DDE was identified as the cause of eggshell thinning in many birds and has since been found to disrupt endocrine hormone metabolism and to change the activity of liver enzymes. Studies have also associated high levels of DDE in breast milk with hyporeflexia in newborn infants, but further investigation is needed to substantiate this finding and to determine if DDE is the causative agent. Current levels of DDT/DDE in Great Lakes fish are not a hazard to human health.

Dioxin (2,3,7,8-TCDD)

The compound 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) is the most toxic member of a group of chemicals known as polychlorinated-dibenzo-p-dioxins (PCDDs). It is highly persistent and bioaccumulates. Dioxins enter the environment as the by-products of industrial processes. The most significant sources are pulp and paper mills using chlorine in the bleaching process and chlorophenoxy herbicide production. Dioxins are released as the result of combustion processes in incinerators and motor vehicles using leaded fuel. As a result, dioxins are ubiquitous in the environment and are found in human tissues. Current average exposures to 2,3,7,8-TCDD and total dioxins and furans are below the Tolerable Daily Intake established by Health and Welfare Canada. Individuals consuming large amounts of freshwater fish contaminated with dioxins and furans increase their health risks. The 2,3,7,8-TCDD congener is an animal carcinogen. Other observed effects include immune suppression, hormonal disruption and developmental problems. Accidental exposures of humans to 2,3,7,8-TCDD have commonly resulted in chloracne. Efforts to control the sources of dioxins must be vigorously maintained because of the effects seen after long-term exposure in rats and monkeys.

2,3,7,8-TCDF

The compound 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) is a polychlorinated dibenzofuran (PCDF). PCDFs are structurally and chemically similar to PCDDs. They are not produced intentionally and result from some of the same industrial processes listed for PCDDs. In general, 2,3,7,8-TCDF is ten times less toxic than 2,3,7,8-TCDD, but has similar toxicological properties. It also tends to bioaccumulate in fat. Although the total average Canadian exposure to 2,3,7,8-TCDD-like compounds is below the Tolerable Daily Intake, efforts to control the sources of both PCDDs and PCDFs must be vigorously maintained.

Toxaphene

Toxaphene is a contact insecticide that consists of a complex mixture of chlorinated camphenes. It was widely used in the United States on cotton crops until the late 1970s. Between the late 1970s and early 1980s, the use of toxaphene ceased almost completely and its manufacture was banned in the United States in 1982. While there are only limited data available, the current levels of toxaphene in Great Lakes fish are highest in Lake Superior because of continued atmospheric inputs. Nevertheless, toxaphene exposure from average fish consumption is not a hazard to health.

Polynuclear Aromatic Hydrocarbons

Benzo[a]pyrene

Benzo[a]pyrene (B[a]P) is one of several polynuclear aromatic hydrocarbons (PAHs) that are formed by the incomplete combustion of fossil fuels, wood and tobacco, the incineration of garbage, as well as in steel and coke production and coal liquification and gasification. B[a]P is present at high levels in sediments of specific industrialized areas within the basin. The major route of human exposure to B[a]P is through food with minor contributions from air and water. Ingested B[a]P is not associated with an increased human cancer incidence. Inhalation of large amounts of B[a]P can cause cancer in humans especially in occupational exposure. Under laboratory condition B[a]P is an animal carcinogen. The presence of B[a]P in lake and river sediments is associated with a high incidence of liver tumours in fish.

Toxic Metals

Mercury

Mercury is a non-essential natural element and is a ubiquitous contaminant in air, water and food. Food is the major source of human exposure to mercury. Fish and seafood are major contributors to human intake because of the propensity of organic mercury to bioaccumulate. In the past, mercury was widely used as a slimicide in the pulp and paper industry and formerly in the manufacture of chlorine and caustic soda (chlor-alkali process) and was subsequently discharged to the water. Due to a number of documented episodes of serious mercury toxicity, government actions led to the substitution of mercury in these processes. Reductions in industrial releases of mercury have resulted in a decrease in mercury levels in fish and the restoration of some commercial fisheries in the Great Lakes (walleye in Lake Erie). There are still many advisories on sport fish (e.g., trout and walleye) as a result of mercury contamination from industrial and natural sources. Methyl mercury has been cited as the possible cause of a neurological disease in some native communities which consume large amounts of contaminated fish. It is also a neurotoxin and a developmental toxin in animals.

Alkylated Lead

Alkyl lead compounds (e.g., tetraethyl lead) are produced mainly as lead additives for gasoline. Single acute doses of tetraethyl lead are at least 20 times more toxic than equivalent doses of inorganic forms of lead. Levels of alkylated lead in the environment have decreased since 1981 and will continue to decrease as it is phased out of gasoline. The presence of alkyl lead in the terrestrial environment, especially in urban areas, has been associated with adverse effects on children. Its presence in the Great Lakes basin should be carefully assessed. Alkyl lead should not pose any risk to human health, provided fish consumption guidelines are followed. This conclusion is based on data on alkyl lead residues in fish from the two most contaminated rivers (St. Lawrence and St. Clair).

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Further Reading

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Glossary

Definition of terms as used in this synopsis.

Bioaccumulation

A general term describing a process by which chemical substances are ingested and retained by organisms from the environment directly or through consumption of food containing the chemicals. For a discussion of **biomagnification** please see page 11.

Carcinogen

A substance which induces cancer in a living organism.

Congenital anomalies

Birth defects.

Contaminant

A substance foreign to a natural system or present at unnaturally high concentrations.

Dioxin equivalent

A relative measure of toxicity expressed as enzyme induction in rat liver tissue culture. Dioxin-like chemicals (e.g., PCBs, furans) are compared to the most toxic dioxin congener (2,3,7,8-TCDD).

Effluent

A complex waste material (e.g., industrial liquid stream or municipal sewage) which is discharged into the environment.

Embryotoxicity

Adverse toxic effects of chemical agents on the developing embryo.

Epidemiology

The study of the prevalence and spread of disease in a community.

Indicator species

A species that can provide an integrated measure of environmental changes. In this report, species are selected that accurately reflect contaminant levels in their environment or because they give "early warnings" of adverse health effects.

Long range atmospheric transport

The movement of chemical substances present locally to a remote location often over a number of days or weeks via the atmosphere.

Organochlorine

A complex organic molecule with chlorine atoms attached. These chlorinated organic chemicals (e.g., organochlorine pesticides) are manufactured but can also be produced in combustion or formed in waste disposal sites.

Organohalogen

A complex organic molecule with atoms of fluorine, chlorine, bromine and/or iodine attached. These chemicals are commercially manufactured but can also be produced in combustion or formed in waste disposal sites.

Persistent toxic substance

Any toxic substance that is difficult to destroy or that degrades slowly, i.e., with a half-life in water greater than eight weeks.

Reproductive success

The proportion of reproductive attempts which produce healthy, independent young.

Resuspension

The remixing of sediment particles and pollutants back into the water by storms, currents, organisms and human activities such as dredging.

Teratogen

An agent that increases the incidence of congenital malformations (birth defects).

Toxic substance

A substance that can cause death, disease, birth defects, behavioural abnormalities, genetic mutations or physiological or reproductive impairment in any organism or its offspring or that can become poisonous after concentrating in the food web or in combination with other substances.

Toxicology

The study of the adverse effects of chemical agents on biological systems.

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