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Waters of Lake Huron and Lake Superior: Volume 2, Part A: Lake Huron, Georgian Bay, and the North Channel: Report to the International Joint Commission by the Upper Lakes Reference Group

Upper Lakes Reference Group

M. P. Bratzel

M. E. Thompson

R. J. Bowden

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UPPER LAKES
REFERENCE GROUP

INTERNATIONAL JOINT COMMISSION

THE WATERS OF LAKE HURON AND LAKE SUPERIOR
VOLUME II (Part A)
LAKE HURON, GEORGIAN BAY, AND THE NORTH CHANNEL

THE WATERS OF LAKE HURON AND LAKE SUPERIOR

VOLUME II (Part A)

LAKE HURON, GEORGIAN BAY, AND THE NORTH CHANNEL

REPORT TO THE
INTERNATIONAL JOINT COMMISSION
BY THE
UPPER LAKES REFERENCE GROUP

EDITORIAL COMMITTEE

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R.J. BOWDEN

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1977

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Ottawa, Ontario K1P 5H3

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The patient does not recover health by hearing the medicine described.

Epigram from the Ming Dynasty

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CHAPTER 1
DESCRIPTION OF STUDY AREA

1 DESCRIPTION OF STUDY AREA

INTRODUCTION

Water uses and related water quality problems are determined by natural conditions and how they have been altered by the economic activities of man. Natural conditions include the natural stream flows of surface streams which supply water to the lake; the main water body of the lake; climate which determines the amount and form of precipitation; geology, hydrogeology, and physiography which determine the types of soils, their ability to produce food and fibre, susceptibility to erosion, and the amount and quality of ground water. These natural conditions are then altered by economic and land use activities such as agriculture, industry, urbanized areas, and forestry. These uses generate pollutant loads, and create a demand for public and industrial water supplies, water-borne commerce, water-oriented recreation, and fisheries. Water quality management is concerned with minimizing the impact of economic and land use activities on water quality and with maintaining water quality that will support the water uses demanded.

The purpose of the Upper Lakes Reference study is to assess the impact that this economic activity has had on Lake Huron and Lake Superior and to provide information for future water quality management. Volume II summarizes the results of many individual project reports on Lake Huron and provides the basis for discussions, conclusions, and recommendations provided in Volume I. Lake Huron and its drainage basin are shown in Figure 1-1.

PHYSICAL FEATURES

CLIMATE

Lake Huron is located at the convergence of diverse air masses from the Arctic Ocean, Pacific Ocean, Gulf of Mexico, and the Atlantic Ocean. Their access to the basin is relatively unobstructed, resulting in a climate characterized by four distinct seasonal patterns and extremes of weather throughout the year. During the summer, Pacific air masses predominate nearly half of the time. It is during these occurrences that extremely high temperatures may occur. Frequent periods of uncomfortably hot, humid, tropical weather are caused by air masses which originate over the Gulf of Mexico. However, stations north of the lake have fewer than six months with mean temperatures above 10°C (1). In winter, mean daily temperatures below freezing may last four months. Extreme lows of -45°C have been recorded during spells of cold Arctic air. Pacific air masses enter the basin from the west as cool, dry air or from the south as cool, moist air. In addition to these large air mass patterns, cyclonic storms, which originate over western North America and the Pacific Ocean, frequently pass through the basin.

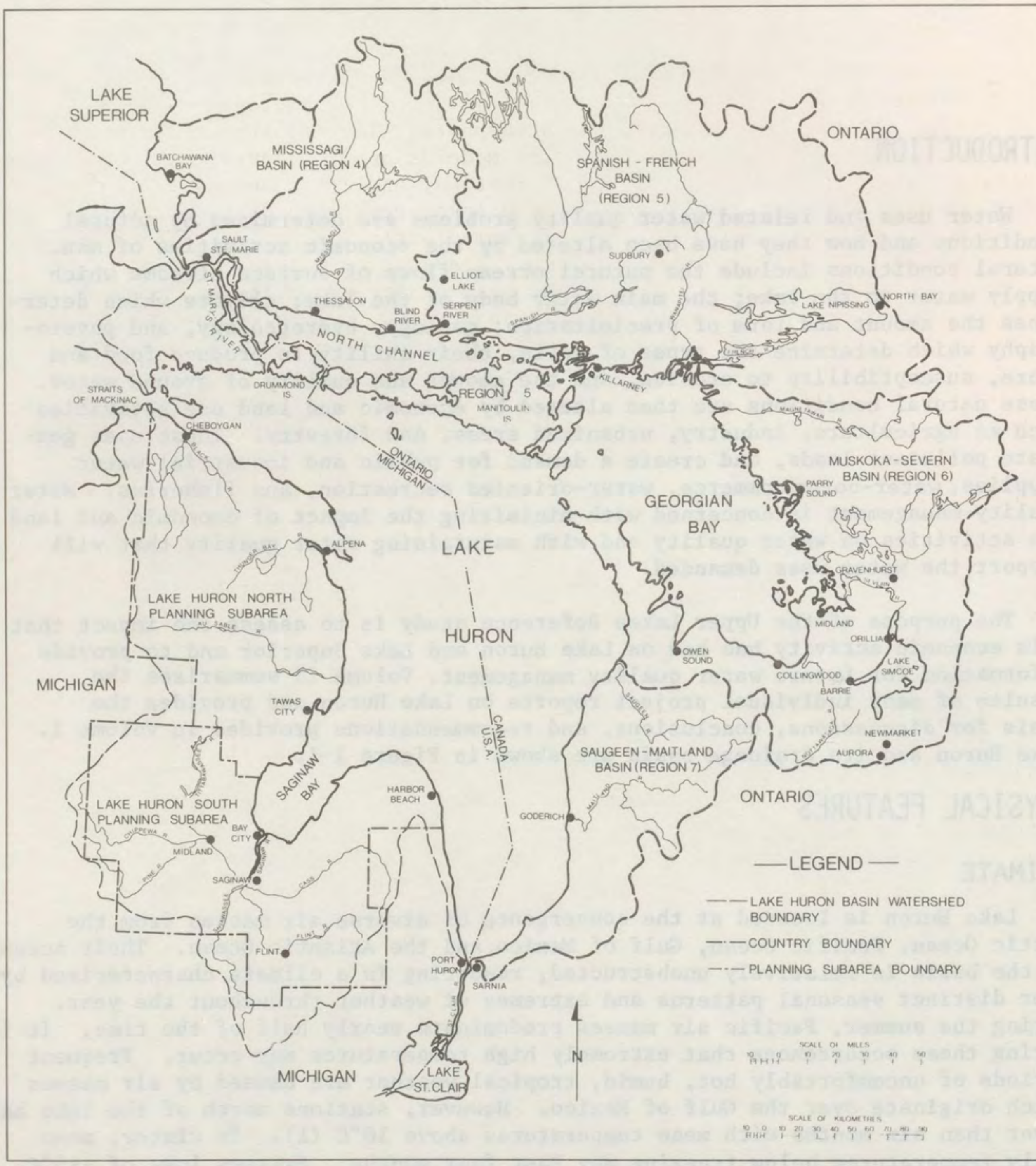

FIGURE 1-1 LAKE HURON BASIN AND STUDY AREA

Spring and autumn are periods of transition. An average of six or seven storms a month produces changeable weather as frontal systems move rapidly, bringing considerable cloud cover and frequent, wide-spread rain. Between storms, warm summy days and crisp, cool nights make these seasons pleasant times of the year.

Due to its size, Lake Huron modifies the climate around it. With such a large volume the lake acts as a vast reservoir for the storage of heat energy and its subsequent exchange with the atmosphere. The lacustrine effects are manifested in a numer of ways, including moderation of temperature, augmentation or suppression of precipitation, fog formation, and increased wind strength. Precipitation on the water surface of the lake provides a direct contribution to water supply and affects lake levels immediately. Annual precipitation on the lake surface averages about 81.1 cm. Evaporation has an important effect on the availability of water and on the heat budget since it is a cooling process. Average annual evaporation is about 66.0 to 71.6 cm, depending on atmospheric conditions (Figure 1-2). The wind can transport pollutants originating inland out over the lake. These pollutants then may enter the lake by diffusion, gravitational settling, or as dissolved and suspended material in precipitation. The prevailing winds determine whether air-borne pollutants will be carried over the lake (Figure 1-3).

HYDROLOGY

Lake Huron is made up of four interconnected bodies of water: the main lake, Saginaw Bay, North Channel, and Georgian Bay (see Figure 1-1). Lake Huron is the second largest of the Great Lakes in water surface area and third in volume. The land area of its drainage basin is 131,000 km^2 and the water surface area is 59,570 km^2 (2). At low water datum, Lake Huron contains 3,540 km^3 of water, has a maximum depth of 229 m and an average depth of 59 m. The total shoreline length including islands is 6,159 km. The long-term average annual precipitation over the Lake Huron drainage basin for the period 1900-1972 was 79.2 cm (2). Fifty-seven percent of the annual precipitation which falls on the land portion of the basin is lost by evaporation and evapotranspiration. Losses from evaporation from the lake surface are 66.0 cm to 71.6 cm per year, depending on atmospheric conditions. Evaporation losses are smallest in spring and greatest in the fall and early winter.

The mean annual runoff for the period 1935-1964 was estimated to be 34.3 cm, about 43% of the average annual precipitation for that period. High runoff occurs generally during March or April due to snowmelt, and low runoff occurs during August and September. During the period of low surface runoff, streams draw a significant amount of water from groundwater, particularly streams located on the eastern shore of Lake Huron. Lake Huron and Lake Michigan stand at virtually the same level since they are connected by the broad and deep Straits of Mackinac, and as a result they are hydrologically considered to be one lake. Average net inflow from Lake Michigan to Lake Huron is estimated to be about 1,400 m^3/s. The St. Marys River is the other major inflow, draining 2,100 m^3/s from Lake Superior. Lake Huron discharges at its southern end through the St. Clair River into Lake St. Clair, which in turn discharges through the Detroit River into Lake Erie. The average outflow of Lake Huron for the period 1900-1972 was 5,070 m^3/s.

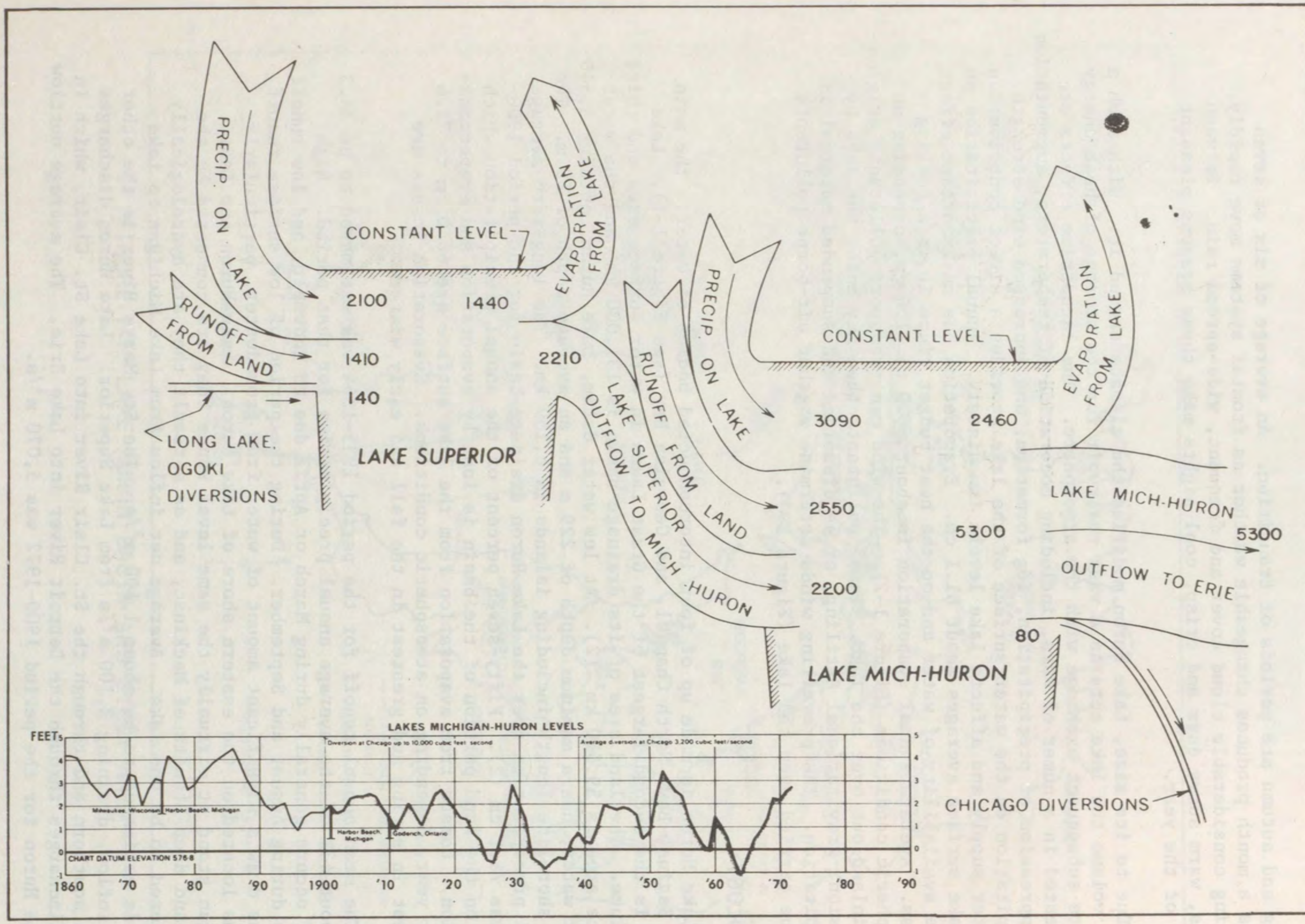

FIGURE 1-2 WATER BALANCE FOR THE UPPER LAKES.

Outflows adjusted so that supplies to the lakes equal withdrawals, i.e., to condition of no change in lake storage. Values are in cubic metres per second.

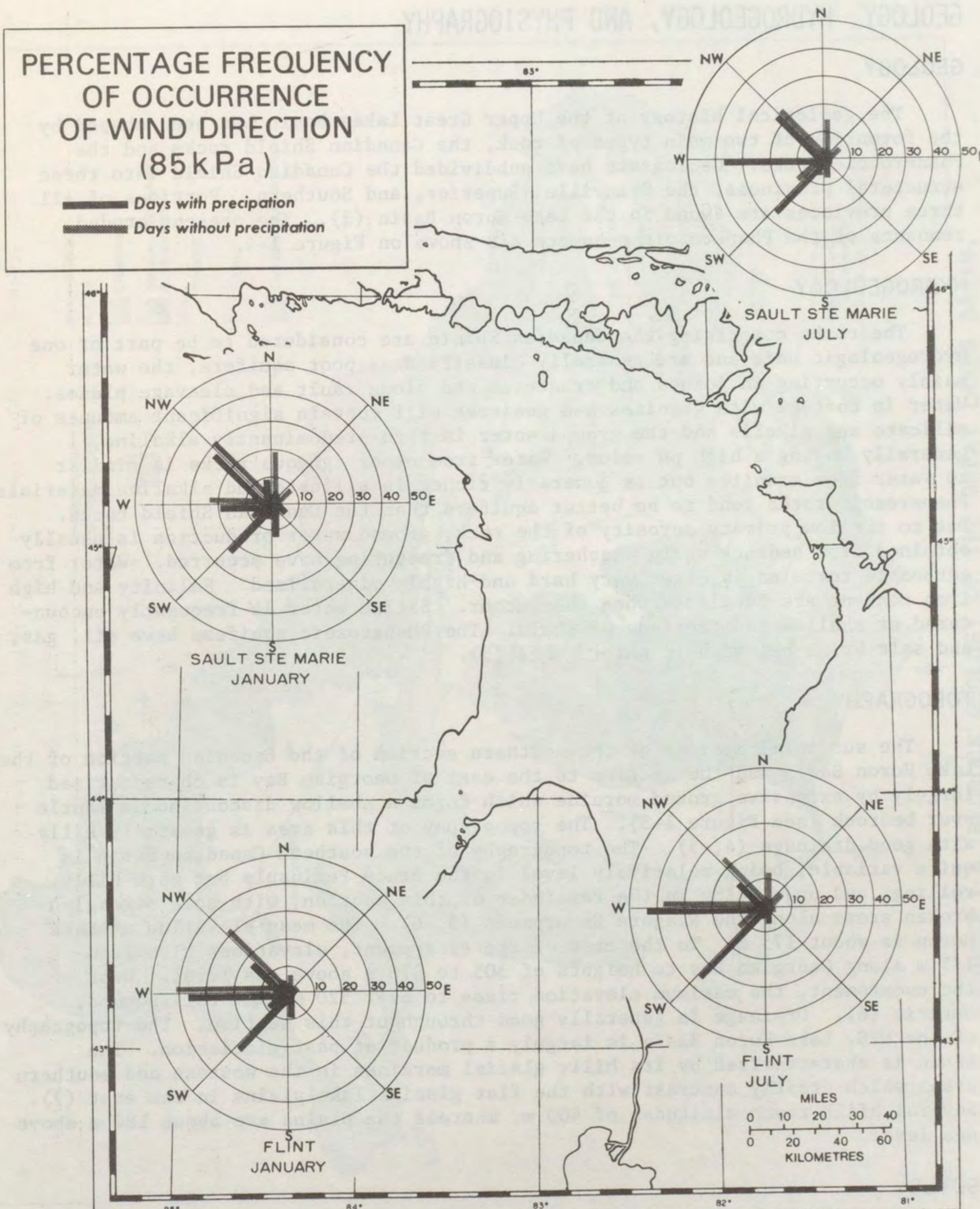
PERCENTAGE FREQUENCY
OF OCCURRENCE
OF WIND DIRECTION
(85 kPa)
Days with precipation
Days without precipitation
SAULT STE MARIE
JULY
SAULT STE MARIE
JANUARY
FLINT
JANUARY
FLINT
JULY
N
NE
E
SE
S
SW
W
NW
10
20
30
40
50
MILES
KILOMETRES
0
10
20
30
40
60
85°
84°
83°
82°
81°
46°
45°
44°
43°

FIGURE 1-3

GEOLOGY, HYDROGEOLOGY, AND PHYSIOGRAPHY

GEOLOGY

The geological history of the Upper Great Lakes Basin has been shaped by the formation of two main types of rock, the Canadian Shield rocks and the Phanerozoic rocks. Geologists have subdivided the Canadian Shield into three structural provinces, the Grenville, Superior, and Southern. Portions of all three provinces are found in the Lake Huron Basin (3). The present eroded remnants of the Phanerozoic sequence are shown on Figure 1-4.

HYDROGEOLOGY

The rocks comprising the Canadian Shield are considered to be part of one hydrogeologic unit and are generally classified as poor aquifers, the water mainly occurring in joints and fractures and along fault and cleavage planes. Water in contact with granites and gneisses will contain significant amounts of silicate and alkalis and the ground water is then predominantly alkaline, generally having a high pH value. Water from other igneous rocks is similar to water from granites but is generally richer in silicate and alkaline materials. Phanerozoic rocks tend to be better aquifers than the Canadian Shield rocks. Due to the low primary porosity of the rock, ground water production is usually obtained from bedrock where weathering and fracturing have occurred. Water from carbonate terrains is often very hard and highly mineralized. Salinity and high iron content are localized when they occur. Saline water is frequently encountered at shallow penetrations of shale. The Phanerozoic aquifers have oil, gas, and salt brine below their water zones (3).

TOPOGRAPHY

The surficial geology of the northern section of the Canadian portion of the Lake Huron Basin and the section to the east of Georgian Bay is characterized largely by extensive ground moraine which forms a shallow discontinuous mantle over bedrock (see Figure 1-5). The topography of this area is generally hilly with good drainage (4, 5). The topography of the southern Canadian Basin is quite variable, being relatively level in the Bruce Peninsula but more hilly, rolling, and undulating in the remainder of this section, with some strongly broken areas along the Niagara Escarpment (5, 6). The mean elevation of Lake Huron is about 175 m. To the east of the escarpment, elevations rise from 175 m along Georgian Bay to heights of 305 to 370 m above sea level. West of the escarpment, the maximum elevation rises to over 520 m near Collingwood, Ontario (6). Drainage is generally good throughout this section. The topography of the U.S. Lake Huron Basin is largely a product of past glaciation. The basin is characterized by its hilly glacial moraines in the western and southern areas which greatly contrast with the flat glacial lake plains in the east (7). Several hills reach altitudes of 400 m, whereas the plains are about 180 m above sea level.

SOILS

North of Lake Huron and east of Georgian Bay in Canada, soils generally are predominantly coarse textured with bedrock at a third of a metre or less (5).

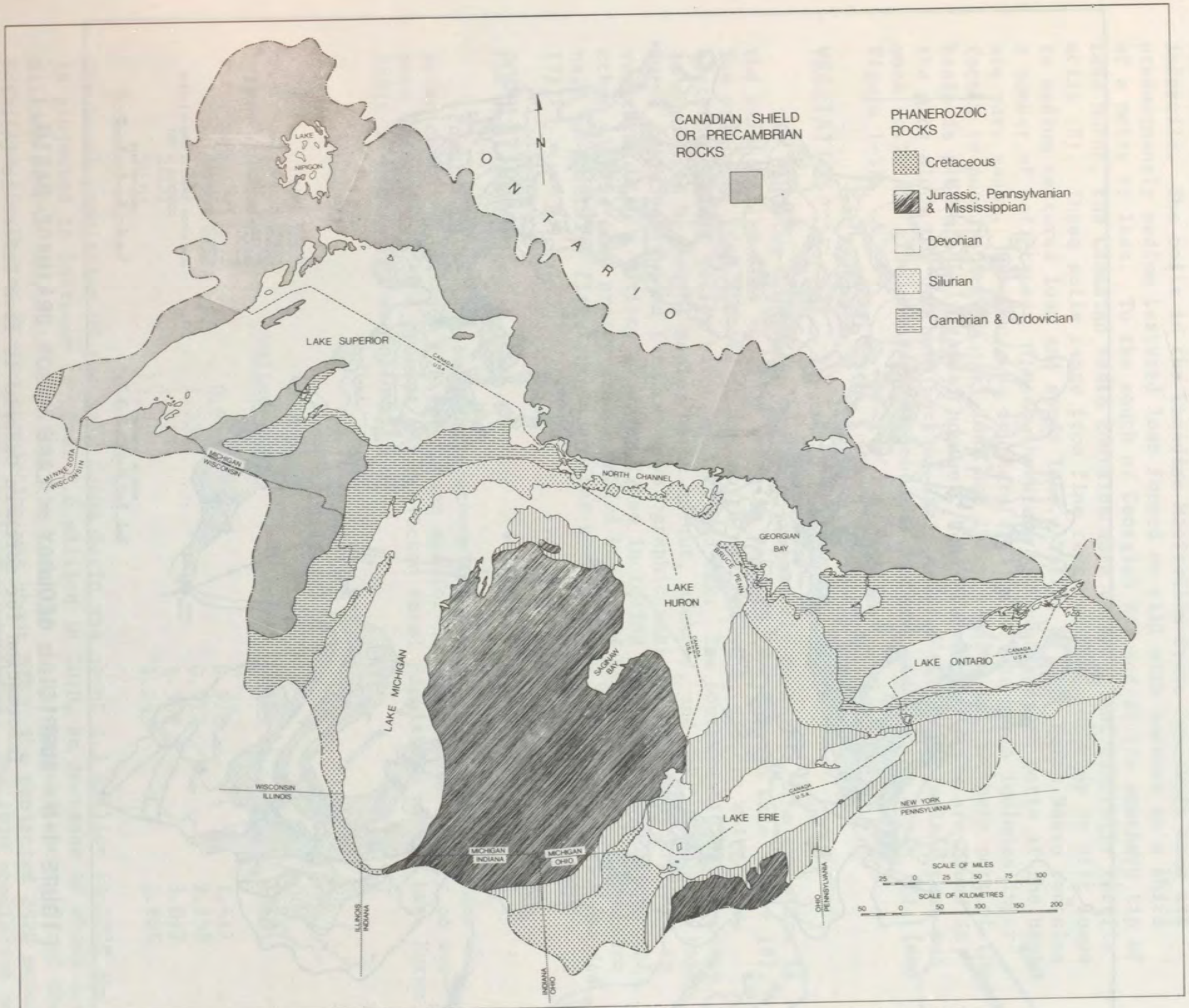

FIGURE 1-4 BEDROCK GEOLOGY OF THE GREAT LAKES BASIN.

Information from Reference (3).

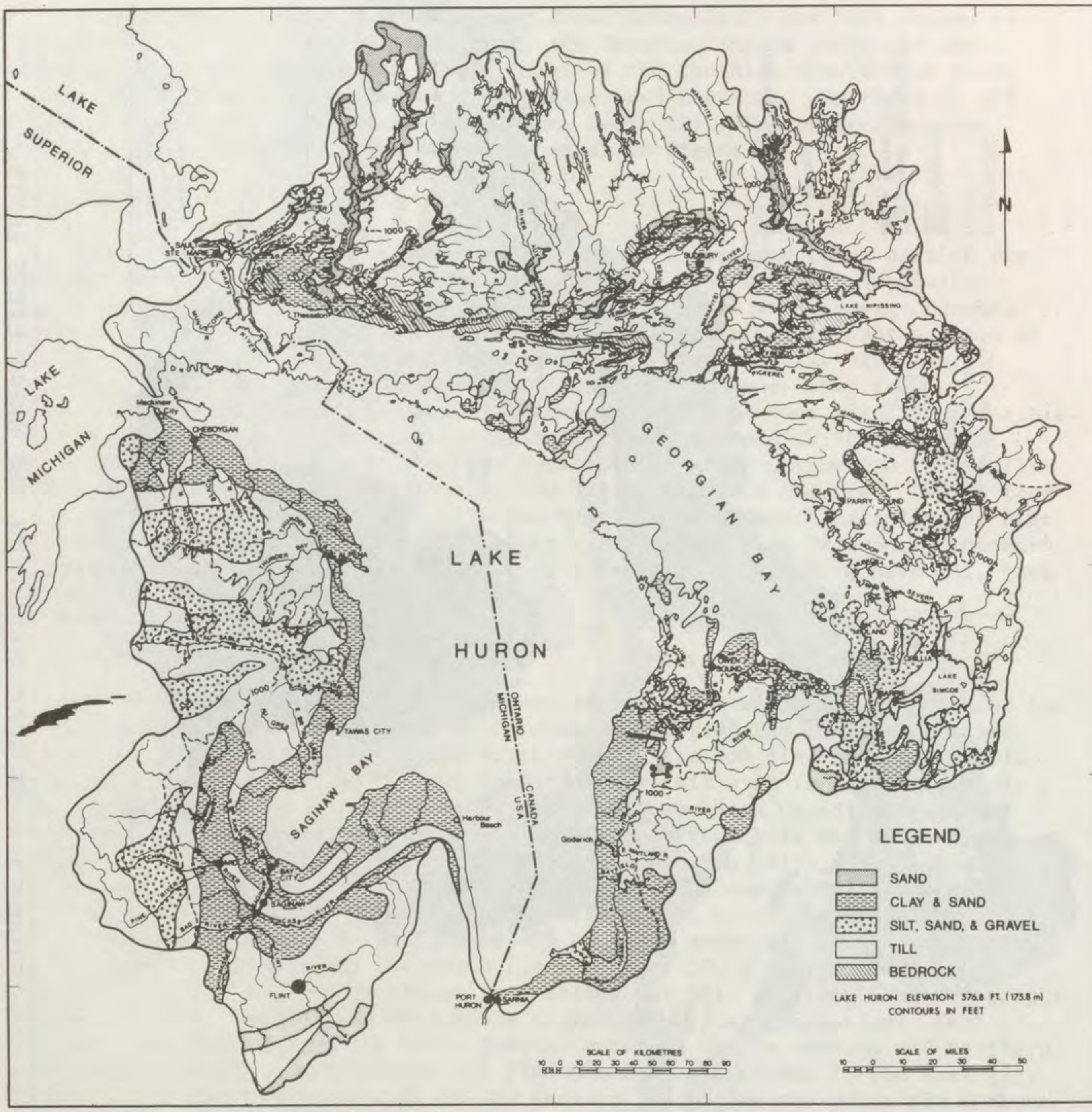

FIGURE 1-5 SURFICIAL GEOLOGY - LAKE HURON DRAINAGE BASIN.
Information for northern Ontario is from Reference (4), southern Ontario from Reference (5), and U.S. from Reference (32).

The soil texture in this area can be described as sandy loam and generally infertile. The soils in the Canadian Manitoulin-Bruce Peninsula area are predominantly medium textured loam formed on till with bedrock at a third of a metre or less. To the south of Georgian Bay and at the southern tip of Lake Huron, the Canadian Basin contains more variable but generally fertile soils (5). These soils range from fine textured soils of clay or silt loams to medium textured loam and sandy loam. The U. S. Lake Huron Basin contains a number of soil-types. The southwestern and southeastern parts of the basin are very sandy. However, the southern section of the basin includes imperfectly to poorly drained clay loam and loamy sands. The northern part of the basin is predominantly sands; however, heavier textured soils are found in the area along the northern part of Saginaw Bay. Extensive lowland peat and muck soils are also found throughout the northern part of the basin (8) (see Figure 1-5).

VEGETATION

The Canadian Lake Huron Basin is extensively forested. The exception is the well settled area south of Georgian Bay and east through Lake Simcoe (9). The principal tree species in the north are red pine, eastern white pine, eastern hemlock, yellow birch, maple, and oak. The southern tip of the basin is dominated by beech, maple, black walnut, hickory, and oak. The U. S. Lake Huron Basin is divided into two physiographic regions. The northern half is vegetated with a variety of cover types including north forest jack pine and other timber, open grassy areas, wooded bogs, and brush lands. The southern half is generally flat terrain and has been heavily farmed and is less wooded (7).

POPULATION

Population and the supporting economic activity that it creates are the prime cause for demands for water uses and for adequate water quality to support those uses. The present and projected total population of the Lake Huron Basin is summarized as follows:

	Population (millions)		
Year	United States	Canada	Total
1950	0.839	0.578	1.417
1970	1.236	0.923	2.159
2000	1.679	1.368	3.047
2020	1.892	1.733	3.625

The total population of the Lake Huron Basin was about 2.2 million in 1970 and is projected to increase to about 3.6 million in 2020, an increase of about 1.4 million or 64% (10, 11). In 1970, the Canadian population was about 43% of the total and the United States population was about 57%. The projected 2020 population is about evenly divided between the two countries. The 1970 population of both the U.S. and Canadian Lake Huron Basin was about 40% rural and 60% urban.

Although the U. S. and Canadian definitions of urban and rural population are not identical, the difference does not cause a major error in comparing population figures. The population distribution of the Lake Huron Basin is summarized on Figure 1-6.

The northern portion of the U. S. Lake Huron Basin is predominantly rural. In 1970 the population of the 11 northern counties was 74% rural, and six had no urban population. In contrast, the population of the southern portion is 60% urban and contains three Standard Metropolitan Statistical Areas (SMSA's) or areas of significant urban and economic development (12). These are Flint, Bay City, and Saginaw, Michigan, all in the Saginaw River Basin. Combined, they contained about 68% of the 1970 population of the U. S. Lake Huron Basin.

In the northern Canadian Lake Huron area, isolated urban communities scattered along road and rail routes dot the largely undeveloped hinterland (13). Settlement has largely been in response to the discovery and exploitation of forest and mineral resources. The Sudbury Census Metropolitan Area or area of significant urban and economic development is the only major population centre. It is located in a large mineral mining and refining area near the northern shore of Georgian Bay. Its 1971 population of 155,424 was about 17% of that in the Canadian Lake Huron Basin. The Canadian Lake Huron Basin south of Georgian Bay was first settled to exploit the lumber resources and later for agriculture. Agriculture has remained the predominant economic activity, but it does not support large urban centres. Since World War II, the eastern Georgian Bay area has rapidly evolved as the "cottage country" of Ontario. The non-resident population greatly exceeds permanent residents in many municipalities of the Canadian Shield, particularly in Parry Sound, Muskoka, and Haliburton.

LAND USE AND DEVELOPMENT

The land use patterns in the Lake Huron Basin are shown on Figure 1-7. Land use and development are discussed under the categories of agriculture, industrial, municipal, and forestry. The Lake Huron Basin Economic Forecast is shown on Figure 1-8. All dollar values in this section have been corrected to 1975 dollars.

AGRICULTURE

Poor soil and a severe climate limit agricultural productivity in the northern areas of the Lake Huron Basin (14, 15). The southern portions have considerably better developed agriculture. Livestock and dairying are the most important agricultural activities in all but a few areas. In the southern section of the U. S. basin cash grain and other field crops predominate, although even in this area livestock sales amount to 40% of farm products sold. This section produces one third of the field bean crop of the entire United States. In Canada, there have been substantial increases in field crops, fruits, and vegetables in the Muskoka-Severn area, but in general, the trend shows a decline of field and forest products and an increase of greenhouse and nursery production. With few exceptions, the trend also shows a decrease of total area under cultivation, number of farms, and an increase in average farm size. In the Saugeen-Maitland area the total area under crops actually increased over the 1951-1971 period. The total land area of the basin is almost 12 million hectares, 3.5 million of it in the U.S. (14) and 8.5 million in Canada (16). Forest range and undeveloped land comprise

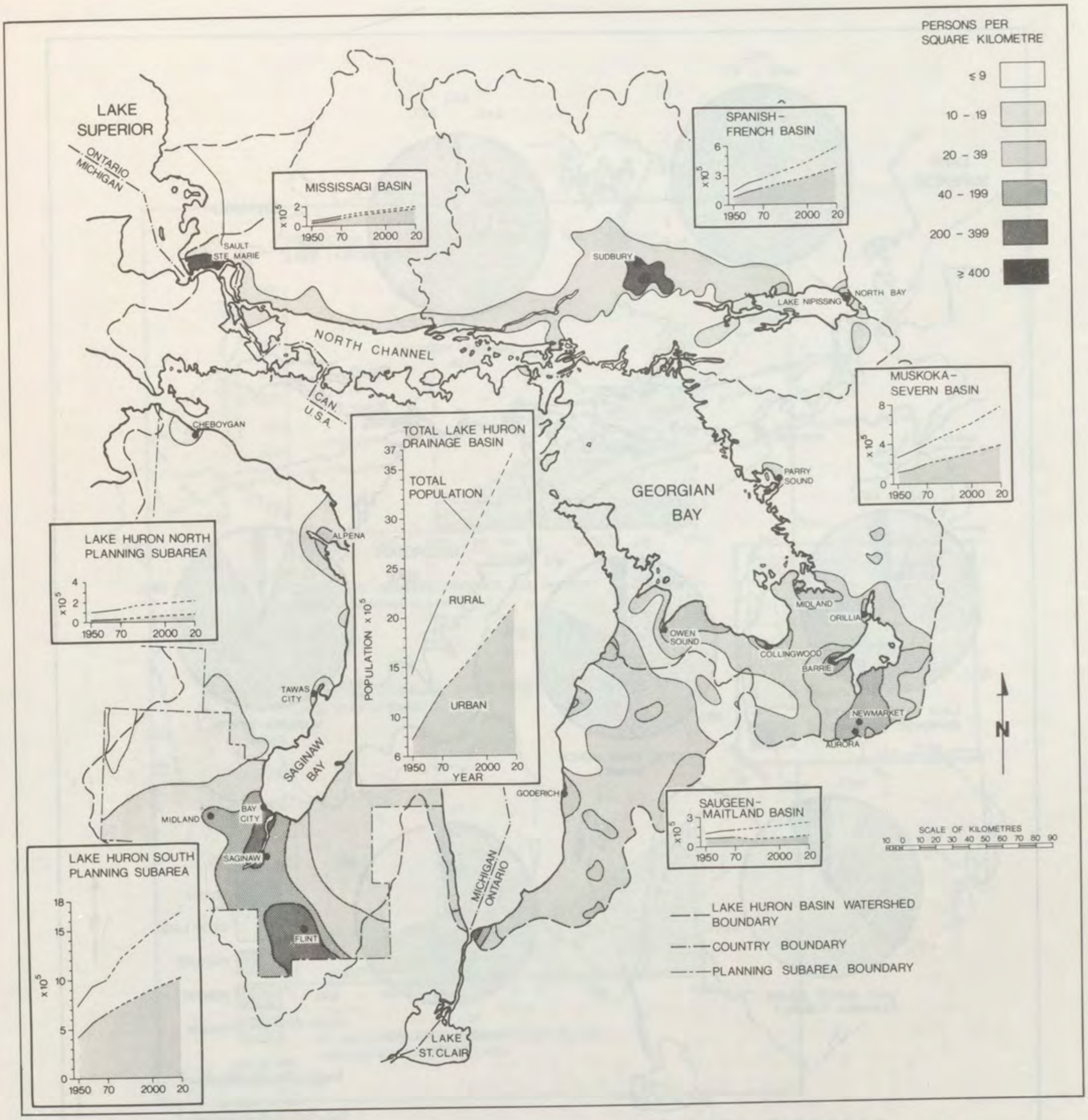

FIGURE 1-6 POPULATION DENSITY DISTRIBUTION AND TRENDS IN THE LAKE HURON BASIN. Information from References (11) and (13).

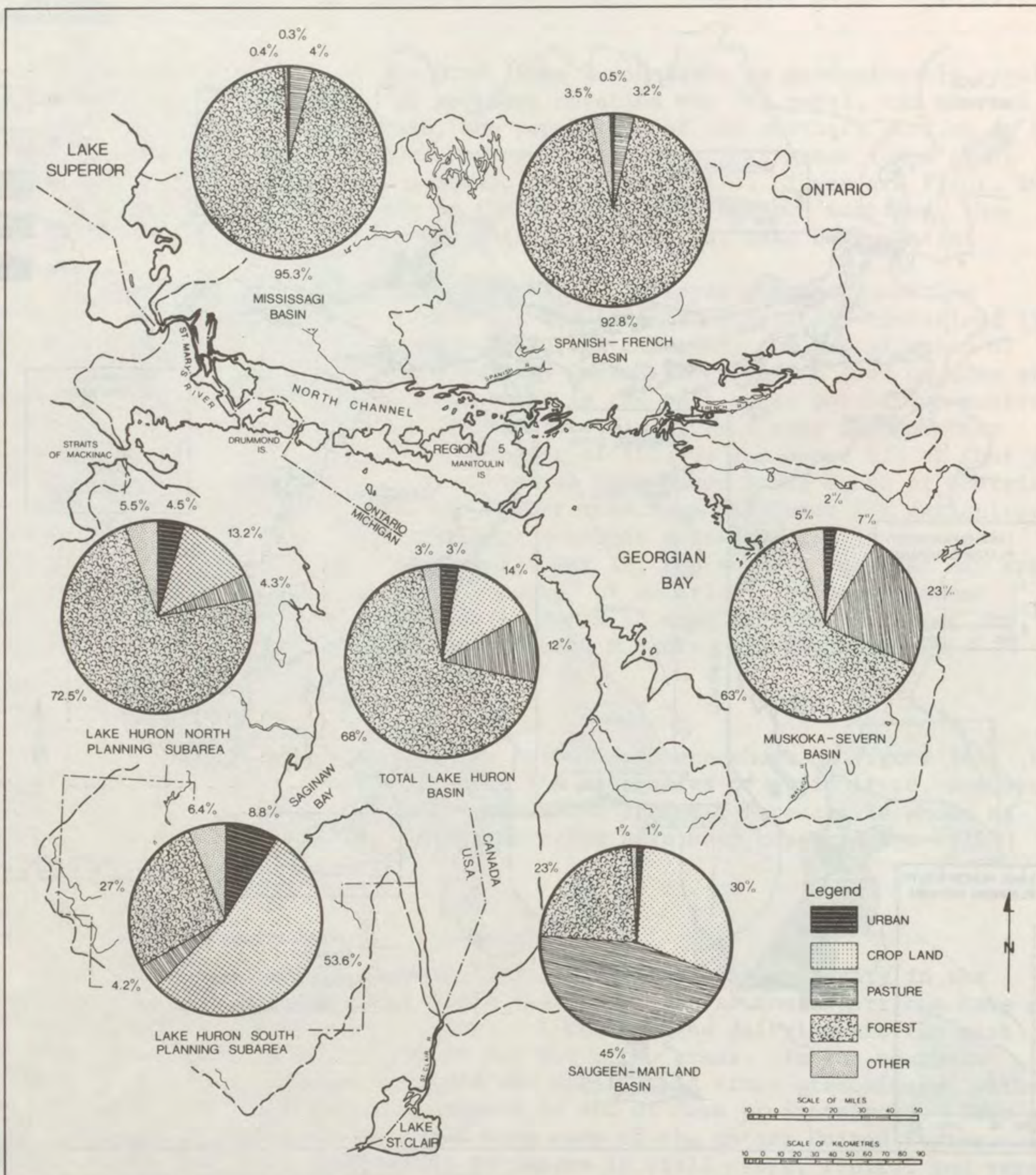

FIGURE 1-7 LAKE HURON BASIN - LAND USE
U.S. information from Reference (14); Canadian information from Reference (16).

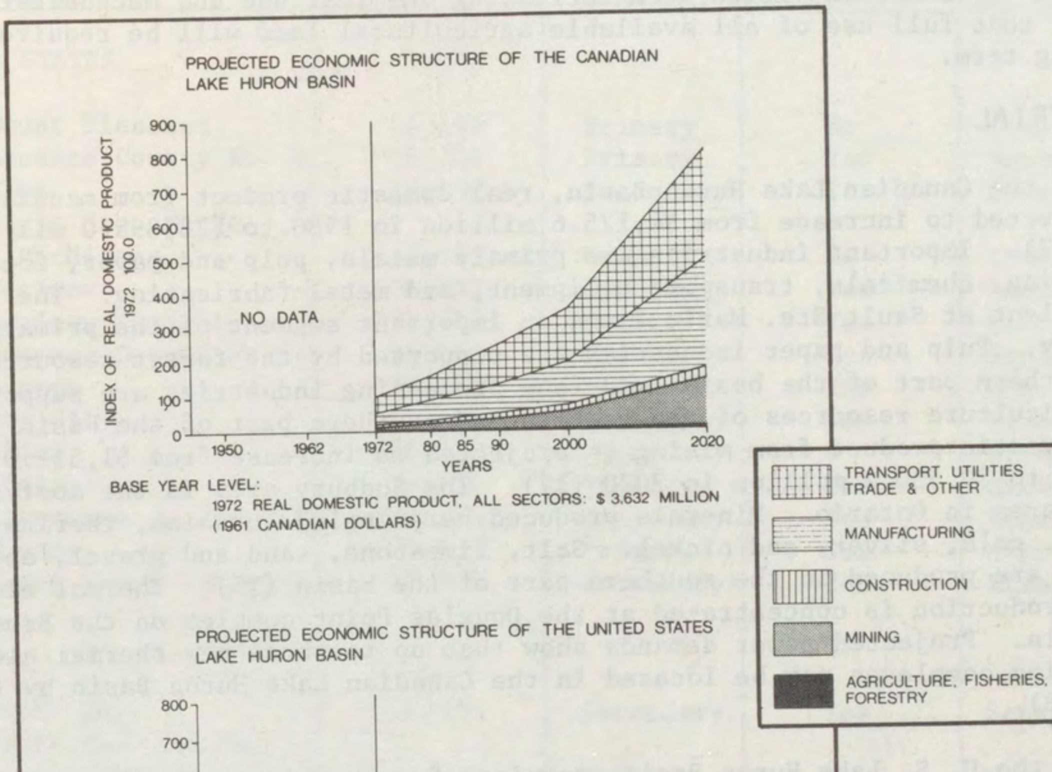

FIGURE 1-8 LAKE HURON BASIN - ECONOMIC FORECAST

U.S. information from Reference (12); Canadian information from Reference (17).

49% (1.67 million ha) of the total land area in the U.S., and 75% (6.45 million ha) in Canada. Cropland is 34.4% (1.18 million ha) of the U. S., and 5.9% (0.5 million ha) of the Canadian total. Pastureland is 4.2% (145,300 ha) in the United States and 15.1% (1,303,900 ha) in Canada. Future agricultural total earnings in the U. S. portion are estimated at $87.2 million in 1980, and are projected to increase to $122.4 million by 2020 (10). The total value of the agricultural real domestic product of the Canadian portion is estimated at $98.8 million in 1980 (15), and is projected to increase to $437.0 million by 2020 (17). The forecasted "world food crisis" and declining marginal increases in yields from increasing chemical use and mechanization suggest that full use of all available agricultural land will be required in the long term.

INDUSTRIAL

In the Canadian Lake Huron Basin, real domestic product from manufacturing is projected to increase from $4,125.6 million in 1980 to $23,395.0 million in 2020 (17). Important industries are primary metals, pulp and paper, food processing, chemicals, transport equipment, and metal fabricating. The Algoma Steel Plant at Sault Ste. Marie forms an important segment of the primary metals industry. Pulp and paper industries are supported by the forest resources of the northern part of the basin, and food processing industries are supported by the agriculture resources of the eastern and southern part of the basin (15). Real domestic product from mining is projected to increase from $1,511.0 million in 1980 to $9,530.2 million in 2020 (17). The Sudbury area is the most important mining area in Ontario. Minerals produced here include uranium, thorium, yttrium, gold, silver, and nickel. Salt, limestone, sand and gravel, and oil and gas are produced in the southern part of the basin (15). Thermal electric power production is concentrated at the Douglas Point complex on the Bruce Peninsula. Projected power demands show that up to three new thermal electric generating complexes may be located in the Canadian Lake Huron Basin by the year 2000 (18).

In the U. S. Lake Huron Basin, earnings from manufacturing are projected to increase from $3,105.9 million in 1980 to $9,996.9 million in 2020 (10). The three SMSA's of Bay City, Flint, and Saginaw are projected to produce 84% of both the 1980 and 2020 earnings from manufacturing (12). Important manufacturing industries are motor vehicles and equipment, chemicals and allied products, primary metals, and machinery. In terms of earnings, paper and allied products is the largest industry in the northern part of the basin. Earnings from mining are projected to increase from $28.1 million in 1980 to $51.3 million in 2020 (10). Mineral commodities produced include clay, peat, petroleum and natural gas, salt, sand and gravel, and limestone. Cement and lime are manufactured from both local and imported raw materials and bromine, calcium compounds, iodine, magnesium compounds, and potash are extracted from natural brines. Thermal electric power installed capacity is projected to increase from 1,707 megawatts in 1970 to 75,157 megawatts in 2020. By the year 2020, nuclear installed capacity is projected to be 90% of the total (19).

TABLE 1-1

PRESENT SEWAGE TREATMENT FACILITIES IN THE LAKE HURON BASIN

FACILITY	POPULATION SERVED	TYPE OF SEWAGE SYSTEM TREATMENT	PHOSPHORUS REMOVAL	COLLECTION
UNITED STATES				
Mount Pleasant	14,100	Primary	No	Separate
Genesee County No. 2	22,000	Primary	Yes	Separate
Alma	10,200	Secondary	Yes	Separate
Sault Ste. Marie, Michigan	13,000	Primary	No	Combined
Saginaw	106,000	Secondary	Yes	Combined
Saginaw Township	27,500	Primary	Yes	Mixed
Genesee County No. 3	11,000	Secondary	Yes	Separate
Alpena	15,200	Secondary	Yes	Mixed
Bay City	53,300	Secondary	Yes	Mixed
Flint	264,700	Secondary	d	Mixed
Midland	35,100	Tertiary	Yes	Mixed
Zilwaukee	23,100	Secondary	Yes	Separate
Owosso	20,000	Primary	Yes	Mixed
Buena Vista Township	11,000	Secondary	Yes	Mixed
CANADA				
North Bay	46,000	Secondary	Yes	Separate
Sault Ste. Marie, Ontario	77,500	Primary	No	Mixed
Owen Sound	18,000	Primary	Yes	Mixed
Midland	11,000	Primary	Yes	Mixed
Sudbury	91,200	Secondary	No	Separate
Barrie	42,500	Secondary	Yes	Separate
Orillia	22,000	Secondary	Yes	Separate
Newmarket	17,700	Secondary	Yes	Separate
Aurora	13,500	Secondary	Yes	Separate
Collingwood	10,600	Primary	Yes	Separate
OTHERS				
68 facilities	195,800	a	b	c
TOTAL	1,172,000			

a. By population served: 55,000 (5.2%) primary, 102,400 (9.6%) secondary, 12,100 (1.2%) intermediate, and 25,800 (2.4%) lagooned.

b. No other Canadian facilities have phosphorus removal.

c. By population served: 51,500 (4.8%) separate, 144,300 (13.6%) combined or mixed (combined and separate).

d. Under construction.

MUNICIPAL

Urbanization in the Lake Huron Basin has been moderately rapid in recent years and generally kept pace with the population increase. Future trends indicate similar characteristics. Figure 1-6 shows the population densities and trends. Figure 1-7 shows the percentages of land use in the basin and its subbasins, including urban use. The total basin population in 1970 was approximately 2,159,000 and the urban population was 1,250,000 or 58% of the total. The largest portion of this population is concentrated in the four most urbanized counties in the U. S. basin (Midland, Bay, Saginaw, and Genesee), and in three areas in Canada (Simcoe County of the Severn Basin, the Sudbury area of the Spanish-French Basin, and the Sault Ste. Marie area of the Mississagi Basin). Of the 120,120 km^2 of land area only 3,130 are urban. Table 1-1 shows details of the sewage facilities of major municipalities. These sewered communities represent a population of 1,172,000 or approximately 94% of the urban population.

FORESTRY

In the Canadian Lake Huron Basin, the portion north of Lake Huron and east of Georgian Bay is about 90% forest covered, but the portion south of Georgian Bay is only about 20% forest land. Forest lands are predominantly crown owned in the northern portion and privately owned in the southern portion (15). In the northern basin, the principal tree species are red pine, eastern white pine, eastern hemlock, yellow birch, maple, and oak. The southern tip of the basin is a deciduous forest region, and the principal tree species are beech, maple, black walnut, hickory, and oak (9). Most forest-based industries are located in the northern portion of the basin. The Canadian real domestic product from the forestry industry is projected to increase from $42.6 million in 1980 to $176.6 million in 2020 (17). The northern part of the U. S. Lake Huron Basin is about 70% forest covered, and the southern part is only about 27% forest covered. The tree species in the U. S. Basin are similar to those in the Canadian portion. The northern part of the basin contains most of the forest-based industry. The harvested value of forest production in the U. S. Lake Huron Basin is projected to increase from $14.3 million in 1980 to $25.5 million in 2020 (20).

WATER USES

Water uses include municipal water supply, industrial water supply, waterborne transportation, recreation, and commercial fisheries. Shoreland uses are shown on Figures 1-9, 1-10, and 1-11.

MUNICIPAL WATER SUPPLY

The Canadian municipalities that obtain water supplies from Lake Huron are scattered all along the lake shore (18). Four municipalities, Sault Ste. Marie, Collingwood, Owen Sound, and the Lake Huron Water Supply System, have the major municipal water supplies and use an average of 166,600 m^3/d. The Lake Huron Water Supply System supplies the city of London, Ontario which is not in the Lake Huron Basin. Assuming no change in proportional demand from industry, no change in the percent of the urban population served, and no change in per capita use, the 2020 demand in the Canadian Basin is projected to be 340,000 m^3/d and serve 631,400 people.

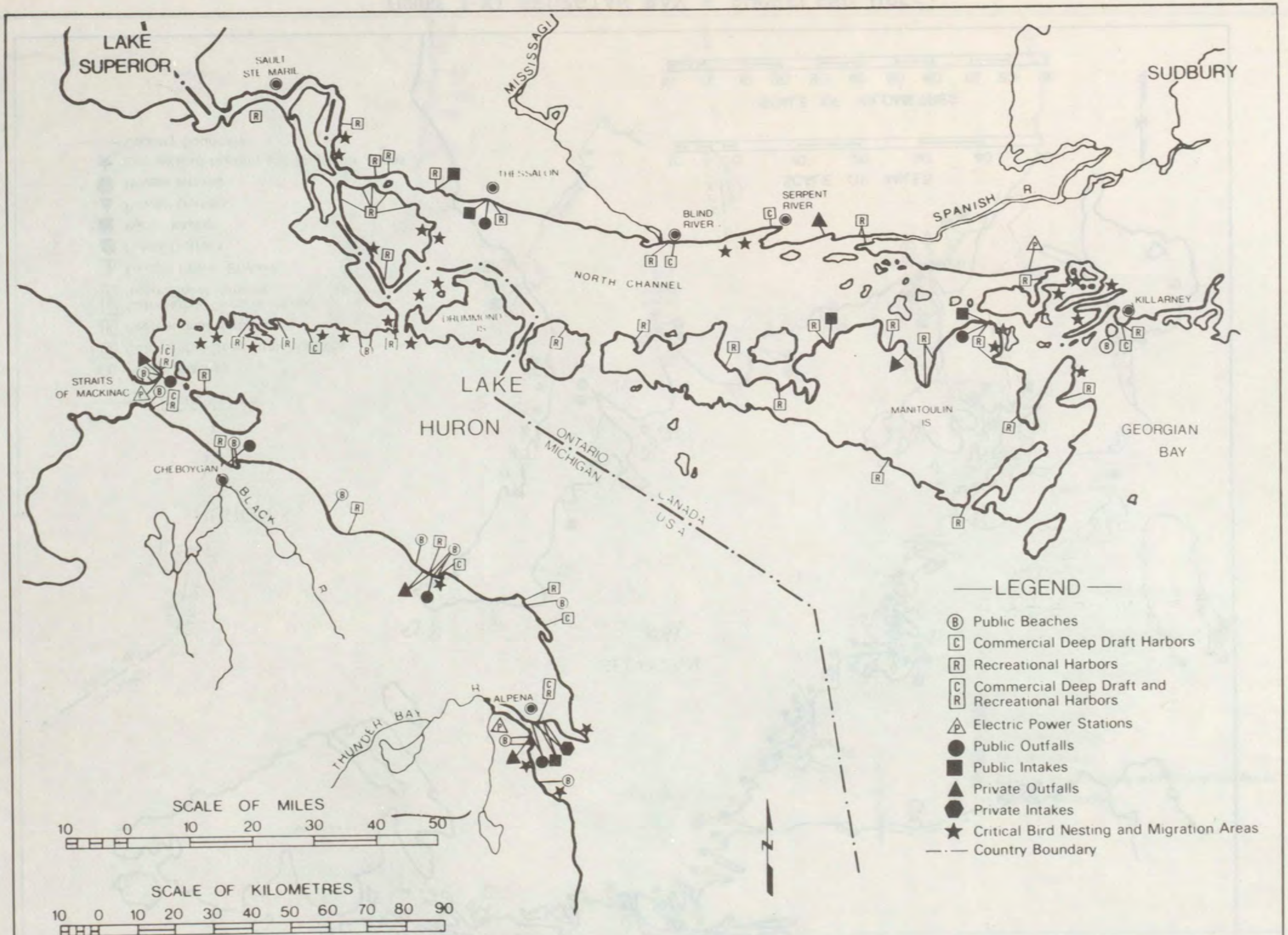

FIGURE 1-9 NORTHERN LAKE HURON AND NORTH CHANNEL - SHORELAND USES

FIGURE 1-10 GEORGIAN BAY - SHORELAND USES

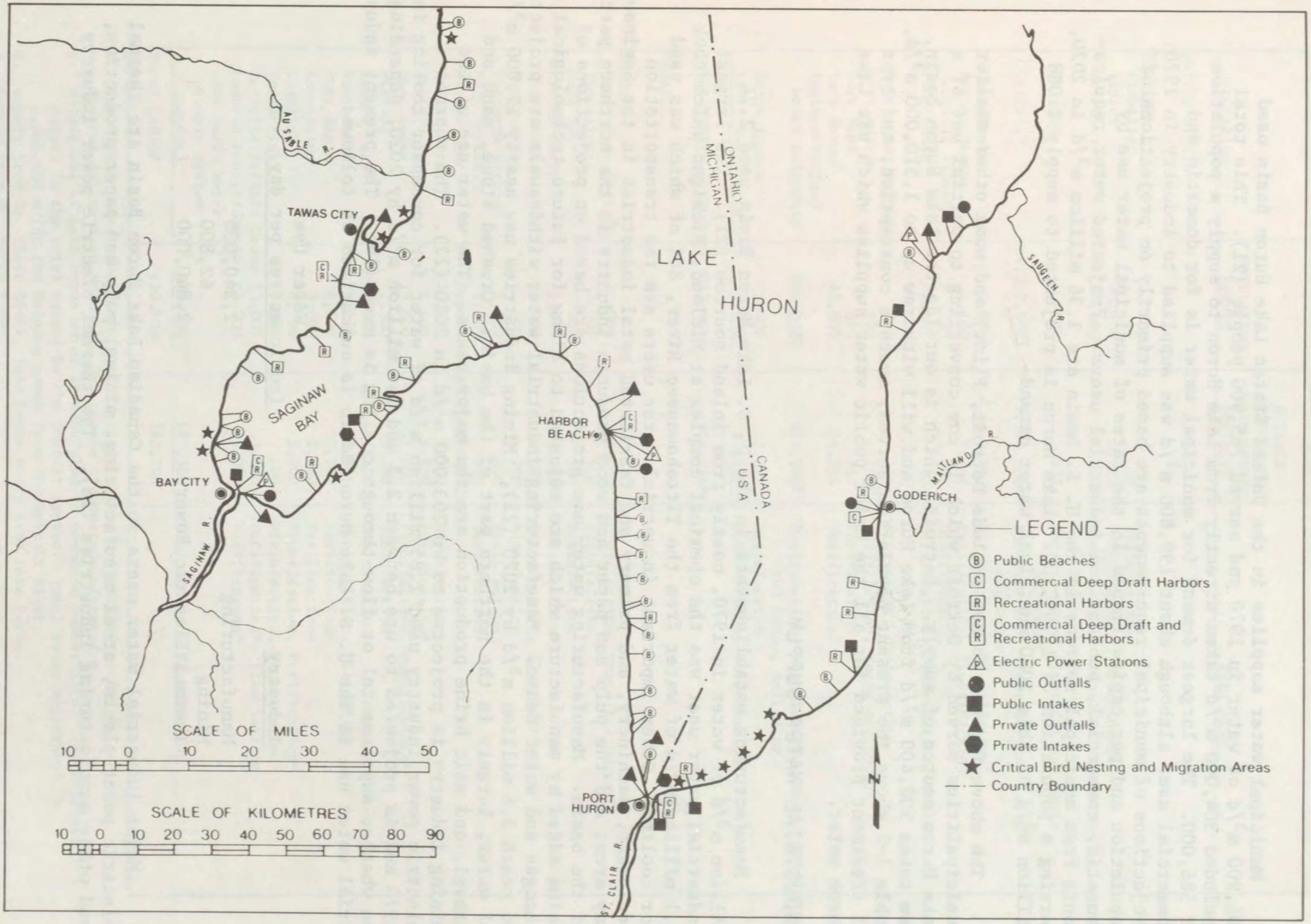

FIGURE 1-11 SOUTHERN LAKE HURON - SHORELAND USES

Municipal water supplies in the United States Lake Huron Basin used 501,900 m^3/d of water in 1970 and served 765,900 people (21). This total included 304,000 m^3/d taken directly from Lake Huron to supply a population of 386,000. The largest demand for municipal water is for domestic and commercial use, although about 199,800 m^3/d was supplied to industry in 1970. Projections of municipal requirements are based primarily on projections of population and per capita trends in the rates of municipal water use by domestic, commercial, public, and industrial users. Projected water requirements from municipal sources in the U. S. Basin are 1.38 million m^3/d in 2020, serving a population of 1,799,200. Lake Huron is projected to supply 1.088 million m^3/d of this 2020 municipal water demand.

The above figures do not include Detroit, Flint, and some other smaller municipalities served by Detroit which is now converting to partial use of a Lake Huron source of supply. Detroit, which is outside the Lake Huron Basin, now takes 908,400 m^3/d from Lake Huron and will withdraw up to 1,510,000 m^3/d. Table 1-2 shows the present population served, average consumption, and type of treatment provided for all the major public water supplies which use Lake Huron water.

INDUSTRIAL WATER SUPPLY

Manufacturing establishments in the U. S. Lake Huron Basin used 2.24 million m^3/d of water in 1970, mostly from inland sources (21). The largest industrial water user was the chemical complex at Midland, Michigan which took 1.1 million m^3/d of water from the Tittabawassee River, 80% of which was used for cooling. Other important industrial water users are the transportation equipment, machinery, and primary and fabricated metal industries in the Saginaw Bay area; and the pulp and paper and wood products industry in the northern part of the basin. Manufacturing water use projections are based on projections of value added by manufacture which are adjusted to allow for future technological changes and water reuse. Manufacturing industrial water withdrawals are projected to reach 3.6 million m^3/d by 2020 (21). Mining industries use nearly 17,000 m^3/d of water, largely in the northern part of the basin. Crushed stone, sand and gravel, and salt brine production are the major users. The water use of the mining industry is projected to be 203,000 m^3/d in 2020 (22). The thermal electric power industry used 2.85 million m^3/d of water for condenser cooling in 1970 and is projected to use between 2.3 and 146 million m^3/d by 2020, depending on whether supplemental or flow-through cooling is used (19). The present industrial water use in the U. S. Lake Huron Basin is summarized as follows:

Industry	Water Use (cubic metres per day)
Manufacturing	2,240,000
Mining	62,800
Thermal Electric Power	2,840,000

Major industrial water users in the Canadian Lake Huron Basin are thermal electric power plants, steel manufacturing, mining, pulp and paper production, and other manufacturing industries (18). The thermal electric power industry

TABLE 1-2

Lake Huron Public Water Supply Summary

LOCATION	POPULATION SERVED	AVERAGE CONSUMPTION (CUBIC METRES PER DAY)	TREATMENT
UNITED STATES			
Michigan			
Alabaster	40	38	Disinfection
Alpena	13,800	5,678	Purification[a], Fluoridation
Bay City	78,000[b]	41,000[b]	Purification, Fluoridation, Softening, Taste and Odour
De Tour	600	151	Purification, Fluoridation, Taste and Odour
Detroit[c]	(4,000,000)	(1,510,000)	Purification, Fluoridation, Taste and Odour
East Tawas	4,000[b]	2,000[b]	Purification, Fluoridation
Harbor Beach	2,100	4,466	Purification, Fluoridation
Mackinac Island	700	1,892	Disinfection
Pinconning	1,400	900	Purification, Fluoridation, Taste and Odour
Pointe Aux Barques	300	114[f]	Filtration, Disinfection
Port Austin	900	700[b]	Purification, Taste and Odour
Port Hope	340	151	Purification
Port Huron[d]	41,800	44,284	Purification
Saginaw-Midland Water Authority	224,000[b]	190,000[b]	Purification, Fluoridation, Taste and Odour, Softening
Saint Ignace	3,000	2,271	Disinfection
Sault Ste. Marie[e]	15,000	10,409	Disinfection, Fluoridation
Total UNITED STATES	385,980[b]	304,054[b]	
CANADA			
Ontario			
Sault Ste. Marie[e]	72,000	36,400	Disinfection, Taste and Odour
Thessalon	2,000	500	Disinfection
Gore Bay	800	500	Disinfection
Little Current	1,400	1,300	Disinfection
Parry Sound	6,200	3,200	Disinfection, Fluoridation
Waubaushene	300	200	Disinfection
Victoria Harbour	1,200	300	Disinfection
Port McNicoll	1,300	900	Disinfection
Wasaga Beach	(System under Construction)		
Collingwood	10,400	5,900	Disinfection
Meaford	4,400	4,600	Purification[a]
Owen Sound	19,000	15,000	Fluoridation, Purification[a]
Wiarton	2,300	3,700	Disinfection
Lion's Head	300	100	Disinfection
Southampton	5,100	1,600	Disinfection, Filtration
Port Elgin	4,500	2,700	Purification[a]
Kincardine	5,000	2,300	Purification[a]
Goderich	6,700	5,000	Fluoridation, Purification[a]
Bruce Mines	300	100	Disinfection, Fluoridation
Petrolia/Brights Grove	10,000	3,600	Purification[a], Fluoridation
Lambton County/Sarnia	65,000	25,000	Purification[a]
Lake Huron Water Supply System (London)	232,200	109,300	Disinfection, Fluoridation
Total CANADA	450,400	222,200	

a. Purification includes disinfection, coagulation, sedimentation, and filtration.
b. Figures differ from Volume I, due to use of updated information.
c. Withdrawal of Lake Huron water is scheduled to commence summer 1976. The population figure is the total served by the Detroit system. Total water withdrawal is 2,660,000 m^3/d; the balance comes from the Detroit River.
d. Supply from St. Clair River, just below entry from Lake Huron.
e. Supply from St. Marys River.
f. Estimated.

in the Bruce-Douglas Point area used 2.26 million m^3/d of water from Lake Huron for condenser cooling in 1972. Future demand of the power industry is estimated to reach over 80 million m^3/d by 2000, partly to meet the power needs of industrial expansion throughout the basin. Most of the remaining industrial water demand of 1.4 million m^3/d in 1972 was taken from Lake Huron. It was used largely for steel manufacturing in Sault Ste. Marie, 578,000 m^3/d; pulp and paper production in the northern part of the basin, 220,000 m^3/d; and mining in the Sudbury area, 457,000 m^3/d. Future demand for industrial process and cooling water is projected to reach 2.4 million m^3/d by 2020, largely for mining in the northern part of the basin and for steel manufacturing. The projections are based on the regional economic growth rates and assume that water withdrawals will increase by only 25% of this growth rate due to recycling and water conservation measures. The present industrial water use in the Canadian Lake Huron Basin is summarized as follows:

Industry	Water Use (cubic metres per day)
Pulp and Paper	230,000
Manufacturing	656,000
Mining	522,000
Thermal Electric Power	2,260,000

TRANSPORTATION

Water-borne commerce is a major economic activity on the Great Lakes. Lake Huron is a carrier lake. Relatively few of the cargoes which it carries originate or terminate in ports on the lake. Most of the traffic is raw materials being shipped from Lake Superior to mills on Lake Michigan and the Lower Lakes. The Saginaw River area is by far the busiest harbour in the U.S. Lake Huron Basin (24). Principal receipts are limestone, coal, and general cargo. General cargo is also exported. Other major harbours are Calcite, Stoneport, and Alpena, Michigan. About 46% of the limestone traffic of the U.S. Great Lakes is shipped from this area. In 1969, 640,000 tonnes of coal were received at Alpena, while 2.1 million tonnes of cement were shipped. Total shipments and receipts are projected to be 24.9, 36.7, and 52.8 million tonnes in 1980, 2000, and 2020 respectively, and will generate total income of $352, $515, and $732 million in the respective years (Figure 1-12).

Goderich is the only significant Canadian port on the main body of Lake Huron. During 1973, more than one million tonnes were received at Goderich. Smaller ports include Blind River, Killarney, Serpent River, Collingwood, Midland, Parry Sound, and Owen Sound. Sault Ste. Marie, Ontario, with its steel mill and paper industry is by far the busiest Canadian port in the basin, but it is not located on the lake itself.

Important impacts on water quality caused by water-borne commerce include maintenance dredging of harbours and channels, vessel waste discharges, and cargo spills, including oil and hazardous materials.

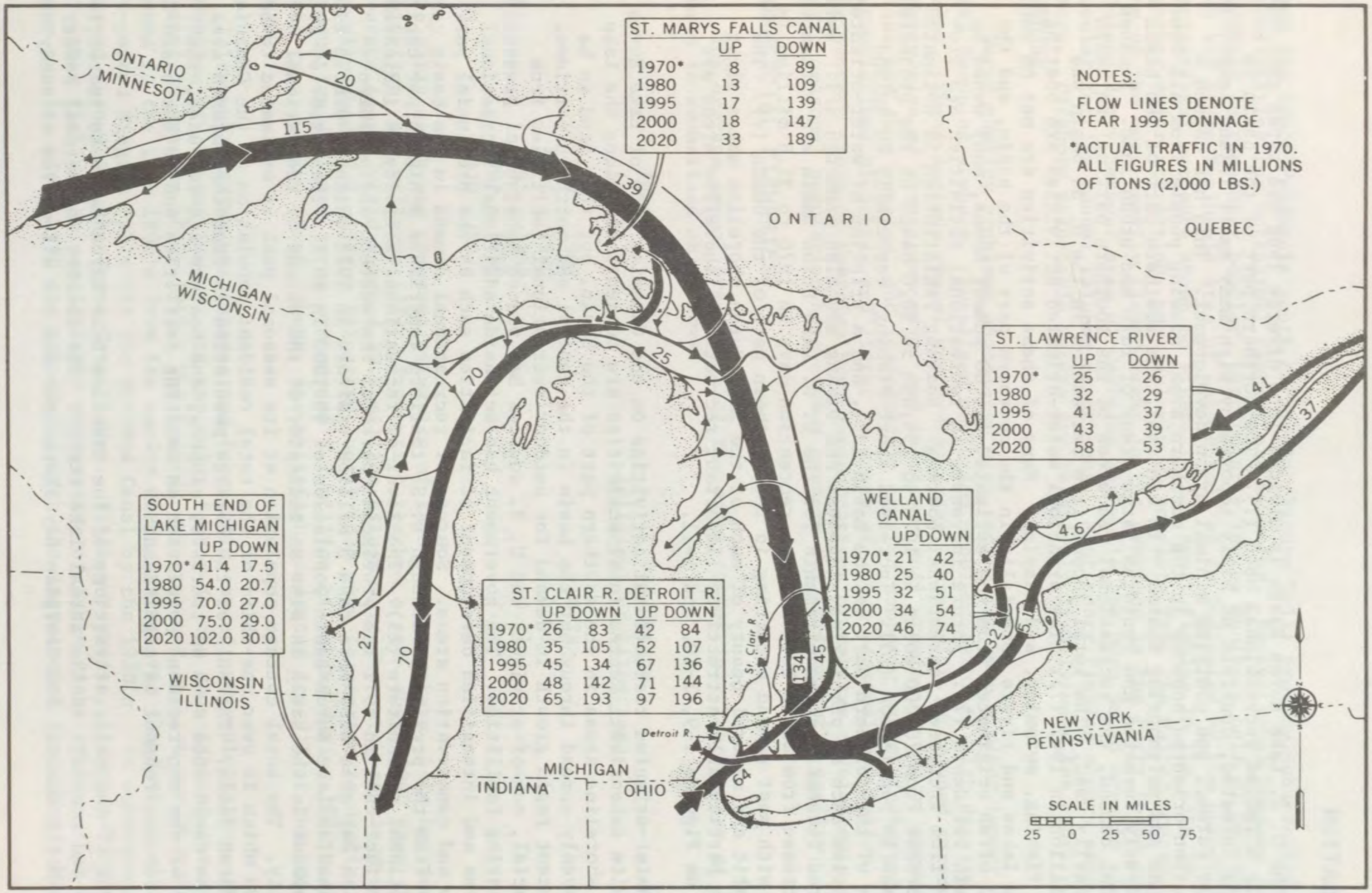

FIGURE 1-12 GREAT LAKES SHIPPING TONNAGE

RECREATION

The U. S. Lake Huron Basin is divided into diverse land use types that have greatly affected recreational uses (7). The northern part of the basin is heavily forested, consists of hilly topography with many small inland lakes, is lightly farmed, and contains minimal urban development. This has caused a recreation-oriented economy in the northern area, drawing people from all over Michigan and neighboring states. In contrast, the southern part of the basin is sparsely forested and contains large areas of farm and urban land. Because of local demand, the recreational resources of the southern part of the basin are heavily used. The total income from recreation in the U. S. basin was $63 million in 1967 (7). The principal water-oriented activities are boating, sport fishing, swimming, and camping. Many of these activities are met on small inland lakes and rivers especially in the northern part of the basin, and the demand often originates from the estimated 44,000 summer homes, many owned by nonbasin residents (7). Future increases in recreational activities are projected from increased recreational boating. Boating registration is estimated to increase from 70,000 boats in 1970 to 139,000 in 2020 based on the projected increase in population (25). Increased sport fishing, especially on inland waters of the northern part of the basin (25), and a tripling of water-oriented activities such as picnicking, camping, and hiking are also expected (7). Water-oriented recreational requirements for the U. S. Lake Huron Basin are estimated to increase from about 10.1 million recreation days in 1970 to 31.8 million in 2020, with most demand occurring in the southern part of the basin (7). The aesthetic and natural beauty of much of the Lake Huron shoreline makes sight-seeing particularly attractive. Important recreational shoreline areas are shown on Figures 1-9, 1-10, and 1-11.

Water-oriented recreational activities on the Canadian side of Lake Huron are quite extensive. Recreational activities are concentrated along the Lake Huron shoreline areas in the southern part of the basin, but they tend to be more evenly spread throughout the basin in the central and northern portions. The recent rapid growth in demand for outdoor recreational facilities from provincial, out-of-province, and U. S. sources has placed substantial pressures on existing facilities. The government has set aside additional recreational reserves and intensified development of facilities such as the provincial park system and conservation areas. Sources of recreational demand in the basin come mainly from the province, although U. S. tourists contribute a higher per capita recreational expenditure (15). The level of recreational activity is indicated by the fact that in 1972 the provincial parks of the western and southern Georgian Bay area drew more than 3 million visitors in 1972 which is over 3 times the Canadian Lake Huron Basin population of 938,000 in 1971. The extent of cottage development in the basin is also an indicator of the extent of recreational activity. The total cottage population at its seasonal peak is estimated to be 345,000 which is over one-third of the total resident population of the Canadian Lake Huron Basin. The bulk of the cottage population is from the Toronto area. When the components such as tourists, campers, and boaters are included, the impact of the non-resident population on existing facilities and on the basin land and water environment is significant.

One of the major attractions of the Canadian Lake Huron Basin to recreationalists and tourists is the actual lake itself. The scenery and natural beauty of the North Channel and Georgian Bay shorelines and the kilometres of sandy beach from the Bruce Peninsula south to Sarnia (Figure 1-11) provide substantial opportunities for cottaging, camping, and swimming. Recreational boating is becoming increasingly popular, particularly in the southern half of Georgian Bay and Bruce Peninsula area of Lake Huron, as is indicated by the number of recreational harbours shown on Figure 1-11. Sport fishing in the lake is another major attraction, particularly to tourists from the United States. One of the most heavily fished areas in the province is the Parry Sound and Midland-Honey Harbour area of Georgian Bay while the Owen Sound area is also popular for its annual rainbow trout runs. Most sport fishing occurs near shore. Offshore main-basin waters are relatively lightly used for sport fishing.

Water quality problems associated with recreation have a minor impact on Lake Huron as a whole. Localized pollution problems occur in high density areas. These include vessel waste discharges, especially in crowded marinas, destruction of vegetative cover and increased soil erosion by use of snowmobiles and dune buggies, and inadequately treated domestic waste discharges and accumulations of debris and litter in areas of large seasonal population. Along the eastern shore of Georgian Bay, concentrations of cottage developments and large seasonal population have caused concern for environmental quality.

COMMERCIAL FISHERIES

The average annual production of the major commercial fish species of Lake Huron is summarized as follows:

Period (years)	Production (millions of kilograms)
1879 - 1909	10.78
1945 - 1949	4.61
1955 - 1959	3.21
1965 - 1969	2.83
1970 - 1974	2.18

The early catch was composed primarily of lake trout, suckers, lake herring, whitefish, and walleyes (27). Production reached a peak about 1900 when the average annual yield reached 10.8 million kilograms. The catch remained high, usually about 9.1 million kilograms, until 1940 when it started to decline. Production declined to an average of 2.2 million kilograms during 1970 - 1974, when carp, yellow perch, chubs, and whitefish accounted for 71% of the total catch.

Although fishing was intense and frequently caused overexploitation, the invasion of the sea lamprey was the major factor in the reduction of the catch and change in species after 1940. The lamprey was presumed to have entered the Great Lakes in the late 1800's from its native ocean habitat via the Erie Canal, and by-passed Niagara Falls via the Welland Canal by the 1920's. It subsequently spread throughout the Upper Great Lakes. It is a parasite, living on the blood of other fish and is particularly destructive of large fish. The decline of many species after 1950 was associated with the increase of the alewife which was another marine invader that entered the Great Lakes via the same route as the sea lamprey. The small herring-like alewife became the most abundant fish in Lake Huron by 1965 and is believed to compete to the disadvantage of native species by causing a major reduction in the size and abundance of small food organisms eaten by fish.

The International Great Lakes Fishery Commission initiated a program to control the sea lamprey that became fully effective in Lake Huron in 1970. The reduced sea lamprey population resulted in sharp increases in whitefish and suckers, and contributed to the success of planting hatchery-reared trout and salmon. The lake trout which reached virtual extinction in the 1950's is being reintroduced along with "splake" which is a hybrid of lake and brook (speckled) trout that was developed to be less vulnerable to sea lamprey predation. Recent introductions of Pacific salmon and steelhead trout have had substantial success. Chinook and coho salmon and steelhead trout have thrived well on the abundance of alewives which are similar to their food in the ocean environment. Success of recent introductions of the kokanee salmon which feeds on smaller food organisms has not yet been evaluated, but the pink salmon which has similar feeding requirements is increasing rapidly in Lake Huron where it spread from an introduction in Lake Superior in 1956. The salmon and trout are used primarily for a growing recreational fishery.

WASTE ASSIMILATION

Waste assimilation from both point and diffuse sources occurs throughout the basin. An important area of waste assimilation from point source waste discharges is the Saginaw Bay area. Here the wastes discharged to the Saginaw River have caused nutrient enrichment and other water quality problems in Saginaw Bay. Waste assimilation from nonpoint sources occurs throughout the basin where pollutants are carried to the lake in land drainage or in wash-out or by absorption from the atmosphere. Much of the waste assimilation from nonpoint sources is caused by the agricultural economy of the southern half of the basin. Here the drainage from agricultural lands carries sediments, fertilizers, and other pollutants to the lake.

CHAPTER 2
LEGISLATIVE BASIS FOR WATER QUALITY MANAGEMENT

was another marine invader that entered the Great Lakes via the same route as the sea lamprey. The small herring-like alewife became the most abundant fish in Lake Huron by 1967 and is believed to compete to the disadvantage of native species by causing a major reduction in the size and abundance of small food organisms eaten by fish.

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WASTE ASSIMILATION

Waste assimilation from [illegible] sources occurs throughout the basin. In [illegible] point source waste discharges to the Saginaw [illegible] to the Saginaw River have caused [illegible] problems in Saginaw Bay. Waste assimilation [illegible] the [illegible] waste pollutants are carried to [illegible] drainage or in wash-out or by absorption from the atmosphere. [illegible] of the waste assimilation from nonpoint sources is caused by the agricultural [illegible] of the southern half of the basin. Here the drainage from agricultural lands carries sediments, fertilizers, and other pollutants to the lake.

2 LEGISLATIVE BASIS FOR WATER QUALITY MANAGEMENT

Chapter 2 describes the legislative mechanisms directed toward governmental management of the Upper Lakes. Some of the federal, state, or provincial laws are of recent passage because many of the concerns about water quality of the Upper Lakes are of relatively recent origin. The appropriate laws and responsible agencies are briefly described by jurisdiction: U.S. federal, Michigan, Canada federal, and Ontario. Chapter 2 also contains definitions of certain technical terms used in this report. The various water quality criteria, standards, objectives, and guidelines developed by the several jurisdictions are also presented in Appendix C.

TERMINOLOGY

CRITERIA, STANDARDS, OBJECTIVES, AND GUIDELINES

Criteria, standards, objectives, and guidelines are four terms that have been widely used in water quality literature and legislation. All refer to rules and limitations on chemical and physical constituents but each term has been defined differently in different documents. The only reasonably consistent difference is that the term *standard* implies statutory, legally enforceable limits whereas the other three terms do not. The differences in meaning between *criteria*, *objectives*, and *guidelines* are so slight that the terms can be used interchangeably. The term *objective* means desirable levels of water quality to be attained in either short or long term water resource management programs for specific water bodies. The term *criteria* usually refers to evaluated scientific data and the term *guidelines* is usually recommendations for characteristics of water for specific uses. For the purpose of this report the term *standard* means legally enforceable water quality limitations. *Criteria* and *guidelines* may be inferred to mean *objectives*.

CLASSIFICATION OF WATER

The Reference Group classified water as nondegraded, degraded, or polluted. *Nondegraded* water is high quality water that does not show significant anthropogenic effects. *Degraded* water shows the effects of cultural activity that result in occasional violations of objectives. *Polluted* water shows frequent or severe violations of water quality for which remedial actions are required.

CLASSIFICATION OF PROBLEMS

The Reference Group classified problems as local or whole lake. For a *local* problem, the water quality degradation affects only a specific geographic area, such as a harbour, embayment, or a river mouth. For a *whole-*

lake problem, the water quality degradation is not readily attributable to specific or controllable sources but is found throughout the water body, such as DDT or PCB's.

INTERNATIONAL ASPECTS OF GREAT LAKES WATER QUALITY MANAGEMENT

International aspects of management of the Great Lakes are controlled by the International Joint Commission, which was created by, and operates under the Boundary Waters Treaty of 1909 (1). Great Britain, acting on behalf of Canada, and the United States entered into the Boundary Waters Treaty ". . . to prevent disputes regarding the use of boundary waters and to settle all questions which are now pending between the United States and the Dominion of Canada involving the rights, obligations or interests . . . along their common frontier and to make provision for the adjustment and settlement of all such questions as may hereafter arise. . . . " Jurisdiction over cases involving any use or obstruction or diversion of the waters was given to the Commission. The Commission is authorized to inquire into and report with appropriate recommendations on questions or matters arising along the boundary which the governments refer to it. The Commission is composed of 3 U.S. and 3 Canadian commissioners, appointed by the President of the U.S. and by the Canadian Privy Council, respectively.

The Commission has inquired into a number of pollution questions referred to it by the governments. Continued population and industrial growth and concurrent water quality degradation led to the 1964 reference to study pollution problems on Lake Erie, Lake Ontario, and the international portion of the St. Lawrence River. The 1969 report by the International Lake Erie Water Pollution Board and the International Lake Ontario-St. Lawrence River Water Pollution Board, known as the Lower Lakes Report (2), led to the Commission recommending (3) to the federal governments that the U.S. and Canada agree on adoption of water quality objectives; programs for reduction of phosphorus discharges; controls and/or compatible regulations on dredging, solid waste disposal, oily, hazardous, or toxic materials, and shipping wastes. The Commission further recommended that it be specifically authorized to coordinate, evaluate, and verify the remedial programs and their results.

In response, the Great Lakes Water Quality Agreement (4) was signed by the President of the United States and the Prime Minister of Canada on April 15, 1972. The Agreement established water quality objectives, a timetable for reduction of phosphorus loadings, and a nondegradation philosophy. It provided for joint institutions and committed both countries to develop compatible regulations for vessel design, construction, and operation to prevent discharge of harmful quantities of oil and hazardous polluting substances and for control of discharges of other vessel wastes. The Agreement also requires monitoring and exchange of information in accordance with procedures established by the Commission in consultation with the federal, state, and provincial governments.

The Agreement contained two references to the Commission, one of which led to the establishment of the Upper Lakes Reference Group. This group is made up of officials from the agencies or institutions having expertise and responsibilities relevant to the terms of the reference study. The composition, study plan, and organization of the Reference Group are summarized in Chapter 2 of Volume I; details are given in the Reference Group's study plan (5).

LEGISLATIVE BASE FOR MANAGING THE UPPER LAKES BASIN

U.S. FEDERAL

MAJOR LEGISLATION AND SALIENT FEATURES

Public Law 92-500

The legislative foundation for water quality management in the United States is Public Law 92-500, the Federal Water Pollution Act Amendments of 1972. Major programs under this Act are the chief mechanisms for meeting the goals of the Great Lakes Water Quality Agreement.

Under the Act the individual states have the primary responsibility for water quality control, with the federal government in a supporting role but able to take action in interstate or international problems or when the state is unable to act.

The Act provides federal funding for construction of municipal sewage treatment facilities, and provides for and requires a higher level of water quality management planning and public participation in planning. Further, it created a regulatory mechanism requiring uniform technology-based effluent limitations, and a national permit system for all point source discharges.

The objective of the Act is to "restore and maintain the chemical, physical and biological integrity of the Nation's waters." Two mileposts specified are:

(1) To reach, "wherever attainable", a water quality that "provides for the protection and propagation of fish, shellfish, and wildlife" and "for recreation in and on the water" by July 1, 1983.

(2) To eliminate the discharge of pollutants into navigable waters by 1985.

The Act provides for achieving its goals in phases with accompanying requirements and deadlines. It also requires that water quality be monitored and that annual reports be made to Congress. Section 108 of the Act provides for a special program to "develop new methods and techniques . . . for the elimination or control of pollution within all or any part of the watersheds of the Great Lakes." It further provides that "such program should include measures to control point sources of pollution; area sources of pollution, including acid mine drainage, urban runoff, and rural runoff; and in-place sources of pollution, including bottom loads, sludge banks, and polluted harbor dredgings."

The comprehensive requirements of PL 92-500 have resulted in greater compatibility in state legislation. All of the states participate in the construction grants program, all states in the Great Lakes Basin except Illinois and Pennsylvania have permit-issuing authority under the National Pollutant Discharge Elimination System (NPDES) program, all states have emergency response programs, and all states must report on water quality each year.

Other Acts

Other Acts which effect management of the Upper Lakes include:

(1) The Coastal Zone Management Act, which encourages the adoption of comprehensive coastal zone management plans.

(2) The National Environmental Policy Act (NEPA), which requires governmental agencies to weigh environmental considerations in their decision making. NEPA has served as a model for similar legislation at the state level.

(3) The Water Resources Planning Act established the Water Resources Council which provides for the optimum development of natural resources through coordinated planning of water and related land resources.

(4) The Clean Air Act, which requires the monitoring and reduction of atmospheric pollution.

(5) The Federal Insecticide, Fungicide and Rodenticide Act restricts use of pesticides and requires thorough testing of new pesticides for environmental and human health effects before they may be used.

MAJOR AGENCIES, THEIR FUNCTIONS AND INTERRELATIONSHIPS

The U.S. Environmental Protection Agency (EPA) is the primary federal agency responsible for the implementation of the Federal Water Pollution Control Act, the National Environmental Policy Act (NEPA), the Clean Air Act, and the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). The U.S. EPA is also the lead U.S. agency in the implementation of the Great Lakes Water Quality Agreement.

The U.S. EPA administers the municipal construction grants program, issues NPDES permits where states have not been granted permit authority, publishes guidelines and standards on levels of treatment, takes direct enforcement action on interstate or international problems, reviews environmental impact statements required under NEPA, and administers the Clean Air Act and FIFRA.

The National Oceanic and Atmospheric Administration conducts research on the physical properties of the Great Lakes and provides mapping and weather services.

The U.S. Army Corps of Engineers maintains federal navigation channels and operates the locks at Sault Ste. Marie.

The U.S. Coast Guard is responsible for marine safety on the Great Lakes and enforces oil spill and vessel discharge regulations.

IMPLEMENTATION PROGRAMS

PL 92-500 provides federal funds for 75% of the eligible construction costs of municipal sewage treatment plants and interceptor sewers. The grants system also covers the cost of planning and design of municipal facilities. Some states supplement federal funding through state grants. State and federal funds obligated between 1971 and 1975 total 2.56 billion dollars (6).

Federal regulations and programs available to assist industries in abating pollution are industrial revenue bonds, accelerated tax depreciation, investment tax credits, loan guarantees, and loans provided by the Small Business Administration. Some states provide property tax exemptions, sales and use tax exemptions, and franchise and income tax deductions.

ENFORCEMENT MECHANISMS

The principal means of enforcement of both municipal and industrial treatment requirements is the NPDES program. This system requires that all industries and municipalities apply for a discharge permit. The U.S. EPA or the state agency with permit authority issues the permits with effluent limitations. Where additional treatment facilities or process modifications are required to meet the effluent limitations, interim limitations are specified and a schedule for construction is established. Dischargers are required to monitor their discharges and periodically report the results. Violations of effluent limitations or failure to meet construction schedules result in enforcement actions which include a warning letter, an administrative order, or a referral to the U.S. Attorney or to the State Attorney General asking for a civil penalty or criminal prosecution.

Effluent limitations are based on guidelines published by the U.S. EPA defining best practicable control technology and best available control technology, new source performance standards, and pretreatment regulations. Permits are issued for a maximum of five years after which they must be renewed, at which time a higher level of treatment technology may be required.

OTHER FEDERAL AGENCIES

The following is a list of other U.S. federal agencies that are involved in pollution control activities within their area of responsibility:

(1) The Department of Agriculture has two of its agencies with pollution control responsibilities: the Forest Service and the Soil Conservation Service.

(2) The Department of Commerce has one of its agencies involved in pollution control activities: the National Oceanic and Atmospheric Administration.

(3) The Department of Health Education and Welfare has three of its agencies with pollution control responsibilities: the Food and Drug Administration, the National Institute of Environmental Health Sciences, and the Public Health Service.

(4) The Department of Housing and Urban Development has some responsibilities in pollution control.

(5) The Department of Interior has eight of its agencies involved in pollution control activities: the Bureau of Mines, the Bureau of Outdoor Recreation, the Bureau of Reclamation, the National Park Service, the Office of Land Use and Water Planning, the Office of Water Research and Technology, the Fish and Wildlife Service, and the Geological Survey.

(6) The Department of State has one of its agencies with pollution control responsibilities: the Office of Oceans and International Environmental and Scientific Affairs.

(7) The Department of the Army has one of its agencies involved in pollution control: the Army Corps of Engineers.

(8) The Department of Transportation has two of its agencies with pollution control responsibilities: the Coast Guard and the Federal Highway Administration.

(9) The Department of the Treasury has one of its agencies involved in pollution control: the Customs Service.

Other federal agencies or organizations include the following:

(1) Citizens Advisory Committee on Environmental Quality
(2) Council on Environmental Quality
(3) Energy Research and Development Administration
(4) Federal Energy Administration
(5) Federal Maritime Commission
(6) General Services Administration
(7) National Aeronautics and Space Administration
(8) National Commission on Water Quality
(9) National Science Foundation
(10) Nuclear Regulatory Commission
(11) Smithsonian Institute
(12) United States National Commission for UNESCO (United Nations Educational, Scientific and Cultural Organization)
(13) Water Resources Council

MICHIGAN

MAJOR LEGISLATION AND SALIENT FEATURES

The passage of PL 92-500 has greatly altered the legislative base upon which water pollution control in Michigan is conducted. In general, water pollution control has become a joint federal-state program rather than purely a state program. Important Michigan statutes are listed below.

By creating the Water Resources Commission and outlining its main statutory responsibilities, Act No. 245 (Public Acts of 1929) is the most important state statute relating to the functions of the Commission. Under its provisions, the Commission is directed to: control the pollution of any surface or underground waters of the state and the Great Lakes; control alterations to watercourses of all rivers and streams; establish pollution standards for all waters of the state; examine and certify operators of industrial waste treatment facilities discharging wastes into the waters of the state; issue permits for all dischargers to the waters of the state; require the registration of all manufactured products, production materials, and waste products where certain wastes are discharged; and assess an annual surveillance fee to waste dischargers.

In addition to these statutory requirements, the Commission is authorized to issue permits which include performance timetables requiring remedial and preventive measures to control pollution, seek court enforcement of its permits, cooperate and negotiate with other governments and governmental units, and coordinate with any act of the U.S. Congress.

Act No. 245 further provides and authorizes reasonable entry for inspection purposes and monitoring, the promulgation of rules, penalty provisions and appeals, and other procedures necessary for the Commission to carry out its functions.

Act No. 329 (Public Acts of 1966) establishes a state water pollution control fund to assist local governmental units in financing construction of wastewater treatment works. Other provisions of the Act outline the requirements of an Official Plan and the formula by which priority is assigned to treatment works projects.

The Soil Erosion and Sedimentation Control Act (Act No. 347, Public Acts of 1972) authorizes the Water Resources Commission, in cooperation with the Michigan Department of Agriculture, to implement a comprehensive statewide soil erosion and sediment control program.

The Liquid Industrial Waste Haulers Act (Act No. 136, Public Acts of 1969) gives the Water Resources Commission the authority to license all persons engaged in the business of removing liquid industrial wastes from the premises of another, including the licensing of all vehicles used to transport the liquid industrial wastes.

The Watercraft Pollution Control Act (Act No. 167, Public Acts of 1970) strengthened and expanded Michigan's watercraft pollution control program which had been in effect under Water Resources Commission administrative rules. Effective January 1, 1971, all toilet-equipped watercraft moored or operated on Michigan waters must be equipped with self-contained marine toilets or incinerating devices to prevent all overboard discharge of sewage wastes. In addition, the Act requires that all marinas capable of handling 15 or more watercraft be equipped with marine toilet pump-out facilities.

The Cleaning Agents and Water Conditioners Act (Act No. 226, Public Acts of 1971) limits the amount of elemental phosphorus which may be contained in a cleaning agent after July 1, 1972, to 8.7%. In addition, the Act authorizes the Water Resources Commission to promulgate rules to further restrict the nutrient content or other contents of cleaning agents and water conditioners to prevent unlawful pollution.

Act. No. 98 (Public Acts of 1913) requires the certification of municipal wastewater treatment plant operators and issuance of permits for construction of municipal wastewater treatment facilities. Both collection and treatment are covered by this legislation.

MAJOR AGENCIES, THEIR FUNCTIONS AND INTERRELATIONSHIPS

The agencies responsible for the protection of the Great Lakes environment in Michigan are the Michigan Department of Natural Resources (DNR) and the Michigan Department of Public Health.

The Michigan DNR is the primary agency responsible for preserving, protecting, and restoring the waters of the state for their designated uses. This is done by establishing water quality standards for receiving waters, issuing and enforcing NPDES and state wastewater discharge permits, and monitoring both discharges and receiving waters. Under the federal and state assisted construction grants program, funds are available to municipalities for the construction of waste treatment works. The DNR is also responsible for the preservation and propagation of fish and wildlife.

The Michigan Department of Public Health is responsible for the identification and control of human health problems. This includes protecting the quality of public water supplies and protecting against radioactivity in the environment.

FEDERAL AND STATE RELATIONSHIPS

As pointed out above, the water pollution control program in Michigan was primarily a state program before 1972. Since the passage of PL 92-500, the program has become a joint federal-state effort. Much of the joint responsibility has been delegated to the state and is thus handled in a similar manner as before. Nevertheless, the federal role has been considerably expanded. Details of the federal-state relationship in various functions are outlined in the state program plan which is submitted each year to qualify for federal grant funds. The more important relationships are discussed below.

IMPLEMENTATION PROGRAMS

Three main activities are involved in controlling water pollution: standards, enforcement, and monitoring. These three activities must be properly integrated to achieve high quality waters.

Standards for receiving waters are set by the state. They essentially define what is unacceptable pollution. Without this type of definition, "pollution" is a very nebulous term. Effluent guidelines are set by the U.S. EPA. They are basically effluent standards to be met, unless they cause receiving water standards to be violated. In that case more restrictive effluent limitations are established.

Enforcement includes the issuing of wastewater discharge permits and ensuring that they are complied with. The discharge limitations contained within the permits are based on the standards. The permits also contain schedules of compliance which set forth the steps needed to meet standards if they cannot be met at present.

The monitoring activity includes studies of both effluents and receiving water quality. It includes studies of water, sediments, the fish and other biological organisms in the water, and in some cases the atmosphere. Monitoring supports both the standards and enforcement activities.

A fourth activity, the municipal construction grant program, has become very important in Michigan's water pollution control effort. To assist communities in planning and constructing wastewater treatment facilities, construction grant monies are available from the federal government and the state. Municipalities may apply for federal grants to cover 75% of the eligible cost and state grants for 20% of the eligible costs. The Michigan DNR and the U.S. EPA jointly administer this program.

ENFORCEMENT MECHANISMS

Effluent from treatment facilities is monitored periodically by the Michigan DNR. In addition, dischargers are required by NPDES permits to conduct regular self-monitoring. Any discharge of pollutants above the amount specified in the NPDES permit or any violation of the compliance schedule subjects the discharger to possible enforcement action. This action consists of one or a combination of several enforcement remedies, depending on the situation. These include enforcement letters, notices of non-compliance, notices of violation, appearances before the Michigan Water Resources Commission, Water Resources Commission Orders, and, as a final action, litigation against the discharger. Litigation may be used to recover civil penalties of up to $10,000 a day or criminal penalties of up to $50,000 per day. These same types of enforcement actions can be taken against a non-permitted discharge such as an oil spill.

CANADA FEDERAL

MAJOR LEGISLATION AND SALIENT FEATURES

Under the British North America Act of 1867 (BNA Act), the Canadian federal government has legislative powers over shipping, navigation, inland and coastal fisheries, and to some extent over interprovincial and international undertakings. The provinces, on the other hand, have authority to legislate in the field of domestic and industrial water supply, pollution abatement, power development, irrigation, reclamation, and recreation.

Under these constitutional arrangements, the federal and provincial governments are together responsible for managing the water resources in Canada. To meet its responsibility in this area, the federal government has enacted several pieces of legislation to control, from the federal viewpoint, the development and use of Canada's water resource. Of these, six federal acts are perhaps the ones most used in managing the water resources of the Great Lakes system: Canada Water Act, The Fisheries Act, The Canada Shipping Act, The Navigable Waters Protection Act, The Environmental Contaminants Act, and The National Housing Act.

The Canada Water Act provides for the management of Canada's water resource through research, planning, and implementation taking into consideration such factors as conservation, man-made developments, and water utilization. The Act covers three general areas in water resource management: the supply and demand of water, water quality management in critically polluted areas, and comprehensive water resource management programs. The Act contains mechanisms for setting up formal agreements with the provinces for the purpose of carrying out joint cooperative studies as and when required. The Canada Water Act contains provisions for establishing water quality objectives, users fees, waste discharge fees, and heavy fines for polluters. Under the Act, the phosphorus content in commercial cleansing agents and detergents has been reduced by regulation to 2.2% of the product with further reductions to take place in future months.

The Fisheries Act and its amendments are the basis for federal involvement in pollution control and effluent standards. The Act contains many provisions such as the installation of special structures in waterways to facilitate the movement of fish around obstructions, water intake screens, and pollution control devices. The Fisheries Act prohibits the discharge of substances deleterious to fish or to man's use of fish. The Act contains regulations limiting the discharge of specific pollutants and provides for the review of plans of new or modified pollution control works to ensure compliance with these regulations.

The Canada Shipping Act, administered by the Department of Transport, covers a wide range of shipping requirements and contains regulations governing oil discharges from vessels. The Act provides for fines of up to $100,000 for pollution of Canadian waters by oil from vessels and ship owners are required to post bonds of up to $14,000,000 for clean-up purposes in the event of oil spills.

The Navigable Waters Protection Act, also administered by the Department of Transport, contains a number of provisions concerning disposal of solid wastes in navigable waters which may hinder navigation. Regulations pertaining to dredging, dumping of dredge spoils, wharf and harbour construction, and pipe line crossings are covered in this Act. The Navigable Waters Protection Act also considers pollution problems and provides mechanisms for reviewing construction projects to determine their environmental impact on the water resources.

The Environmental Contaminants Act, administered by the Department of the Environment, was proclaimed in 1976 and is designed to regulate the introduction, use, distribution, and the processing of materials in quantities greater than 500 pounds per year. Under this Act, hazardous chemicals and compounds imported into Canada or developed in Canada are assessed to determine their potential for causing environmental damage before they are released for general use. The assessment process is carried out by an Environmental Contaminants Board of Review appointed by the Department of the Environment and the Department of National Health and Welfare. The Board inquires into any substance which may cause injury to human health or the environment.

The National Housing Act, administered by the Central Mortgage and Housing Corporation (CMHC), provides for the availability of federal funds for municipal sewage works. Recent amendments to the Act have eased funding for certain classes of projects, particularly in small communities. CMHC grants are now available to regional governments and municipalities for the development of long-range comprehensive regional sewerage collector plans and until April 1, 1980, CMHC loans for storm trunk sewers will also be available. The amendments provide for the use of new technology in the municipal pollution treatment field and also provide for the requirement of a CMHC-provincial agreement for the funding of the projects.

MAJOR AGENCIES, THEIR FUNCTIONS AND INTERRELATIONSHIPS

Canada's Department of the Environment is the most heavily involved federal department engaged in studying, surveying, and recommending pollution control measures in the Great Lakes system. This role is carried out largely in cooperation with other federal departments and provincial agencies. Most of the Department's activities associated with the Great Lakes are centred at the Canada Centre for Inland Waters (CCIW) facilities at Burlington, Ontario. Research into a wide variety of fields including physical, chemical, and biological aspects of water is conducted at CCIW in close association with international, provincial, university, and private research organizations. CCIW provides important information and advice in such areas as hydraulics, eutrophication, analytical and numerical methods, toxic substances, oil spill clean-up, waste, and radioactivity from physical and geochemical, biological, microbiological, economic, and social standpoints. Other departmental activities at CCIW include research on wastewater treatment processes for industrial and municipal pollution control plants and the conduct of hydrographic and water quality surveys. Research into the environmental significance of toxic substances and the environmental degradability of phosphorus substitutes in detergents is another important program carried out at CCIW.

CMHC provides financial support under the National Housing Act to municipalities in Ontario for the construction of sewage treatment plants. This support is usually in the form of low interest loans with a 25% forgiveness clause written into the terms of repayment. In addition, under the Act, CMHC provides grants to Ontario municipalities for the development of five-year comprehensive regional sewerage collector plans. CMHC also provides loans for trunk storm sewers. Loans and grants are administered through the Central Mortgage and Housing Corporation-Ontario Municipal Sewerage Agreement. CMHC maintains close liaison with the Department of the Environment and other federal departments through joint reviews of plans and projects.

Canada's Department of National Health and Welfare takes the lead in developing drinking water standards and objectives. In addition, the Department carries out studies on the effects of toxic and hazardous substances on human health and, in consultation with other federal departments and other government agencies, sets maximum allowable limits on these substances in fish and other marine foods for human consumption.

The Department of Transport, as stated before, regulates sewage discharge and oil spills from vessels in the Great Lakes System through the Canada Shipping Act and controls dredging and dumping in the Great Lakes through the Navigable Waters Protection Act. The Department of Transport also assumes control of clean-up operations in the Great Lakes in the event of oil spills and other major releases by appointing on-scene commanders and providing equipment and personnel in accordance with the Joint Canada-United States Marine Pollution Contingency Plan.

Canada's Department of Finance contributes to the management of the Great Lakes water resource system by providing for attractive tax deductions on capital expenditures for industrial pollution control facilities through rapid write-off provisions. This provides a strong incentive to industry to press on with pollution control measures, thereby reducing waste loads entering the Great Lakes system.

Other federal departments are involved in different ways in studying and managing the Great Lakes water resource system such as the Department of Public Works, concerned with installations and dredging operations and the Department of Agriculture, concerned with pollution from land runoff.

FEDERAL AND PROVINCIAL RELATIONSHIPS

As discussed previously, the federal government under the British North America Act has authority over shipping, navigation, and fisheries in the Great Lakes System while the provincial government legislates on matters related to domestic and industrial water supply, pollution abatement, power development, irrigation, reclamations, and recreation. In carrying out their respective roles, close cooperation exists between the Canadian federal government and the Ontario provincial government. In recent years, these cooperative efforts have been formalized in federal-provincial agreements, three of which are the Canada-Ontario Agreement on Great Lakes Water Quality, the Central Mortgage and Housing Corporation-Ontario Municipal Sewerage Agreement, and the Canada-Ontario Accord for the Protection and Enhancement of Environmental Quality.

The Canada-Ontario Agreement on Great Lakes Water Quality was signed in August 1971 in response to the International Joint Commission's recommendations concerning pollution of the Lower Lakes and in anticipation of the early conclusion of the Canada-United States Great Lakes Water Quality Agreement. The Canada-Ontario Agreement provides for the encouragement of speed-up of municipal sewage treatment plant construction by increasing the flow of capital funds and provides for the reduction of phosphorus in the most critically affected waters in the Great Lakes system.

The Canada-Ontario Agreement also provides for federal-provincial cost-sharing of research into pollution abatement programs to develop methods for reducing costs of waste treatment programs and to ensure that best technological advances are incorporated in abatement programs.

The Canada-Ontario Agreement has recently been amended to exclude the original provisions for capital funding of sewerage works. This is now covered in the Central Mortgage and Housing Corporation-Ontario Municipal Sewerage Agreement.

Research projects covering many areas of sewage handling and treatment including chemical additives, sludge separation and disposal, hazardous and toxic substances, and sewerage collector systems are carried out under the Canada-Ontario Agreement.

The Central Mortgage and Housing Corporation-Ontario Municipal Sewerage Agreement was signed in September 1975. The principal objectives of this Agreement are to support the control of water and soil pollution in Ontario and to encourage the provision of serviced land for residential development in undeveloped areas of the province. The Agreement provides for financial support of these activities through the form of grants or loans. Under this Agreement, $400,000,000 will be made available for Great Lakes sewage treatment and storm sewer projects in the fiscal years 1975 to 1977.

The Canada-Ontario Accord for the Protection and Enhancement of Environmental Quality was signed in October 1975. Under this Accord, the federal and provincial governments agree to the development of criteria, natural ambient objectives, and the identification of areas of joint interest where these would apply. The Accord also provides for the development by Canada, in consultation with the province, of national baseline effluent and emission requirements and guidelines for specific industrial groups and specific pollutants for agreed-upon classes of industries. The Accord describes the mechanisms whereby both governments may carry out pollution control programs under their respective legislative authority to meet agreed-upon objectives and federal and provincial requirements.

The Accord defines how pollution control enforcement regulations will be carried out with respect to the two governments. Provision is made for speed-up of joint programs of data gathering, assessment, research, and design which have been initiated under the Canada-Ontario Agreement. Also under this Accord, when and where national effluent requirements have not been developed, the province will apply best practicable technology for controlling emissions and waste discharges in air and water.

ENFORCEMENT MECHANISMS

Under the Canada-Ontario Accord for the Protection and Enhancement of Environmental Quality, Ontario establishes and enforces requirements at least as stringent as the agreed baseline requirements and carries out surveillance of effluents and emissions, including their impact on ambient quality and compliance with standards and objectives.

Also under the Accord, the federal and provincial governments cooperate in monitoring air and water quality in areas of joint interest and in interpreting the data with respect to trends and objectives. The provincial government carries out most of the compliance monitoring, conducts environmental impact assessment on specific site developments, and grants approvals for constructions.

ONTARIO

MAJOR LEGISLATION

The Ontario Water Resources Act

This Act provides for the control of water pollution through the establishment of water and sewage projects under the supervision of the province. The Act empowers the Minister of the Environment to enter into agreements with municipalities providing for the design, construction, operation, and financing of water and sewage works. The Minister is empowered to disseminate information and advice concerning the collection, production, transmission, treatment, storage, supply, and distribution of water or sewage and may conduct research programs and prepare statistics.

In addition, the discharge of materials into the waters of the province which may impair these waters is prohibited with appropriate fines of up to $10,000 upon summary conviction (Section 32). The Minister may also, upon application to the Supreme Court, obtain an injunction to prohibit discharges in cases where impairment might result (Section 31). Approval for the establishment or alteration of sewage works for the collection, transmission, or disposal of wastes is mandatory before any work is undertaken (Section 42).

An industry may be required by order to make investigations and submit reports to the Ministry of the Environment and to install or construct facilities for the collection, transmission, treatment, or disposal of sewage (Section 69). Any municipality or person responsible for discharge, deposit, or escape of pollutant material is required to notify the Ministry forthwith (Section 32(3)). The Act also provides for the right of Ministry employees and agents to inspect premises at any time and to conduct surveys and investigations (Section 20).

Section 62 of the Ontario Water Resources Act empowers the Minister, subject to approval by Cabinet, to regulate among other matters water works; sewage works; plumbing; sewage strength; classification and licensing of water and sewage plant operators; standards of quality for water supplies, sewage effluents, receiving streams, and water courses; operating standards for water and sewage works; sewage from pleasure craft and shore reception facilities; and the use of water from any source of supply. Regulations on water quality standards have not as yet been established by the province; rather, the Ministry employs guidelines and criteria for water quality management and effluent requirements to protect water quality for the greatest number of uses.

The Environmental Protection Act

This Act prohibits the deposit, emission, or discharge of any contaminant into the natural environment which may impair its use, cause impairment of the quality of the natural environment, cause injury or damage to property or life, cause harm or discomfort to a person, or adversely affect the health or safety of a person (Section 14).

The Act further provides for the issuance of control orders which, following a report or an investigation by an inspector, may be used to require an industry to reduce the level of contaminants being discharged (Section 6). Also, where there are reasonable grounds to believe that the discharge of a particular contaminant may constitute a danger to human life, health, or property, a stop order may be issued (Section 7).

The Act further provides that no person shall construct or alter any plant that may emit contaminants or alter the rate of production without approval (Section 8).

Under the Act, a person responsible for a source of contaminants may submit a program to prevent or to reduce that contaminant and the Ministry may issue a "Program Approval" which effectively formalizes the program (Section 10).

The Environmental Protection Act also provides that every person responsible for a source of contaminants shall furnish such information as a provincial officer requires for the purpose of the Act or the regulations (Section 83(3)).

The Pesticides Act

The sale and use of pesticides is rigidly controlled in Ontario by the Pesticides Act. Registered pesticides are classified on the basis of toxicology and potential environmental impact. The distribution, availability, and use are regulated and classified.

Environmental Assessment Act and Regulations

Sections of this Act related to the formation of the Environmental Assessment Board were recently proclaimed by the Lieutenant Governor. In October 1976, regulations under the Act were proclaimed which require, for provincial government projects with a significant effect on the environment, the submission of an assessment for approval to the Minister of the Environment who may submit the proposal to the Board for a hearing. The public is encouraged to inspect and comment on the proposals. Eventually, municipal and private projects will be brought under the regulations.

Other Legislation

Other legislation which may be applicable from time to time in implementing various aspects of the Water Quality Agreement include:

(1) The Planning and Development Act (1973)
(2) The Planning Act
(3) Niagara Escarpment Planning and Development Act
(4) The Beds of Navigable Water Act
(5) Ontario Public Lands Act
(6) The Beach Improvement Act
(7) The Ontario Mining Act
(8) The Conservation Authorities Act
(9) The Drainage Act
(10) The Lakes and Rivers Improvement Act

MAJOR AGENCIES, THEIR FUNCTIONS AND INTERRELATIONSHIPS

The Ontario Ministry of the Environment has general responsibilities for environmental planning and management, pollution control and associated research, and operating services. It administers the Ontario Water Resources Act, the Environmental Protection Act, the Pesticides Act, and the Environmental Assessment Act. In addition to the financing and supervision of water and sewage works and the enforcement of the legislation summarized above, the Ministry operates a water-quality and water-quantity monitoring network, and has established extensive laboratory facilities for water-quality analysis. The Ministry also coordinates river basin studies, involving other ministries and local government agencies, which provide a basis for the development of implementation programs to promote more effective use of water and land-based resources.

The Ministry of Natural Resources, through administrative agreement with the federal government, has been delegated responsibility over fisheries matters in Ontario. In addition, the Ministry administers a number of acts which regulate or prohibit the dumping, depositing, or removal of materials into or adjacent to water bodies. These include the Lakes and Rivers Improvement Act, the Mining Act, the Conservation Authorities Act, and the Beach Protection Act.

FEDERAL AND PROVINCIAL RELATIONSHIPS

While Canadian land and water resources are under provincial authority, fisheries and international obligations are federal responsibilities. Duplication of effort in these shared responsibilities has been avoided by administrative agreements involving delegation of responsibility to the province. Recognition that both levels of government have responsibilities in managing the environment has fostered intergovernmental agreements to ensure the development of comprehensive environmental programs. These include the Canada-Ontario Accord for the Protection and Enhancement of Environmental Quality and the Canada-Ontario Great Lakes Water Quality Agreement. The Accord describes the general arrangements for federal-provincial action in pollution control and the Agreement specifies responsibilities that each government, within its jurisdiction, will undertake to implement the Canada-U.S. Agreement.

IMPLEMENTATION PROGRAMS

Since the mid-1950's, wastewater facilities planning has been given priority in Ontario and at present 94% of the sewered population in the drainage system is served by sewage treatment adequate to meet the water quality objectives of the Agreement; 90% of this population employs a secondary level of sewage treatment. In Ontario, the Ministry of the Environment may act as an agent for 30-year low-interest-rate self-liquidating financing and for the construction and operation of municipal sewage works projects. Since 1969, the province has supported two subsidy programs: capital grants up to 75% of the cost of Ministry-financed projects to the extent that annual homeowner costs exceed $130, and capital grants of 15% for provincial projects serving municipalities in an area with the province owning and operating the facilities in perpetuity. In 1974, the latter program was extended to non-Ministry area projects in regional municipalities.

Other programs available to assist industry with the financing of pollution abatement programs include:

(1) Pollution Control Loans - a loan of up to $250,000 from the Ontario Development Corporation to companies which are unable to finance the purchase of equipment from their own resources.

(2) An accelerated capital cost allowance on pollution control for federal and provincial income tax assessment - equivalent to an interest-free loan in that it allows eligible companies to postpone a portion of their tax payments. This provision applies to air and water pollution control equipment that was acquired before 1977.

ENFORCEMENT MECHANISMS

The Ministry of the Environment utilizes water quality guidelines and criteria, together with effluent objectives, to protect water quality. Any party discharging a substance which may impair the quality of a water body is subject to prosecution and fines under Section 32 of the Ontario Water Resources Act. Initially, however, the Ministry attempts to obtain compliance with the criteria and objectives by negotiating a voluntary pollution abatement program with each discharger. Such voluntary programs may receive a "Program Approval" by the Ministry. Voluntary programs may be made legally binding, or control programs may be imposed by a "Control Order". If the programs specified by a Control Order are not implemented, the discharger is liable to prosecution and fines. If human health is endangered the Ministry may issue a stop order and require immediate cessation of the discharge. New, expanded, or altered operations must include pollution control equipment that meets the Ministry's requirements and must receive Ministry Certificates of Approval before construction is undertaken.

OTHER INPUT CATEGORIES

UNITED STATES

COMBINED SEWERS AND STORMWATER

The control of discharges from combined sewers and stormwater sewers is primarily a responsibility of local jurisdictions. Section 105(a) of PL 92-500 provides federal funds for research and demonstration grants to develop methods for controlling these wastes. The primary federal effort is the implementation of Areawide Waste Treatment Management Programs authorized by Section 208 of PL 92-500 which provides for areawide planning for control of urban nonpoint pollution sources.

VESSEL WASTES

The control of discharges of sanitary wastes from vessels is the responsibility of the U.S. Coast Guard. Section 312 of PL 92-500 requires that all vessels navigating the waters of the U.S. be equipped with approved marine sanitation devices. Section 104(j) of PL 92-500 directs the Coast Guard to do research and development on marine sanitation devices with particular emphasis on equipment to be installed on small recreational vessels. The Coast Guard may authorize anyone to board and inspect vessels in the navigable waters of the U.S. in enforcement of the prohibition against discharge of sewage from the vessel (133 U.S.C. 1163(1)).

SPILLS

The control of spills of oil and hazardous materials is a shared responsibility between the U.S. Coast Guard and the U.S. EPA. The Coast Guard has primary jurisdiction over spills into traditionally navigable waters from vessels and shoreside facilities. The U.S. EPA has primary responsibility for spills into upstream or traditionally non-navigable waters. Section 311 of PL 92-500 prohibits the discharge of oil or hazardous substances into the navigable waters of the U.S., requires that all such discharges be reported to the Coast Guard or U.S. EPA, and authorizes the Coast Guard or U.S. EPA to require the discharger to clean up the spill at the expense of the discharger. Section 311(c)(2) of PL 92-500 requires that a national contingency plan be established in order to provide for response to spills. Industries that store or transport significant quantities of oil or hazardous materials are required to develop and maintain spill prevention contingency plans as part of their Section 402 permits.

DREDGING

Dredging and disposal of dredged material is regulated by the U.S. Army Corps of Engineers under the provisions of the Rivers and Harbors Act of 1899 and under the provisions of Section 404 of PL 92-500. Section 404 requires that permits be issued for all dredging activities in the navigable waters of the U.S. Guidelines for the issuance of permits are to be developed by the U.S. EPA in conjunction with the Corps of Engineers.

CANADA

COMBINED SEWERS AND STORMWATER

Under the Canadian program on urban drainage, the strategy development phase under the Canada-Ontario Agreement is largely completed and implementation has begun. Two projects have been designed to provide information on legislative and regulatory practices in Europe, the U.S., and Canada. The most effective of these practices are being incorporated into proposals for implementation in Ontario. A preliminary draft policy together with supplementary guidelines to control the runoff from new urban developments and existing municipalities has been prepared and is under review.

VESSEL WASTES

Ontario regulations apply to pleasure craft only. The objective is total containment; however, the Ministry of the Environment will accept adequate flow-through systems on large vessels as an interim measure. The overboard discharge of any form of raw sewage is prohibited.

SPILLS

Ontario has a Contingency Plan for Spills of Oil and Other Hazardous Materials. Annex VI of the Plan, "Legislation", contains excerpts from the following statutes affecting activities in Ontario pertaining to the problems associated with pollution spills: Environmental Protection Act, Ontario Water Resources Act, Pesticides Act, Public Lands Act, Drainage Act, Gasoline Handling Act, Petroleum Resources Act, and Energy Act.

DREDGING

If a dredging activity comes under provincial jurisdiction, an application to dredge must be made to the Ministry of the Environment, which will then advise the applicant what it considers acceptable within the terms of the Ontario Water Resources Act. The Ministry also tests for contaminated sediments and monitors water quality in connection with the dredging.

The environmental impact of dredging is assessed using the Ministry's Marine Construction Guidelines. After the implementation of the Ontario Environmental Assessment Act, a more comprehensive review will be implèmented. At present, there are guidelines for open water and land disposal of dredged spoils. Criteria are continually being reviewed in the light of data obtained from dredging projects on water quality and water use effects, and in light of new information in the literature.

There are no provincial statutes which contain direct reference to dredging, although the following legislation could be applied indirectly to exercise control over a dredging activity: Ontario Water Resources Act, Environmental Protection Act, Beds of Navigable Waters Act, Public Lands Act, Conservation Authorities Act, Beach Protection Act, Public Health Act, and Lakes and Rivers Improvement Act.

OTHER INPUT CATEGORIES

UNITED STATES

COMBINED SEWERS AND STORMWATER

VESSEL WASTES

SPILLS

DREDGING

CHAPTER 3
MATERIAL INPUTS

3.1 INTRODUCTION AND MATERIAL BALANCE

INTRODUCTION

Chapter 3 describes material inputs to Lake Huron. This first section introduces and summarizes the remainder of Chapter 3. Included are material balances for certain selected parameters. Chapters 3.2 through 3.11 present the study results for the various input categories. These input categories are direct municipal and direct industrial wastewater discharges, tributaries, interlake transport, atmospheric deposition, shoreline erosion, thermal discharges, radioactivity discharges, dredging activities, vessel waste discharges and spills. Chapter 3.12 presents future projections of material inputs which were obtained from a mathematical model.

The measurements and estimates of material inputs presented in this chapter form a baseline from which future comparisons can be drawn. They also show the significance of various input categories and sources and provide a basis for discussion in Chapters 4, 5, and 6. They were used by other groups in the Upper Lakes study, including the group which calibrated the future projections model. Detailed project reports are available for several of the input categories. These are referenced where appropriate and should be consulted if more detailed information is needed.

GENERAL DESCRIPTION OF THE MATERIAL BALANCE

Material balances have been assembled for five significant parameters for Lake Huron. The balances are essentially tabulations of the material inputs to and outputs from the lake. In addition to material balances for the whole lake, separate tabulations have been made for the North Channel, Georgian Bay, and the main body of Lake Huron. This has been done because these three areas are like separate lakes in many ways. The data which are shown here were obtained from the subsequent sections of Chapter 3 and the backup project reports.

The main reason for preparing the material balances is to help gain a general understanding of these large water bodies as whole systems. The balances are not expected to be exact models of the whole lake. Neither can they be expected to simulate the problems of Lake Huron which are primarily local in nature. However, the balances can be quite enlightening as to major factors which influence the lake. Often they lead to important new questions as discussed in the following paragraph.

The material balance gives a general indication as to whether mankind is presently affecting the whole lake. If not, the material balance can be a starting point for determining what future conditions could cause whole-lake problems. In either case, the material balance will show which inputs are most significant. From this evaluation, the most effective remedial or preventive measures can be considered. A balance can also be a starting point for determining the fate of pollutant inputs. If accumulation is occurring within the lake the balance can help in estimating the steady-state concentration which would be expected at current (or projected) input rates.

The material balance equation can be summarized as follows:

$$\sum \text{INPUTS} - \sum \text{OUTPUTS} = \text{ACCUMULATION}$$

Since the water bodies being considered are very large, the time required to reach steady state is very long. Therefore, the accumulation term is probably not zero, and inputs will not equal outputs. Accumulation may occur as sedimentation or as an increase in the concentration of the material in the lake. This depends on the nature of the material.

Important considerations which are not taken into account here are the dynamic physical, chemical, and biological equilibria in the lake. These can cause exchange of material between the lake water and the lake bottom, and in some cases the atmosphere. Whether these are significant depends on the nature of the particular material being balanced.

THE MATERIAL BALANCE PARAMETERS

Quantitative measurement of all sources of a particular material and subsequent workup of the data to form a material balance is very expensive. Therefore, material balances have been prepared for five parameters which are important to the lake as a whole. These parameters are listed below:

(1) Total Phosphorus -- Phosphorus is considered by many to be the nutrient most likely to limit growth of algae and other aquatic organisms. Phosphorus input is greatly affected by the amount of human civilization in a basin and is probably the key cause of unnatural eutrophication. Many inputs of phosphorus are relatively easy to control. "Total" phosphorus is used in the balance because many of the various chemical forms can become available to the biota in the lake.

(2) Total Nitrogen -- Nitrogen is also considered an important nutrient. It may be limiting in some areas of Lake Huron. Since the atmosphere contains mostly nitrogen, natural equilibrium forces may result in exchange which would not be taken into account in the balance. However, this is probably not significant in Lake Huron because it does not contain large numbers of nitrogen-converting organisms. As with phosphorus, "total" nitrogen is used in the balance because many of the various

chemical forms can become available to the biota in the lake.

(3) Reactive Silicate -- Silicon is considered to be the limiting nutrient for diatoms, the most common algae in Lake Huron. Therefore, if silicon is limited, less desirable algae take their place.

(4) Total Dissolved Solids -- This is the best measure of total impurities in the lake. It is measured by multiplying conductivity, measured in microsiemens per centimetre, by 0.65 (1). About half of the total dissolved solids in Lake Huron is bicarbonate ion. The bicarbonate ion approaches equilibrium with limestone in the lake bottom and with carbon dioxide in the atmosphere. Therefore, the balance may be affected somewhat by these exchanges.

(5) Chloride -- This is an easily-measured, non-reactive substance used to check the validity of the balances. It is also a portion of the dissolved solids which is greatly influenced by human civilization in the basin. It may be an important factor in regulating the amount of dissolved solids in the lake.

Material balances for toxicants present in trace amounts, such as mercury, DDT, and PCB's, would have been desirable in this study. They were not done because most of the input sources sampled were below the detection limit for these materials. Therefore, any such tabulation would have been meaningless. The importance of these trace materials to the whole-lake systems is becoming increasingly apparent. As soon as analytical techniques will permit, material balance tabulations should be done.

MATERIAL BALANCE TABULATIONS

The material balance tabulations are shown in Tables 3.1-1 through 3.1-20. Observations and comments are listed on each table. The tables are arranged in the following order:

	Total Phosphorus	Total Nitrogen	Reactive Silicate	Total Dissolved Solids	Chloride
Whole-Lake Huron	3.1-1	3.1-2	3.1-3	3.1-4	3.1-5
Main-Lake Huron	3.1-6	3.1-7	3.1-8	3.1-9	3.1-10
North Channel	3.1-11	3.1-12	3.1-13	3.1-14	3.1-15
Georgian Bay	3.1-16	3.1-17	3.1-18	3.1-19	3.1-20

Several important points are common to all of the tables. The municipal and industrial inputs shown are only those which go directly to the lake. Wastewater discharges upstream from tributary mouths are not shown separately but are included in the tributary inputs. For phosphorus, independent calculations were made to estimate the amounts entering the tributary from wastewater discharges. These upstream discharges plus the direct phosphorus inputs equal the total phosphorus entering the lake from municipal and industrial sources (assuming all which enters the tributaries eventually reaches the lake). These estimates were based on average phosphorus concentrations in treated municipal effluent and the total average volume of treated sewage entering the tributaries.

Sampled tributaries include all the larger ones plus any smaller ones which have significant upstream wastewater inputs. Unsampled ones were estimated based on similar sampled streams (Chapter 3.3).

Atmospheric inputs shown are based on sample results. Independent estimates of the atmospheric inputs obtained from mathematical models often varied from the sample results (Chapter 3.5). In general, confidence in the atmospheric input estimates is not as great as the tributary, municipal, and industrial input estimates.

There are several sources of material inputs which have been estimated but do not have a significant effect on the material balances. These are not shown on the summary tables, but are discussed below.

Vessel waste inputs (Chapter 3.10) are not significant for any of the material balance parameters and are therefore not shown on the tables.

Dredging inputs (Chapter 3.9) are based on gross amounts of dredged material dumped in the lake. It is likely that only a small portion of this material is available to the lake water. The problems associated with this material tend to be primarily localized. In view of the uncertainty in estimating the amount "available" to the lake (which is felt to be small in relation to the total inputs), dredging inputs have not been shown in the summary tables.

Shore erosion inputs are discussed in Chapter 3.6. As with dredging inputs, it is not now known what portion of the total amounts of the material balance parameters contained in material eroded from the shoreline are available to the lake water. However, they are suspected to be relatively small and are not shown on the tables.

Spills and storm sewer inputs are omitted from the material balance summary tables. They are felt to be relatively small in relation to the total inputs. They are also variable and difficult to estimate.

Groundwater inputs to Lake Huron have not been measured or estimated. However, they are also suspected to be small relative to the other inputs. In general, there is very little information available on groundwater inputs to Lake Huron.

All material balance outputs from Lake Huron via the St. Clair River were calculated using concentrations from southern Lake Huron. Outputs calculated using concentrations in the river were somewhat different due to the presence of material eroded from the shoreline. This is discussed in more detail in Chapter 3.4.

MATERIAL BALANCE SUMMARY

As mentioned above, observations and comments are shown on each material balance table. It is difficult to generalize about the various water bodies or parameters. However, a bar graph has been prepared (Figure 3.1-1) to illustrate the material balances for whole-Lake Huron. Certain generalities are evident:

(1) Tributaries and interlake transport are the major input sources.

(2) Atmospheric inputs are a significant source of nitrogen. Although smaller, they are also important for phosphorus. They are minor for the other three parameters.

(3) Direct municipal and direct industrial sources are minor inputs in all cases. Thus, Lake Huron is quite different in this respect from Lakes Erie and Ontario.

(4) There is a net accumulation of the nutrients phosphorus, nitrogen, and silicon. This is probably due to the sedimentation of dead algae. The balance between inputs and outputs is very close for total dissolved solids and chloride.

FIGURE 3.1-1

WHOLE LAKE HURON MATERIAL BALANCE SUMMARY

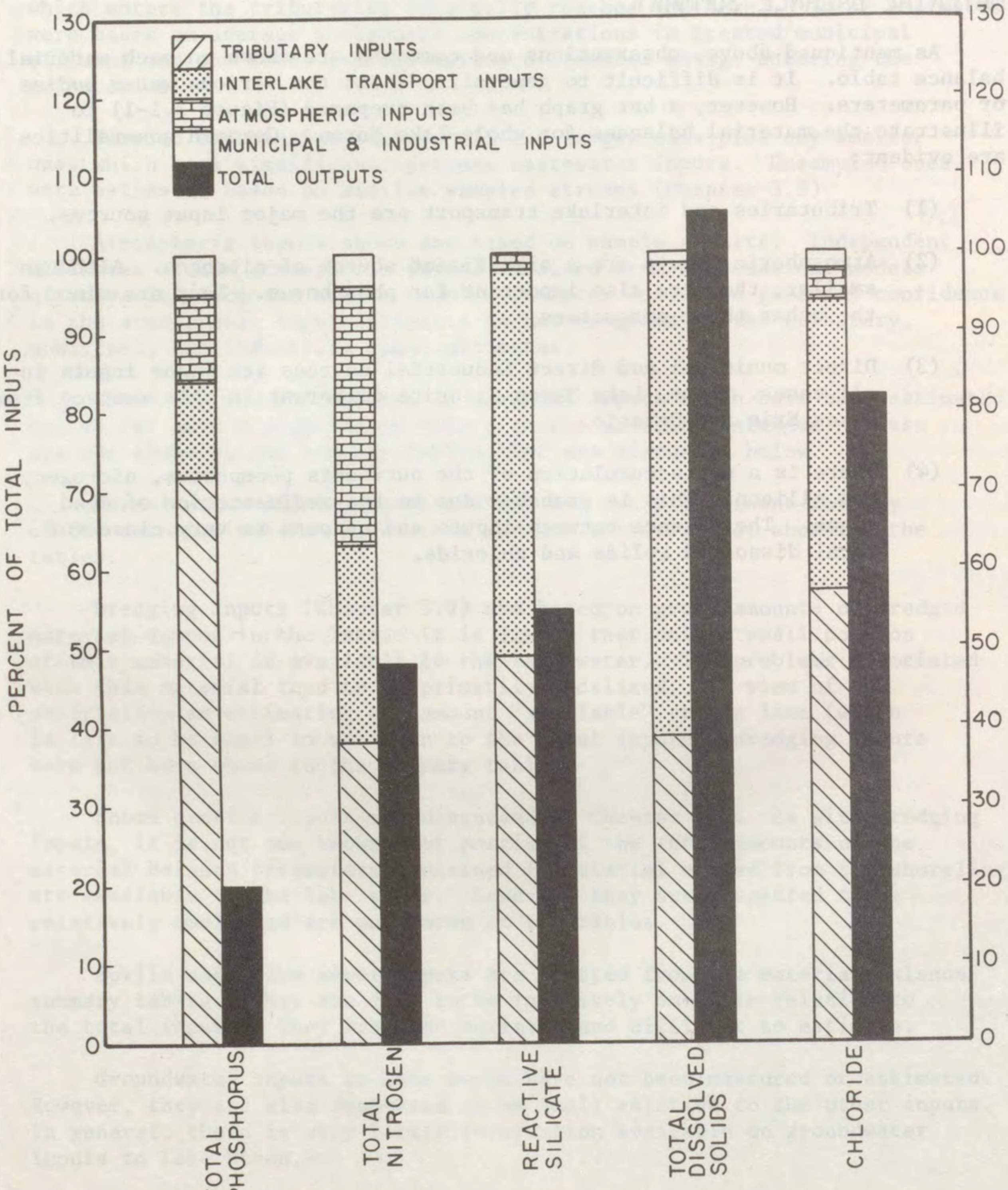

TABLE 3.1-1

WHOLE LAKE HURON MATERIAL BALANCE FOR TOTAL PHOSPHORUS (AS P)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	62	67	1,670[a]	172	1,970
ONTARIO	128	14	1,950	174	2,270
ATMOSPHERIC INPUTS					620
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					255
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					402
TOTAL INPUTS					5,520
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					1,080

a. Includes an adjusted value for the Saginaw River. The adjustment was based on the departure of streamflow from the annual average at the time of sampling (2).

OBSERVATIONS AND COMMENTS

1. Tributaries account for 72% of the total inputs. The total is about evenly divided between the U.S. and Canada. However, the largest single tributary input is from the Saginaw River on the U.S. side, which contributes one-third of the tributary total from both countries.

2. *Direct* municipal and industrial sources account for only about 5% of the total inputs. Independent calculations show that about 26% of the phosphorus entering the lake via tributaries originates from upstream municipal and industrial sources. Thus, about 23% of the total inputs originate from *all* municipal and industrial discharges. Recent construction of phosphorus removal facilties at wastewater treatment plants has reduced total phosphorus inputs to the present 23% from a somewhat higher level. Additional facilities now planned will reduce the total municipal and industrial input to about 11%.

3. Interlake transport from Lake Superior and Lake Michigan accounts for about 12% of the total inputs. Atmospheric inputs account for about 11% of the total.

4. About 20% of the input phosphorus is measured as output. This seems somewhat low. However, sedimentation of phosphorus is usually quite significant in lakes of this type. Therefore, it is difficult to tell how much of the difference is due to sedimentation and how much results in increasing concentrations in the lake.

5. The loadings from municipal, industrial, and tributary sources are projected to increase 22% by 2020. This assumes that the present general level of waste treatment continues and that non-point source inputs remain constant. Therefore, the projected increase is entirely due to the forecast population increases and industrial expansions. No loading projections have been made for the other sources, including atmospheric inputs.

TABLE 3.1-2

WHOLE LAKE HURON MATERIAL BALANCE FOR TOTAL NITROGEN (AS N)

SOURCE	LOADINGS IN TONNES PER YEAR				TOTAL
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		
			SAMPLED	UNSAMPLED	
MICHIGAN	325	467	24,800	3,760	29,400
ONTARIO	719	6,610	26,100	3,690	37,100
ATMOSPHERIC INPUTS					52,000
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					18,800
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					21,900
				TOTAL INPUTS	159,000
				TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)	76,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 37% of the total inputs, which are about equally divided between the U.S. and Canada.

2. Atmospheric inputs account for 33% of the total inputs.

3. Interlake transport inputs from Lake Superior via the St. Marys River and Lake Michigan via the Straits of Mackinac account for 26% of the total inputs.

4. The measured output is about 48% of the total inputs. Sedimentation and exchange with the atmosphere may be significant for nitrogen. Therefore, it is not known how much of the difference between input and output results in increasing concentrations in the lake.

5. The loadings from municipal, industrial, and tributary sources are projected to increase 94% by 2020. This assumes that the present general level of waste treatment continues and that non-point source inputs remain constant. Therefore, the projected increase is entirely due to the forecast population increases and industrial expansions. No loading projections have been made for the other sources, including atmospheric inputs.

TABLE 3.1-3

WHOLE LAKE HURON MATERIAL BALANCE FOR REACTIVE SILICATE (AS SiO_2)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	488	843	85,100	10,300	96,700
ONTARIO	326	0	119,000	10,400	130,000
ATMOSPHERIC INPUTS					9,200
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					70,900
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					150,000
TOTAL INPUTS					457,000
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					248,000

OBSERVATIONS AND COMMENTS

1. Inputs are about equally divided between tributary and interlake transport inputs. Tributaries account for about 49% of the total, and interlake transport about 48% of the total.

2. The total of outputs from Lake Huron is about 54% of the total inputs.

3. The loadings from tributaries depend primarily on their flow rates. Concentrations do not seem to depend on human civilization to any great extent. This would indicate that the lake should be closer to steady state for silicate than for other materials more strongly influenced by civilization. For this reason, it is surprising that there is not a better balance between inputs and outputs. Perhaps sedimentation of diatoms is occurring.

4. The loadings from municipal, industrial, and tributary sources are projected to increase 80% by 2020. This assumes that the present general level of waste treatment continues and that non-point source inputs remain constant. Therefore, the projected increase is entirely due to the forecast population increases and industrial expansions. No loading projections have been made for the other sources, including atmospheric inputs.

TABLE 3.1-4

WHOLE LAKE HURON MATERIAL BALANCE FOR TOTAL DISSOLVED SOLIDS

SOURCE	LOADINGS IN TONNES PER YEAR				TOTAL
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		
			SAMPLED	UNSAMPLED	
MICHIGAN	21,400	69,000	3,580,000	548,000	4,220,000
ONTARIO	18,100	23,600	4,340,000	529,000	4,910,000
ATMOSPHERIC INPUTS					110,000
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					10,100,000
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					4,020,000
TOTAL INPUTS					23,400,000
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					24,600,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 38% of the total inputs, about equally divided between U.S. and Canadian sources.

2. Interlake transport from Lake Superior and Lake Michigan account for 60% of the total inputs. Most of this is from Lake Michigan.

3. The measured output was 5% greater than the total inputs. This is a very close balance and indicates that the lake is close to steady state for total dissolved solids.

4. The loadings from municipal, industrial, and tributary sources are projected to increase 62% by 2020. This assumes that the present general level of waste treatment continues and that non-point source inputs remain constant. Therefore, the projected increase is entirely due to the forecast population increases and industrial expansions. No loading projections have been made for the other sources, including atmospheric inputs.

TABLE 3.1-5
WHOLE LAKE HURON MATERIAL BALANCE FOR CHLORIDE

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	4,340	10,700	405,000	54,400	474,000
ONTARIO	3,270	7,880	245,000	22,600	279,000
ATMOSPHERIC INPUTS					49,000
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					401,000
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					76,700
				TOTAL INPUTS	1,280,000
				TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)	1,050,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 57% of the total inputs.

2. Interlake transport from Lake Michigan via the Straits of Mackinac and Lake Superior via the St. Marys River account for 37% of the total inputs. Most of this is from Lake Michigan.

3. The measured output is 82% of the total inputs. This is a fairly good balance. However, chloride ion is easily measured and does not tend to change form or settle to the lakebottom. It should balance very closely. The difference would indicate that chloride is increasing toward a slightly higher steady state concentration.

4. The loadings from municipal, industrial, and tributary sources are projected to increase 75% by 2020. This assumes that the present general level of waste treatment continues and that non-point source inputs remain constant. Therefore, the projected increase is entirely due to the forecast population increases and industrial expansions. No loading projections have been made for the other sources, including atmospheric inputs.

TABLE 3.1-6

MAIN LAKE HURON MATERIAL BALANCE FOR TOTAL PHOSPHORUS (AS P)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	62	67	1,670[a]	172	1,970
ONTARIO	8	0	348	81	437
ATMOSPHERIC INPUTS					450
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					255
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					273
INPUT FROM NORTH CHANNEL					261
INPUT FROM GEORGIAN BAY					74
TOTAL INPUTS					3,720
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					1,080

a. Includes an adjusted value for the Saginaw River. The adjustment was based on the departure of streamflow from the annual average at the time of sampling (2).

OBSERVATIONS AND COMMENTS

1. Tributaries account for 61% of the total inputs. Canadian tributary inputs are reduced considerably as Georgian Bay and North Channel act as sinks for phosphorus. The Saginaw River is the largest tributary and accounts for 58% of the tributary total and 35% of all inputs to the lake.

2. *Direct* municipal and industrial sources account for only about 4% of the total inputs. Independent calculations show that 42% of the phosphorus entering the lake via tributaries originates from upstream municipal and industrial discharges. Thus, about 29% of the total inputs originate from *all* municipal and industrial discharges. Recent construction of phosphorus removal facilities at wastewater treatment plants has reduced total phosphorus inputs to the present 29% from a somewhat higher level. Additional facilities now planned will reduce the total municipal and industrial input to about 10%.

3. Interlake transport from Lake Superior, Lake Michigan, North Channel, and Georgian Bay accounts for about 23% of the total inputs.

4. Atmospheric inputs account for about 12% of the total inputs.

5. About 29% of the input phosphorus is measured as output. Sedimentation of phosphorus is usually quite significant in lakes of this type. Therefore, it is difficult to tell how much of the difference is due to sedimentation and how much results in increasing concentrations in the lake.

TABLE 3.1-7

MAIN LAKE HURON MATERIAL BALANCE FOR TOTAL NITROGEN (AS N)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	325	467	24,800	3,760	29,400
ONTARIO	37	0	8,400	2,380	10,800
ATMOSPHERIC INPUTS					34,000
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					18,800
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					14,900
INPUT FROM NORTH CHANNEL					12,500[a]
INPUT FROM GEORGIAN BAY					4,880[a]
TOTAL INPUTS					125,000
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					76,000

a. Filtered nitrate plus nitrite

OBSERVATIONS AND COMMENTS

1. Inputs of nitrogen are about equally divided between tributary, atmospheric, and interlake transport sources. About 41% of the total is from interlake transport, 32% from tributaries, and 27% from atmospheric sources.

2. The measured output is about 61% of the total inputs. Sedimentation and exchange with the atmosphere may be significant for nitrogen. Therefore, it is not known how much of the difference between input and output results in increasing concentrations in the lake.

TABLE 3.1-8

MAIN LAKE HURON MATERIAL BALANCE FOR REACTIVE SILICATE (AS SiO_2)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	488	843	85,100	10,300	96,700
ONTARIO	15	0	18,100	2,760	20,900
ATMOSPHERIC INPUTS					7,510
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					70,900
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					102,000
INPUT FROM NORTH CHANNEL					84,700
INPUT FROM GEORGIAN BAY					48,300
TOTAL INPUTS					431,000
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					248,000

OBSERVATIONS AND COMMENTS

1. Interlake transport accounts for 71% of the total inputs. This is from Lake Superior via the St. Marys River, Lake Michigan via the Straits of Mackinac, and from Georgian Bay and North Channel.

2. Georgian Bay and North Channel provide very little reduction in silicate. Essentially, all the silicate entering those water bodies reaches the Main Lake.

3. Tributaries account for 27% of the total inputs.

4. The total output is about 58% of the total inputs.

5. Silicate loadings do not seem to depend on human civilization to any great degree. This would indicate that the lake should be closer to steady state than for other materials which are more strongly influenced by civilization. For this reason it is surprising that there is not a better balance between inputs and outputs. Perhaps sedimentation of diatoms is occurring.

TABLE 3.1-9

MAIN LAKE HURON MATERIAL BALANCE FOR TOTAL DISSOLVED SOLIDS

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	21,400	69,000	3,580,000	548,000	4,220,000
ONTARIO	1,700	0	2,020,000	304,000	2,330,000
ATMOSPHERIC INPUTS					72,000
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					10,100,000
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					2,730,000
INPUT FROM NORTH CHANNEL					4,910,000
INPUT FROM GEORGIAN BAY					1,740,000
TOTAL INPUTS					26,100,000
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					24,600,000

OBSERVATIONS AND COMMENTS

1. Interlake transport accounts for 75% of the total inputs. This is from Lake Superior via the St. Marys River, Lake Michigan via the Straits of Mackinac, North Channel and Georgian Bay.

2. Tributaries account for 25% of the total inputs.

3. Total outputs are about 94% of total inputs. This is a very good balance and indicates that the lake is near steady state for total dissolved solids.

TABLE 3.1-10

MAIN LAKE HURON MATERIAL BALANCE FOR CHLORIDE

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY SAMPLED	TRIBUTARY UNSAMPLED	TOTAL
MICHIGAN	4,340	10,700	405,000	54,400	474,000
ONTARIO	383	0	110,000	13,800	124,000
ATMOSPHERIC INPUTS					33,000
STRAITS OF MACKINAC INPUT FROM LAKE MICHIGAN					401,000
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					52,100
INPUT FROM NORTH CHANNEL					193,000
INPUT FROM GEORGIAN BAY					87,400
TOTAL INPUTS					1,360,000
TOTAL OUTPUTS (VIA THE ST. CLAIR RIVER)					1,050,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 43% of the total inputs.

2. Interlake transport from Lake Superior, Lake Michigan, North Channel, and Georgian Bay account for 54% of the total inputs.

3. The output is 77% of the total inputs. This is a fairly good balance between inputs and outputs. However, the chloride balance should be very close since it is an easily measured parameter which does not tend to change form or settle to the lakebottom. The difference would indicate that chloride is increasing toward a slightly higher steady state concentration.

TABLE 3.1-11

NORTH CHANNEL MATERIAL BALANCE FOR TOTAL PHOSPHORUS (AS P)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
ONTARIO	60	14	930	28	1,030
ATMOSPHERIC INPUTS					36
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					129
INPUT FROM GEORGIAN BAY					24
TOTAL INPUTS					1,220
TOTAL OUTPUTS (TO LAKE HURON)					261

OBSERVATIONS AND COMMENTS

1. Tributaries account for 79% of the total inputs. Other inputs are minor. The majority of this tributary phosphorus is from land discharge, rather than municipal or industrial point sources.

2. About 22% of the input phosphorus is measured as output. Thus, much of the phosphorus is retained in North Channel and does not reach Lake Huron.

TABLE 3.1-12

NORTH CHANNEL MATERIAL BALANCE FOR TOTAL NITROGEN (AS N)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
ONTARIO	368	6,600	7,660	389	15,000
ATMOSPHERIC INPUTS					3,780
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					7,000
INPUT FROM GEORGIAN BAY					930[a]
TOTAL INPUTS					26,700
TOTAL OUTPUTS (TO LAKE HURON)					12,500[a]

a. Filtered nitrate plus nitrite only

OBSERVATIONS AND COMMENTS

1. Tributaries account for 30% of the total inputs.
2. Interlake transport from Lake Superior via the St. Marys River and from Georgian Bay account for 30% of the total inputs.
3. Direct municipal and industrial point sources account for 26% of the total inputs. This is a relatively large portion of the nitrogen which is potentially controllable. It is primarily from Canadian inputs to the St. Marys River.
4. The measured output is about 47% of the total inputs.

TABLE 3.1-13

NORTH CHANNEL MATERIAL BALANCE FOR REACTIVE SILICATE (AS SiO_2)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
ONTARIO	251	0	48,600	2,480	51,300
ATMOSPHERIC INPUTS					355
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					47,900
INPUT FROM GEORGIAN BAY					5,130
TOTAL INPUTS					105,000
TOTAL OUTPUTS (TO LAKE HURON)					84,700

OBSERVATIONS AND COMMENTS

1. Essentially all of the inputs are from tributaries and interlake transport, with about half from each.

2. Silicate loadings do not seem to depend on human civilization to any great degree. This would indicate that North Channel should be essentially at steady state. The outputs are about 81% of inputs, which seems to verify the steady state condition.

TABLE 3.1-14

NORTH CHANNEL MATERIAL BALANCE FOR TOTAL DISSOLVED SOLIDS

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
ONTARIO	6,260	23,600	634,000	42,400	706,000
ATMOSPHERIC INPUTS					7,980
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					1,290,000
INPUT FROM GEORGIAN BAY					460,000
TOTAL INPUTS					2,460,000
TOTAL OUTPUTS (TO LAKE HURON)					4,910,000

OBSERVATIONS AND COMMENTS

1. Interlake transport from Lake Superior via the St. Marys River and from Georgian Bay accounts for 71% of the total inputs.

2. Tributaries account for 27% of the total inputs.

3. Measured outputs are about double the measured inputs. This discrepancy is surprising and may require further investigation.

TABLE 3.1-15

NORTH CHANNEL MATERIAL BALANCE FOR CHLORIDE

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
ONTARIO	1,020	7,880	56,400	2,240	67,500
ATMOSPHERIC INPUTS					3,360
ST. MARYS RIVER INPUT FROM LAKE SUPERIOR					24,600
INPUT FROM GEORGIAN BAY					18,100
TOTAL INPUTS					114,000
TOTAL OUTPUTS (TO LAKE HURON)					193,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 51% of the total inputs.
2. Interlake transport from Lake Superior and Georgian Bay accounts for 37% of the total inputs.
3. Measured outputs are 69% greater than measured inputs. Chloride ion is easily measured and does not tend to change form or settle to the lakebottom. Therefore, a better material balance should be expected.

TABLE 3.1-16

GEORGIAN BAY MATERIAL BALANCE FOR TOTAL PHOSPHORUS (AS P)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY SAMPLED	TRIBUTARY UNSAMPLED	TOTAL
ONTARIO	60	0	668	66	794
ATMOSPHERIC INPUTS					134
OUTPUT TO LAKE HURON					74
OUTPUT TO NORTH CHANNEL					24
				TOTAL INPUTS	928
				TOTAL OUTPUTS	98

OBSERVATIONS AND COMMENTS

1. Tributaries account for 79% of the total inputs.

2. *Direct* municipal sources account for only about 6% of the total inputs. Independent calculations show that about 5% of phosphorus entering the lake via tributaries originates from upstream municipal and industrial sources. Thus, about 10% of the total inputs originate from *all* municipal and industrial sources.

3. About 11% of the input phosphorus is measured as output. Thus, much of the phosphorus is retained in Georgian Bay and does not reach Lake Huron.

TABLE 3.1-17

GEORGIAN BAY MATERIAL BALANCE FOR TOTAL NITROGEN (AS N)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
ONTARIO	314	0	10,000	927	11,200
ATMOSPHERIC INPUTS					14,200
OUTPUT TO LAKE HURON					4,880[a]
OUTPUT TO NORTH CHANNEL					930[a]
				TOTAL INPUTS	25,400
				TOTAL OUTPUTS	5,810[a]

a.Filtered nitrate plus nitrite only

OBSERVATIONS AND COMMENTS

1. Atmospheric inputs account for 56% of the total inputs.

2. Tributaries account for 43% of the total.

3. The measured output is only 23% of the total inputs. Sedimentation and exchange with the atmosphere may be significant for nitrogen. Therefore, it is not known how much of the difference between input and output results in increasing concentrations in Georgian Bay.

TABLE 3.1-18

GEORGIAN BAY MATERIAL BALANCE FOR REACTIVE SILICATE (AS SiO_2)

SOURCE	LOADINGS IN TONNES PER YEAR				TOTAL
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY SAMPLED	TRIBUTARY UNSAMPLED	
ONTARIO	164	0	52,200	5,110	57,500
ATMOSPHERIC INPUTS					1,340
OUTPUT TO LAKE HURON					48,300
OUTPUT TO NORTH CHANNEL					5,130
				TOTAL INPUTS	58,800
				TOTAL OUTPUTS	53,400

OBSERVATIONS AND COMMENTS

1. Tributaries account for 98% of the total inputs.

2. Silicate loadings do not seem to depend on human civilization to any great degree. This would indicate that Georgian Bay should be essentially at steady state. The outputs are about 91% of inputs, which seems to verify the steady state condition.

TABLE 3.1-19

GEORGIAN BAY MATERIAL BALANCE FOR TOTAL DISSOLVED SOLIDS

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
ONTARIO	10,100	0	1,690,000	181,000	1,880,000
ATMOSPHERIC INPUTS					30,000
OUTPUT TO LAKE HURON					1,740,000
OUTPUT TO NORTH CHANNEL					460,000
				TOTAL INPUTS	1,910,000
				TOTAL OUTPUTS	2,200,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 98% of the measured inputs.

2. Measured outputs are about 12% greater than the measured inputs. This is a fairly good balance and indicates that Georgian Bay is fairly close to steady state for total dissolved solids.

TABLE 3.1-20
GEORGIAN BAY MATERIAL BALANCE FOR CHLORIDE

SOURCE	LOADINGS IN TONNES PER YEAR				TOTAL
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		
			SAMPLED	UNSAMPLED	
ONTARIO	1,860	0	78,500	6,570	86,900
ATMOSPHERIC INPUTS					12,600
OUTPUT TO LAKE HURON					87,400
OUTPUT TO NORTH CHANNEL					18,100
				TOTAL INPUTS	99,500
				TOTAL OUTPUTS	106,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 86% of the total inputs.
2. Measured outputs are about 7% greater than measured inputs. This is an excellent agreement between inputs and outputs.

3.2 MUNICIPAL AND INDUSTRIAL INPUTS

Municipal and industrial facilities have several characteristics in common. Both are capable of discharging significant amounts of any of the parameters addressed in this study. Only municipal and industrial facilities which discharge directly to Lake Huron or are downstream of tributary sampling stations are considered in this subchapter; their locations are shown in Figure 3.2-1. Those which discharge to tributaries are included with the tributary data presented in Chapter 3.3.

Municipal sewerage systems carry the wastes of their service area to a single point for discharge. As a result, these systems accumulate to measurable levels materials which occur naturally only in trace amounts. Most municipal discharges contain primarily treated domestic sewage. The composition of these discharges is fairly similar. However, where large industrial discharges are treated along with the domestic wastes, the effluent composition can be quite different.

Industrial facilities can be significant sources of material inputs because of their size and use of otherwise unusual materials in their production processes. They can be a source of materials which occur naturally only in small amounts, or not at all. Their discharge to the environment can be particularly hazardous.

QUANTITATIVE ESTIMATES OF MATERIAL BALANCE PARAMETER INPUTS

Direct municipal and direct industrial inputs of the five material balance parameters (total nitrogen, total phosphorus, dissolved solids, reactive silicate, and chloride) to Lake Huron are summarized in Table 3.2-1. The relative sizes of these contributions by U.S. and Canadian sources are displayed graphically in Figure 3.2-2. The Michigan inputs comprise a majority of the total loadings for dissolved solids, chloride, and reactive silicate. Nitrogen inputs are primarily from Ontario sources. Phosphorus inputs are about equal from Michigan and Ontario sources, with a much larger portion of the total from municipal sources than for the other four parameters.

These direct municipal and direct industrial inputs are summarized in the material balances of Chapter 3.1, along with all other sources.

QUANTITATIVE ESTIMATES OF SIGNIFICANT PARAMETER INPUTS

Loading estimates for 39 parameters are listed in Table 3.2-2 for the U.S. and Canadian municipal and industrial direct dischargers to

Lake Huron. This listing includes all parameters of significance measured in this study. These inputs are separated by sub-basins in Table 3.23. Included are North Channel and St. Marys River, Georgian Bay, and Lake Huron proper. Details of individual dischargers are shown in the project reports (1, 2).

METHODS OF LOADING ESTIMATION

Michigan and Ontario computed estimates of their respective municipal and industrial inputs to Lake Huron. The sampling methods are described below. If additional information is desired on particular surveys of individual discharges, the appropriate jurisdiction should be contacted.

MICHIGAN

The data used to compute loading estimates for Michigan's direct municipal and industrial discharges were obtained from samples collected by the state. During the two-year study period, one or two 24-hour surveys were conducted for each discharger. Samples were collected, composited over time, and proportioned for flow. Grab samples were taken for a few parameters which could not be composited. Loadings were computed by multiplying the concentrations by the discharge flows averaged over the 24-hour survey period.

ONTARIO

For Ontario's municipal discharges, all parameters except heavy metals and minerals (Na, K, Ca, Mg) were sampled monthly by the dischargers. These samples were simple grab composites over 8- to 24-hour periods. The heavy metals samples were collected similarly three times per year, while the minerals were sampled once per year. Loadings were computed by multiplying the concentrations by the mean daily flows from operating data averaged over the survey years.

The samples for industrial discharges were collected in a similar manner by the dischargers. All parameters were sampled quarterly and the samples were grab composites over 12- to 24-hour periods. Loadings were computed by multiplying the concentrations by average flows representative of the survey periods. In many instances additional data were used from daily industrial sampling programs.

EVALUATION OF THE ACCURACY OF THE ESTIMATES

Two major considerations affect the accuracy of the loading estimates. One is how well the collected data represent the facility at the time of sampling. The second is how well the operating conditions of the facility during the survey characterize the year-round discharge.

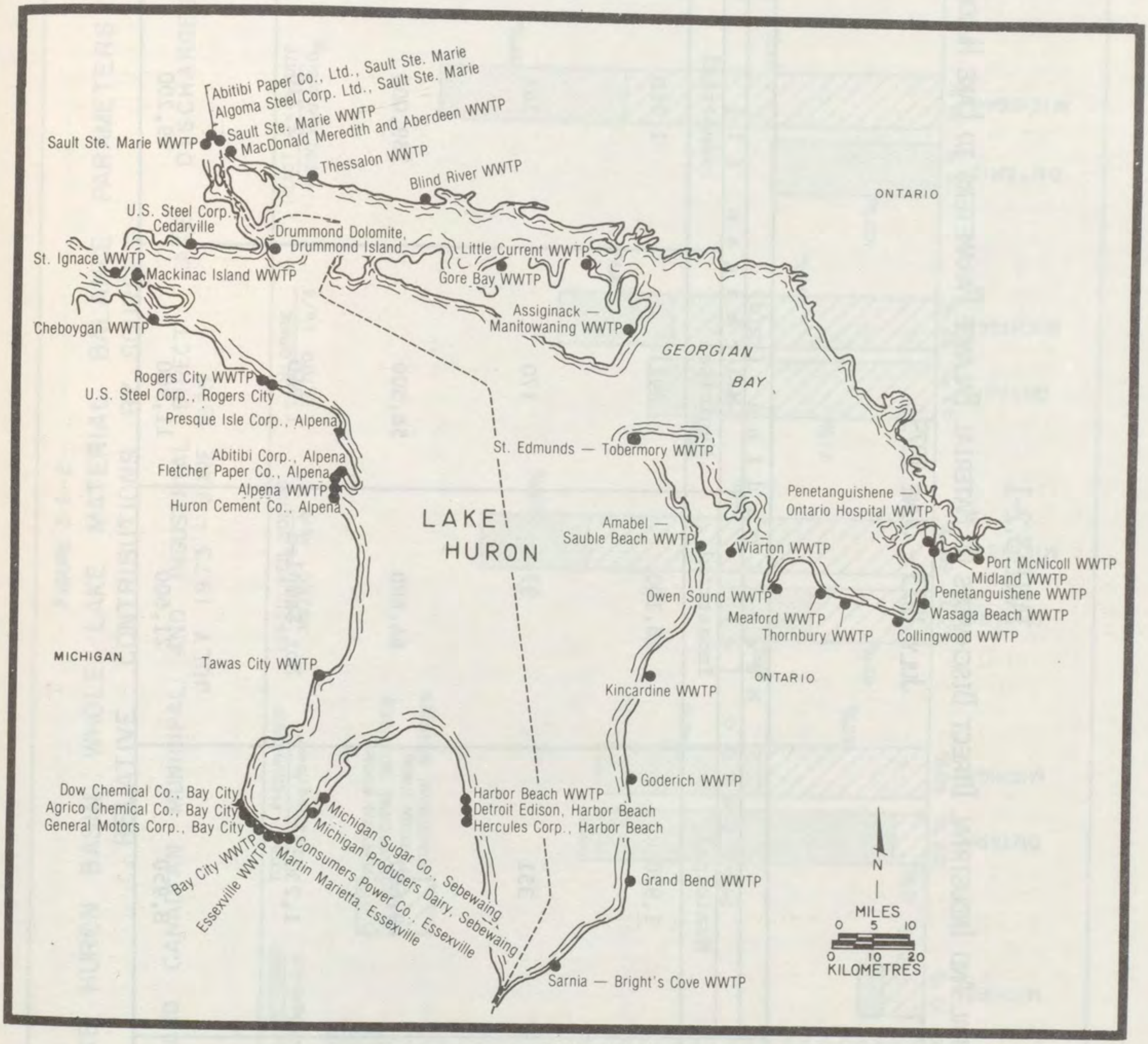

FIGURE 3.2-1
LAKE HURON BASIN MUNICIPAL AND INDUSTRIAL DIRECT DISCHARGERS
U.S. AND CANADIAN FACILITIES SURVEYED
JULY 1973 - JUNE 1975

TABLE 3.2-1

Municipal And Industrial Direct Discharges Of Material Balance Parameters to Lake Huron

July 1973 - June 1975

Parameter	Mean Loading (kg/d)				Total Loading (kg/d)
	Ontario (2)		Michigan (1)		
	Municipal	Industrial	Municipal	Industrial	
Total Nitrogen as N	1,970	18,100	891	1,280	22,200
Total Phosphorus as P	351	37	170	184	742
Dissolved Solids	49,600	64,600	58,500	189,000	362,000
Reactive Silicate as SiO_2	1,230	Not Sampled	1,340	2,310	4,880
Chloride	8,950	21,600	11,900	29,200	71,700

FIGURE 3.2-2

LAKE HURON BASIN : WHOLE LAKE MATERIAL BALANCE PARAMETERS
RELATIVE CONTRIBUTIONS BY SOURCES

U.S. AND CANADIAN MUNICIPAL AND INDUSTRIAL DIRECT LAKE DISCHARGES
JULY 1973 - JUNE 1975

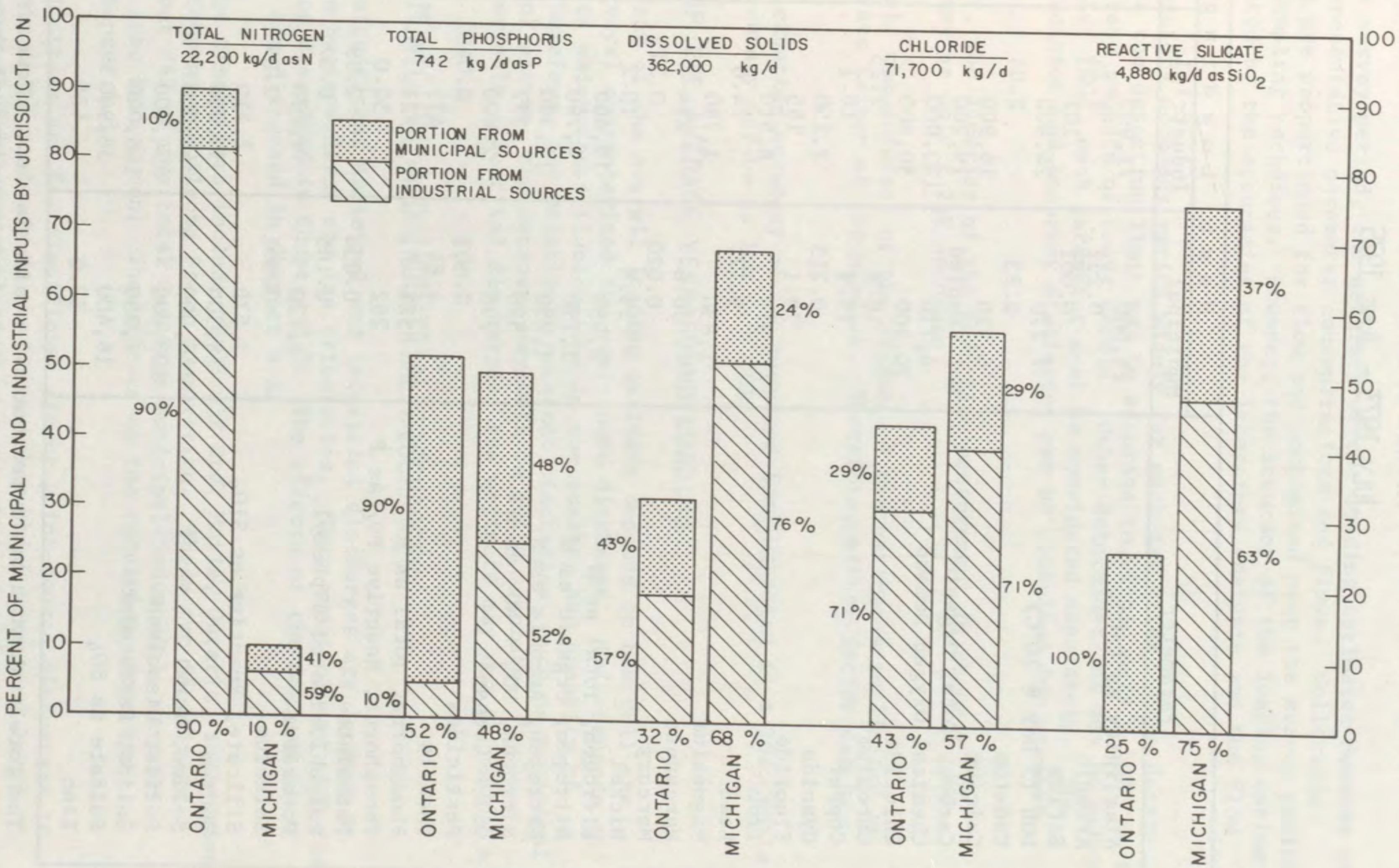

TABLE 3.2-2

TOTAL MUNICIPAL AND INDUSTRIAL DIRECT DISCHARGES TO LAKE HURON

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)		
	Municipal	Industrial	Total
Alkalinity as $CaCO_3$	25,000	71,900	96,900
Arsenic	0.232	9.24	9.47
Barium	<0.001	101	101
BOD (5 Day @ 20°C)	7,270	24,900	32,200
Cadmium	2.23	2.04	4.27
Calcium	6,910	16,900	23,800
Carbon, Total Organic	Not Sampled	19,700	19,700
Chemical Oxygen Demand	6,710	123,000	130,000
Chloride	20,900	50,800	71,700
Chromium	10.9	2.25	13.1
Copper	19.9	18.7	38.6
Cyanide	0.215	2,250	2,250
Fluoride	79.1	165	244
Iron	375	6,510	6,890
Lead	9.12	14.0	23.1
Magnesium	1,830	1,780	3,610
Manganese	30.6	294	325
Mercury	0.020	0.315	0.335
Nickel	19.8	10.2	30.0
Nitrogen, Total as N	2,860	19,400	22,200
Nitrogen, Organic as N	1,190	4,790	5,980
Nitrogen, Ammonia as N	1,250	14,300	15,600
Nitrogen, $NO_3 + NO_2$ as N	396	377	773
Oil - Grease	798	2,800	3,600
Pesticides	0.003	0.040	0.043
Phenols	4.84	477	482
Phosphorus, Total as P	521	221	742
Phosphorus, Reactive PO_4 as P	262	52.0	314
Phthalates	0.034	2.09	2.12
Polychlorinated Biphenyl	0.105	0.022	0.127
Potassium	1,720	4,290	6,010
Selenium	<0.001	2.09	2.09
Silicate, Reactive as SiO_2	2,570	2,310	4,880
Sodium	18,300	30,000	48,300
Solids, Total	116,000	348,000	464,000
Solids, Dissolved	108,000	254,000	362,000
Solids, Particulate	7,230	105,000	112,000
Sulfate as SO_4	16,400	38,900	55,000
Zinc	38.0	435	473

The totals shown above represent all available data. However, some discharges were not sampled for all parameters, and some analytical techniques varied between the two jurisdictions. For details, consult the project reports (1, 2).

MEASURING THE LOADING RATE DURING A SURVEY

During a survey period, the accuracy of the loading estimates depends on obtaining representative parameter concentrations and flows. Collecting samples which are proportioned for flow and composited over the survey period is the best sampling technique. However, the accuracy of the loading estimate is also affected by the accuracies of the laboratory analysis and the flow measurement.

The laboratory accuracy varies widely for each parameter. Some determinations near the detection limit may be accurate to within only ± 50%, as in the case of trace amounts of heavy metals. Other determinations may be accurate to within ± 5%. Thus, each parameter must be considered separately. The laboratory precision and accuracy statistics can be consulted for greater detail (3).

Similarly, the accuracy of the best flow measurement is about ± 10%, while others may be only ± 25% accurate.

In general, the accuracy of the product of two estimates is limited by the less accurate factor of the product. Therefore, either factor can be limiting.

The best expected accuracy of the computed loading rates is ± 10%, while the poorest accuracy may be as low as ± 50%.

ESTIMATION OF THE AVERAGE YEAR-ROUND LOADING

The accuracy of the overall loading estimate depends on how well the survey (or surveys) characterizes the year-round discharge. This depends on numerous factors which cause fluctuations in the quality and quantity of discharges. Therefore, for relatively constant discharges, such as municipal sewage treatment plants, the estimate may well be quite accurate. However, for the more variable industrial discharges, the estimate may not be nearly so good.

SIGNIFICANT MUNICIPAL AND INDUSTRIAL DISCHARGES

The most significant municipal and industrial discharges are located in Michigan on the Saginaw River and its tributaries. They are included with the tributary inputs described in Chapter 3.3. The effects of the Saginaw River on Saginaw Bay are discussed in Chapter 4.2.

Other large dischargers include the Sault Ste. Marie, Ontario, industries, Abitibi Paper Company and Algoma Steel Corporation. These two facilities account for about 84% of the total Canadian municipal-industrial, direct-discharge flow into Lake Huron. The effects on the receiving water are discussed in Chapter 4.3.

In general, there are few significant direct point-source discharges to Lake Huron. This is in contrast to the Lower Lakes which have many large inputs from municipal and industrial sources.

TABLE 3.2-3

MUNICIPAL AND INDUSTRIAL DIRECT DISCHARGES TO LAKE HURON SUB-BASINS

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)						
	North Channel And St. Marys River			Georgian Bay[a]	Main Lake Huron		
	Municipal	Industrial	Total	Municipal	Municipal	Industrial	Total
Alkalinity ($CaCO_3$)	b	b	b	b	2,500	71,900	74,400
Arsenic	c	7.20	7.20	c	0.232	2.04	2.27
Barium	c	d	c	c	c	101	101
BOD_5 (at 20°C)	2,420	20,700	23,100	3,180	1,670	4,190	5,860
Cadmium	e	d	e	0.630	1.60	2.04	3.64
Calcium	2,170	2,900	5,070	3,050	1,690	14,000	15,700
Carbon, Total Organic	b	17,300	17,300	b	b	2,410	2,410
Chem. Oxygen Demand	b	90,400	90,400	b	6,710	32,900	39,700
Chloride	2,800	21,600	24,400	5,100	13,000	29,200	42,200
Chromium	1.33	d	1.33	3.40	6.15	2.25	8.40
Copper	1.80	18.0	19.8	8.70	9.39	0.728	10.1
Cyanide	c	2,250	2,250	c	0.215	4.08	4.30
Fluoride	c	c	c	c	79.1	165	244
Iron	102	4,150	4,250	43.6	230	2,360	2,590
Lead	0.710	d	0.710	3.76	4.65	14.0	18.7
Magnesium	540	494	1,030	798	491	1,290	1,780
Manganese	13.4	172	185	4.10	13.1	122	135
Mercury	0.004	d	0.004	0.009	0.007	0.315	0.322
Nickel	1.30	d	1.30	5.17	13.4	10.2	23.6
Nitrogen, Total as N	1,010	18,100	19,100	860	991	1,280	2,270
Nitrogen, Organic as N	380	4,050	4,430	410	403	742	1,150
Nitrogen, NH_3 as N	605	14,000	14,600	370	272	301	573
Nit., $NO_3 + NO_2$ as N	1.96	76.0	78.0	76.0	318	301	619
Oil - Grease	c	c	c	c	798	2,800	3,600
Pesticides	c	c	c	c	0.003	0.040	0.043
Phenols	3.29	472	475	1.42	0.124	5.48	5.60
Phos., Total as P	164	37.0	201	164	193	184	377
Phos., Reactive as P	87.0	b	87.0	91	83.6	52.0	136
Phthalates	b	b	b	b	0.034	2.09	2.12
PCB	0.008	b	0.008	.018	0.078	0.022	0.10
Potassium	320	1,060	1,380	360	1,040	3,230	4,270
Selenium	c	c	c	c	c	2.09	2.09
Silicate, Reac. as SiO_2	689	b	689	449	1,410	2,310	3,720
Sodium	1,910	2,250	4,160	4,310	12,100	27,700	39,800
Solids, Total	19,700	93,000	113,000	30,600	65,800	255,000	321,000
Solids, Dissolved	17,100	64,000	81,700	27,800	63,200	189,000	252,000
Solids, Particulate	2,570	28,900	31,400	2,810	1,850	75,800	77,700
Sulfate as SO_4	1,990	12,700	14,700	3,110	11,300	26,200	38,000
Zinc	1.76	310	312	6.5	29.8	125	155

The totals shown above represent all available data. However, some discharges were not sampled for all parameters, and some analytical techniques varied between the two jurisdictions. For details, consult the project reports (1, 2).

a. There are no direct industrial discharges to Georgian Bay.
b. Not sampled.
c. Assumed not present in significant amount to warrant sampling.
d. Intake concentration exceeds effluent concentration (at industrial facilities).
e. Below limits of detectability.

3.3 TRIBUTARY INPUTS

Tributaries are the largest source of material inputs to Lake Huron. The loadings of individual tributaries are a function of the basin size, runoff volume, geology, and cultural development. Basins with large populations and diverse industries contribute larger inputs than relatively undeveloped basins of similar size. Sources of materials discharged to the tributaries include municipal and industrial point sources, combined sewer overflows, stormwater runoff from urban and rural areas, soil erosion, and spills. Because of this tremendous variation in the types of inputs to the tributaries, they contain a wide variety of materials.

Tributary flows to Lake Huron are large. Because of this, large amounts of most materials considered in this study enter the lake via the tributaries. The tributaries which were sampled are shown in Figure 3.3-1.

QUANTITATIVE ESTIMATES OF MATERIAL BALANCE PARAMETER INPUTS

The measured tributary inputs of the five material balance parameters (total nitrogen, total phosphorus, dissolved solids, reactive silicate, and chloride) to Lake Huron are summarized by jurisdiction in Table 3.3-1. As shown on the table, tributary inputs from the unsampled portion of the basin were also estimated. The relative sizes of these contributions by U.S. and Canadian jurisdictions are displayed graphically in Figure 3.3-2. These inputs are summarized in the material balances of Chapter 3.1, along with all other sources.

QUANTITATIVE ESTIMATES OF SIGNIFICANT PARAMETER INPUTS

Loading estimates for 39 parameters are listed in Table 3.3-2 for the land drainage and tributary inputs to Lake Huron. This listing includes all parameters of significance measured in this study. These inputs are separated by sub-basins in Table 3.3-3. Included are North Channel and St. Marys River, Georgian Bay, and Lake Huron proper. Details of individual tributaries are shown in the project reports (1, 2).

METHODS OF LOADING ESTIMATION

Michigan and Ontario computed estimates of their respective land drainage and tributary inputs to Lake Huron. The computations are described below.

MICHIGAN

Tributaries were sampled twice per month during three spring months and monthly during the remainder of the year. Grab samples were collected to determine material concentrations. Average streamflows on the days when samples were taken were determined from the appropriate United States Geological Survey streamflow gages. For those tributaries without gages, instantaneous flow measurements were made at the time of sampling. For some ungaged tributaries, stage-discharge relationships were developed to determine flow at the time of sampling. In all cases, the daily flow and associated daily parameter concentrations were used to compute daily loading rates. These were then averaged to yield mean loading rates for the study period.

The Saginaw River was sampled every two weeks throughout the year. For total phosphorus on the Saginaw River only, the calculated loading value was adjusted, based on the departure of streamflow from the annual average, at the time of sampling (5).

The streams sampled did not comprise the entire Lake Huron Basin. Therefore, the unsampled land drainage loading contributions were estimated by using concentrations and flows per unit of drainage area from sampled streams having similar geographic characteristics. Loadings were then determined by multiplying unsampled drainage areas by flow per unit of area and by concentration.

ONTARIO

Ontario's tributaries were grab sampled three to fifteen times per year, depending on the parameter. The parameters with greater variation were sampled more often. Loading estimates were based on the product of the average concentrations and the average flows for the study period. At sampling stations without stream gages, estimates of the average study period flows were made, based on nearby stream gages. Loadings from unsampled areas were estimated in the same way as on the U.S. side.

EVALUATION OF THE ACCURACY OF THE ESTIMATES

Two major considerations affect the accuracy of the tributary loading estimates. One is how well the collected data represent the tributary loading rate at the time of sampling. The second is how well the sampled loading rates characterize the mean annual loading rate.

MEASURING THE LOADING RATE AT THE TIME OF SAMPLING

The accuracy of the instantaneous loading rate depends on whether the sample is representative of the entire stream, as well as the accuracy of the laboratory analysis and the streamflow measurement. For small, swift streams, there should be almost complete mixing vertically and laterally. In slower streams the mixing will be less ideal vertically, and in wider streams the mixing will be less ideal laterally. Sampling locations were chosen to give the best samples possible. However, the accuracy of loading measurements derived from these samples will vary somewhat.

The laboratory accuracy varies widely for each parameter. Some determinations near the detection limit may be accurate to within ± 50%,

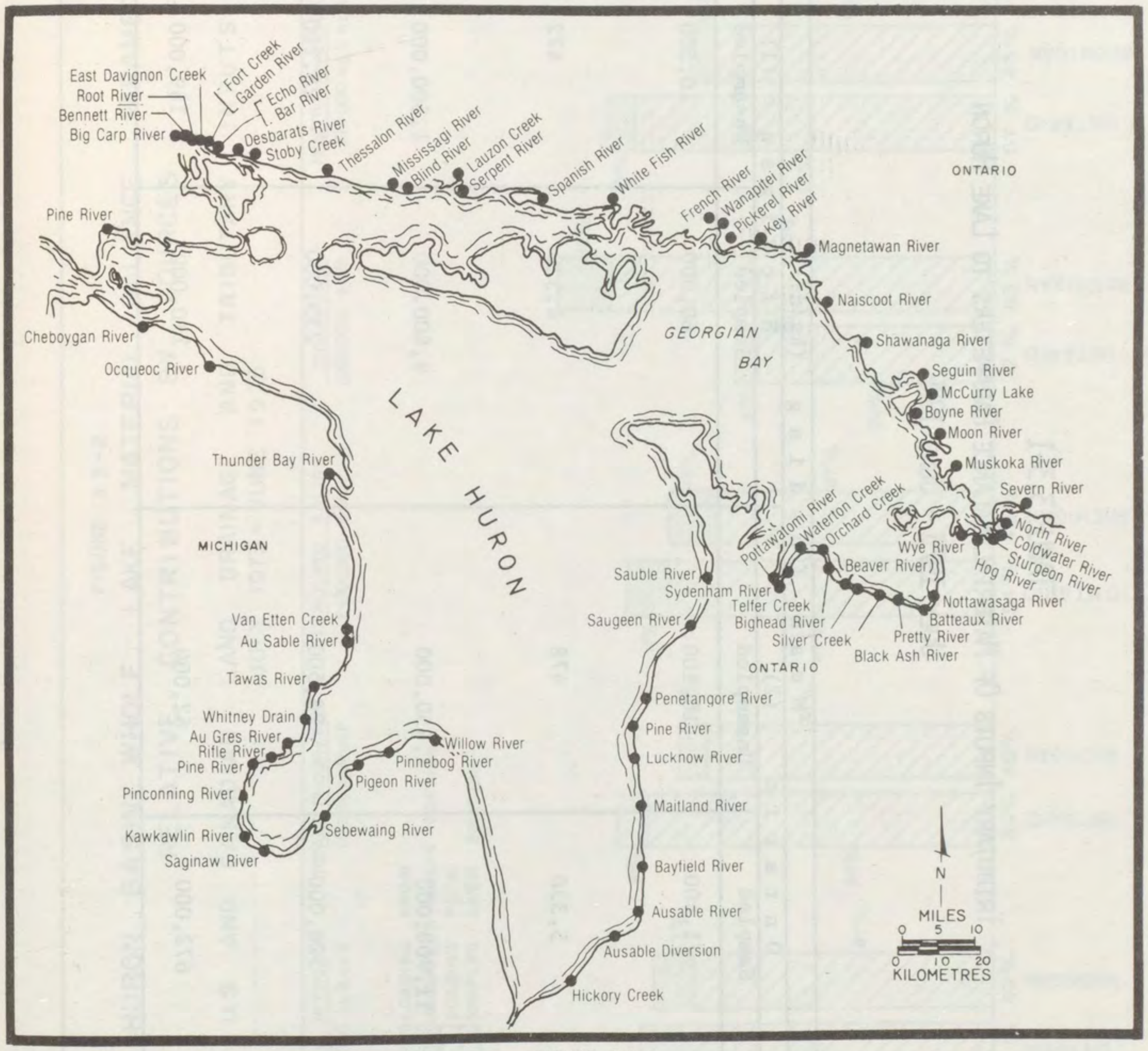

FIGURE 3.3-1
LAKE HURON BASIN LAND DRAINAGE AND TRIBUTARY INPUTS
U.S. AND CANADIAN TRIBUTARIES SAMPLED
JULY 1973 - JUNE 1975

TABLE 3.3-1

TRIBUTARY INPUTS OF MATERIAL BALANCE PARAMETERS TO LAKE HURON

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)				Total Loading (kg/d)
	Ontario (2)		Michigan (1)		
	Sampled	Unsampled	Sampled	Unsampled	
Total Nitrogen as N	71,400	10,100	68,000	10,300	160,000
Total Phosphorus as P	5,330	478	4,520	472	10,800
Dissolved Solids	11,900,000	1,450,000	9,800,000	1,500,000	24,700,000
Reactive Silicate as SiO_2	326,000	28,500	233,000	28,200	616,000
Chloride	672,000	62,000	1,110,000	149,000	1,990,000

FIGURE 3.3-2

LAKE HURON BASIN: WHOLE LAKE MATERIAL BALANCE PARAMETERS
RELATIVE CONTRIBUTIONS BY SOURCES

U.S. AND CANADIAN LAND DRAINAGE AND TRIBUTARY INPUTS
JULY 1973 - JUNE 1975

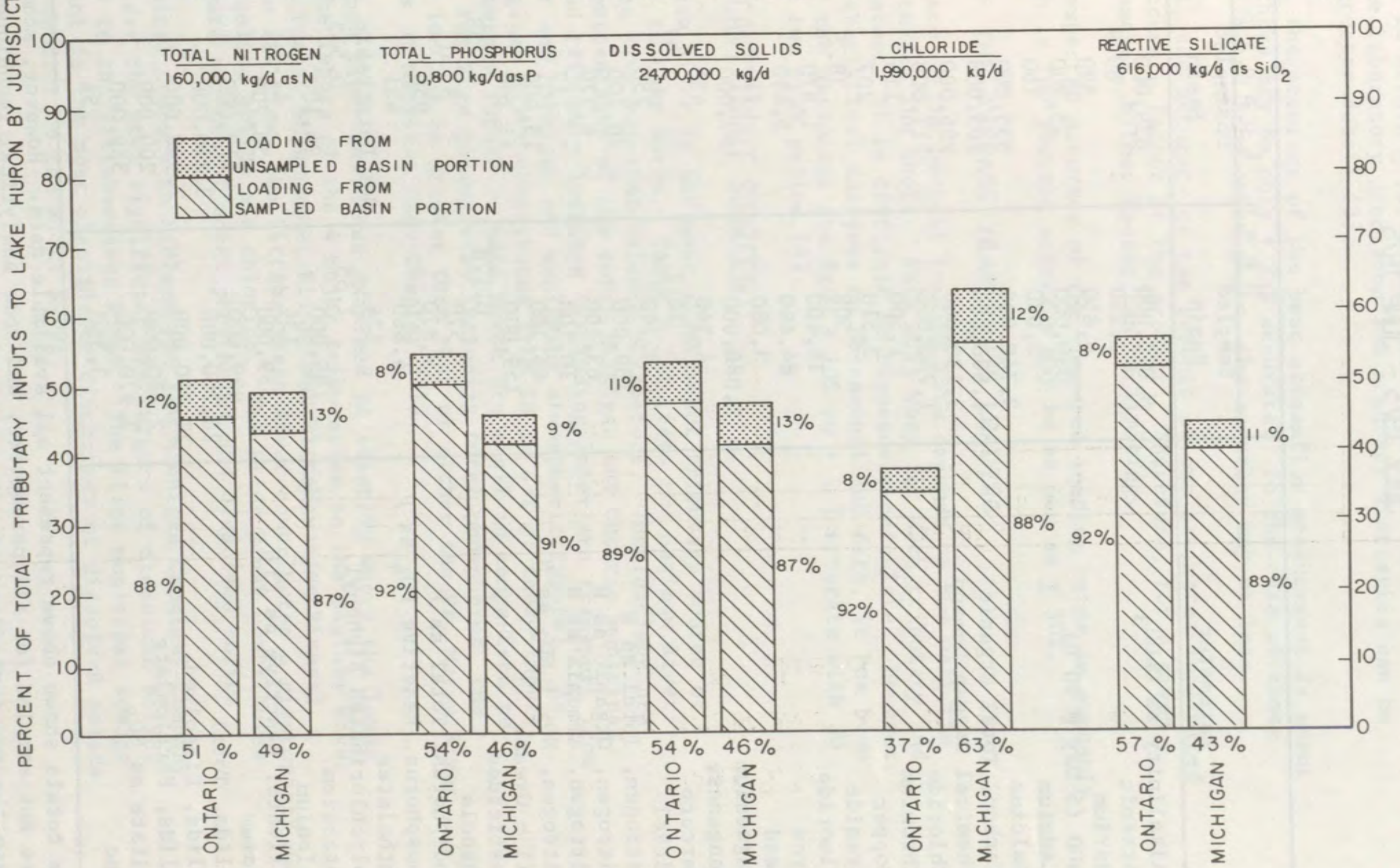

TABLE 3.3-2

TRIBUTARY INPUTS TO LAKE HURON

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)		
	Sampled Basin	Unsampled Basin	Total
Alkalinity as $CaCO_3$	5,010,000	829,000	5,840,000
Arsenic	1,250	80.9	1,330
Barium	6,850	590	7,440
BOD (5 Day @ 20°C)	390,000	25,900	416,000
Cadmium	2,020	160	2,180
Calcium	3,740,000	535,000	4,280,000
Carbon, Total Organic	1,600,000	185,000	1,790,000
Chemical Oxygen Demand	3,130,000	296,000	3,430,000
Chloride	1,780,000	211,000	1,990,000
Chromium	1,500	115	1,620
Copper	3,510	207	3,720
Cyanide	508	38.2	546
Fluoride	16,100	1,870	18,000
Iron	84,600	5,690	90,300
Lead	3,080	215	3,300
Magnesium	1,080,000	167,000	1,250,000
Manganese	4,540	450	4,990
Mercury	10.1	1.97	12.1
Nickel	3,790	258	4,050
Nitrogen, Total as N	139,000	20,400	159,000
Nitrogen, Organic as N	63,100	6,370	69,500
Nitrogen, Ammonia as N	10,100	717	10,800
Nitrogen, $NO_3 + NO_2$ as N	66,100	13,400	79,500
Oil - Grease	159,000	15,200	174,000
Pesticides	0.178	0.058	0.236
Phenols	570	85.0	655
Phosphorus, Total as P	9,870	950	10,800
Phosphorus, Reactive PO_4 as P	4,860	431	5,290
Phthalates	174	Not Detectable	174
Polychlorinated Biphenyl	1.55	0.533	2.08
Potassium	185,000	24,100	209,000
Selenium	134	11.1	145
Silicate, Reactive as SiO_2	559,000	56,700	616,000
Sodium	999,000	112,000	1,110,000
Solids, Total	24,700,000	3,210,000	27,900,000
Solids, Dissolved	21,700,000	2,940,000	24,600,000
Solids, Particulate	2,880,000	200,000	3,080,000
Sulfate as SO_4	2,970,000	359,000	3,330,000
Zinc	3,360	254	3,610

The totals shown above represent all available data. However, some discharges were not sampled for all parameters, and some analytical techniques varied between the two jurisdictions. For details, consult the project reports (1, 2).

as in the case of trace amounts of heavy metals. Other determinations may be accurate to within ± 5%. Thus, each parameter must be considered separately. The laboratory precision and accuracy statistics can be consulted for greater detail (3).

Similarly, the accuracy of the best streamflow measurement is about ± 10%, while others may be only ± 25% accurate. In the case of those streamflows estimated from other gages, the accuracy may be less.

In general, the accuracy of the product of two estimates is limited by the least accurate factor of the product. Therefore, for a given stream and parameter, either factor can be limiting.

The best expected accuracy of the computed loading rates is probably about ± 10%, while the poorest accuracy may be as low as ± 50%.

ESTIMATION OF THE AVERAGE YEAR-ROUND LOADING

The accuracy of the overall loading rate depends on how well the samples characterize the whole. This will vary for each tributary and for each parameter. It is difficult to rigorously calculate. However, by performing statistical analyses on deseasonalized data, it has been estimated that the estimates are from ± 10% to ± 25% accurate with 30 samples over a two year period (4).

MOST SIGNIFICANT INPUT SOURCES

The Saginaw River is the most significant tributary source of material input to Lake Huron. Table 3.3-4 lists the Saginaw River loadings of the five material balance parameters. The loadings are expressed as percentages of the total Michigan and Ontario municipal, industrial, and tributary loadings (excluding interlake transport from Lakes Superior and Michigan and excluding atmospheric inputs). As shown, the Saginaw River contributes from 18 to 47% of these inputs. All other tributary inputs to Lake Huron are small in comparison to the Saginaw. For some parameters, including total phosphorus, the Saginaw River loading is greater than that of either the St. Marys River or the Straits of Mackinac (see Chapter 3.1).

The Saginaw River Basin was examined to identify where the loads originate. The inputs of the 4 major tributaries to the Saginaw River were computed (Cass, Shiawassee, Flint, and Tittabawassee Rivers). In relation to its flow, the Tittabawassee River contributes a disproportionate amount of dissolved solids and chloride. The Flint River contributes disproportionate amounts of total phosphorus and dissolved solids.

Dow Chemical Company in Midland and the Michigan Chemical Company in St. Louis are the most significant dischargers of dissolved solids and chlorides to the Tittabawassee River. The Flint municipal sewage treatment plant is the most significant discharger of dissolved solids and total phosphorus to the Flint River.

TABLE 3.3-3

Tributary Inputs To Lake Huron Sub-Basins

July 1973 - June 1975

Parameter	Mean Loading (kg/d)								
	North Channel And St. Marys River			Georgian Bay			Main Lake Huron		
	Sampled Basin	Unsampled Basin	Total	Sampled Basin	Unsampled Basin	Total	Sampled Basin	Unsampled Basin	Total
Alkalinity ($CaCO_3$)	a	a	a	a	a	a	5,010,000	829,000	5,840,000
Arsenic	366	15.3	382	636	36.0	672	251	29.6	280
Barium	1,963	61.2	2,023	2,190	144	2,330	2,700	385	3,090
BOD_5 (at 20°C)	199,000	2,460	201,000	55,400	5,780	61,200	136,000	17,700	154,000
Cadmium	647	30.6	678	1,090	71.9	1,160	287	57.8	345
Calcium	333,000	23,000	356,000	823,000	111,000	934,000	2,580,000	401,000	2,980,000
Carbon, Total Organi	242,000	10,700	253,000	423,000	31,600	455,000	932,000	143,000	1,080,000
Chem. Oxygen Demand	715,000	35,200	750,000	1,130,000	82,700	1,210,000	1,280,000	178,000	1,450,000
Chloride	155,000	6,120	161,000	215,000	18,000	233,000	1,410,000	187,000	1,600,000
Chromium	410	23.0	433	849	54.1	903	236	38.0	274
Copper	1,320	38.2	1,360	1,540	89.8	1,630	645	79.4	724
Cyanide	180	7.64	187	261	18.0	279	66.7	12.6	79.3
Fluoride	3,087	130	3,220	4,040	431	4,470	9,000	1,310	10,300
Iron	12,700	995	13,700	11,500	1,258	12,800	60,400	3,440	63,900
Lead	1,020	33.7	1,050	1,440	89.8	1,530	619	91.1	710
Magnesium	73,800	3,060	76,900	195,000	36,000	231,000	813,000	128,000	941,000
Manganese	1,800	76.4	1,880	1,640	180	1,820	1,100	194	1,290
Mercury	3.20	0.130	3.33	4.10	0.250	4.35	2.80	1.59	4.39
Nickel	1,090	45.8	1,140	2,060	108	2,170	638	104	742
Nitrogen, Total as N	21,000	1,070	22,100	27,400	2,540	29,900	91,000	16,800	108,000
Nitrogen, Organic as N	11,600	750	12,400	17,800	1,310	19,100	33,700	4,310	38,100
Nitrogen, NH_3 as N	2,580	91.8	2,670	1,600	126	1,730	5,900	499	6,400
Nit., NO_3 + NO_2 as N	6,700	340	7,040	8,020	1,100	9,120	51,400	12,000	63,400
Oil - Grease	34,900	1,220	36,100	40,600	2,950	43,600	83,300	11,000	94,300
Pesticides	0.005	0.001	0.006	0.067	0.004	0.071	0.106	0.053	0.158
Phenols	132	5.36	138	163	10.8	174	275	68.8	344
Phos., Total as P	2,550	76.4	2,630	1,830	180	2,010	5,480	694	6,170
Phos., Reactive as P	1,060	53.6	1,110	1,180	36.0	1,220	2,620	341	2,960
Phthalates	a	a	a	a	a	a	174	b	174
PCB	0.100	0.003	0.103	0.059	0.007	0.067	1.39	0.523	1.91
Potassium	36,700	2,600	39,300	59,000	6,820	65,800	89,700	14,700	104,000
Selenium	32.0	1.86	33.8	72.2	5.17	77.4	29.3	4.04	33.4
Silicate, Reac. as SiO_2	133,000	6,800	140,000	143,000	14,000	157,000	283,000	35,800	318,000
Sodium	105,000	4,600	109,000	152,000	14,400	166,000	742,000	92,500	834,000
Solids, Total	2,080,000	138,000	2,210,000	5,130,000	539,000	5,670,000	17,500,000	2,530,000	20,000,000
Solids, Dissolved	1,740,000	116,000	1,850,000	4,630,000	496,000	5,120,000	15,300,000	2,330,000	17,700,000
Solids, Particulate	328,000	21,400	349,000	504,000	43,100	547,000	2,050,000	135,000	2,190,000
Sulfate as SO_4	542,000	18,400	561,000	681,000	46,700	728,000	1,750,000	294,000	2,040,000
Zinc	873	49.7	922	1,570	108	1,680	917	95.8	1,010

The totals shown above represent all available data. However, some discharges were not sampled for all parameters, and some analytical techniques varied between the two jurisdictions. For details, consult the project reports (1, 2).

a. Not sampled
b. Below limits of detectability

Table 3.3-5 lists point and non-point source loadings to the Saginaw River as percentages of the total Saginaw River load to Lake Huron. The first three entries compare the inputs of Michigan Chemical Company, Dow Chemical Company, and all other significant industries of the Saginaw Basin. Michigan Chemical Company contributes 3% of the total chloride input and 2% of the dissolved solids input. Dow Chemical Company contributes 27% of the total chloride loading and 12% of the dissolved solids. This compares with all other significant basin industries contributing only 1% of the chloride and 1% of dissolved solids. Thus, Michigan Chemical Company and Dow Chemical Company have greater input of these materials than all other basin industries combined.

The fourth and fifth entries of Table 3.3-5 compare the input of the Flint municipal wastewater treatment plant to the combined input of all other municipal plants in the basin. For all three parameters, the input from Flint is about equal to the combined input from other municipalities. The most significant input is for phosphorus, with 61% of the Saginaw River total originating from municipal sewage treatment plants.

The last table entry estimates the fraction of the input to Lake Huron from the non-point sources within the Saginaw basin. This is estimated by subtracting the sum of the point source loads from the total Saginaw basin load to Lake Huron. Thus, the estimate is the minimum non-point source load, because all point source inputs are assumed to reach Lake Huron. The estimate is probably better for dissolved solids and chloride, which do not settle out, than for phosphorus.

TABLE 3.3-4

SAGINAW RIVER LOADINGS TO LAKE HURON

Parameter	Loading in kg/d		Saginaw River Loading as % Of Loading To Lake Huron[a]
	Land Source Loading To Lake Huron[a]	Saginaw River Loading To Lake Huron	
Total Phosphorus as P	11,500	3,590[b]	31
Chloride	2,060,000	960,000	47
Dissolved Solids	25,100,000	6,160,000	25
Reactive Silicate as SiO_2	621,000	111,000	18
Total Nitrogen as N	182,000	50,800	28

a. Includes Michigan and Ontario municipal, industrial and tributary inputs; does not include Lake Michigan, Lake Superior or atmospheric inputs.

b. Method of calculation given in Reference (5).

TABLE 3.3-5
INPUTS TO THE SAGINAW RIVER
SHOWN AS PERCENTAGES OF THE SAGINAW RIVER LOADING TO LAKE HURON

Input Source	Chloride	Dissolved Solids	Total Phosphorus as P
Michigan Chemical Co. St. Louis	3%	2%	< 1%
Dow Chemical Co. Midland	27%	12%	< 1%
Other Industry Saginaw Basin	1%	1%	< 1%
Flint Municipal Sewage Treatment Plant	5%	2%	30%
Other Municipalities Saginaw Basin	7%	3%	31%
Non Point Sources[a] Saginaw Basin	57%	80%	39%

a. Estimated by difference (Saginaw River input to Lake Huron minus the total municipal and industrial point source loadings to the Saginaw River).

3.4 INTERLAKE TRANSPORT

Estimates of the interlake transport of the five material balance parameters are summarized in Table 3.4-1 and are utilized in the material balances given in Chapter 3.1. The flow and concentration data used in the calculations are discussed below.

ST. MARYS RIVER

Estimates of the output from Lake Superior were based on mean concentration measurements made by the Ontario Ministry of the Environment and the Canada Centre for Inland Waters (CCIW) in Whitefish Bay in 1973; the data are given in Chapters 4.1 and 5.3, respectively, of Volume III. The average 1973 flow of the St. Marys River used in the calculation was 2060 m^3/s (1).

Sixty-eight percent of the flow of the St. Marys River is directed to the main body of Lake Huron and 32% to the North Channel (2). Loadings to the main body of Lake Huron and to the North Channel were also assumed to adhere to this 68:32 ratio. The flow characteristics are discussed further in Chapter 5.1.

INTRALAKE TRANSPORT IN LAKE HURON

The flows used to calculate net mass exchange between Georgian Bay and the North Channel, between the North Channel and Lake Huron proper, and between Georgian Bay and Lake Huron proper are described in Chapter 5.1. The concentrations are based on 1974 CCIW cruise data, which are described in Chapter 5.3. In addition to the net phosphorus loading from Georgian Bay to the main body of Lake Huron, given in Table 3.4-1, the phosphorus input associated with the gross flows directed toward Georgian Bay and toward Lake Huron are also presented.

STRAITS OF MACKINAC

The exchange of water between Lake Michigan and Lake Huron through the Straits of Mackinac is exceedingly complex; the flow characteristics are discussed in Chapter 5.1. Pinsak (3) calculated the net loadings for the five material balance parameters by determining the flow direction and velocity and measuring the concentrations of the constituents during the period August-November 1973. The cross-section of the Straits was divided into panels and net flows and mean concentrations were calculated at two-week intervals for each panel. Because the water oscillates on a somewhat irregular short-term basis in the Straits of Mackinac, the net flow for specific panels and time

TABLE 3.4-1

INTERLAKE TRANSPORT ESTIMATES

TRANSPORT			LOADING IN TONNES PER YEAR				
FROM	TO	VIA	TOTAL PHOSPHORUS (as P)	TOTAL NITROGEN (as N)	REACTIVE SILICATE (as SiO_2)	TOTAL DISSOLVED SOLIDS	CHLORIDE
Lake Superior	Lake Huron	St. Marys River	273	14,900	102,000	2,730,000	52,100
Lake Superior	North Channel	St. Marys River	129	7,000	47,900	1,290,000	24,600
Georgian Bay	North Channel	Little Current Channel	24	930[a]	5,130	460,000	18,100
North Channel	Lake Huron	Several Channels	261	12,500[a]	84,700	4,910,000	193,000
Georgian Bay	Lake Huron	Main Channel	74[b]	4,880[a]	48,300	1,740,000	87,400
Lake Michigan	Lake Huron	Straits of Mackinac	255[c]	18,800	70,900	10,100,000	401,000
Lake Huron	Lower Lakes	St. Clair River	1,080	76,000	248,000	24,600,000	1,050,000

a. Filtered nitrate plus nitrite only.

b. This is a net loading. Schertzer (5) estimated the phosphorus input associated with the gross flow from Georgian Bay to Lake Huron to be 375 t/a and from Lake Huron to Georgian Bay to be 275 t/a. See also Chapter 5.1.

c. This is a net loading (3). Schertzer (5) estimated the phosphorus input associated with the gross flow from Lake Michigan to Lake Huron to be 418 t/a. See also Chapter 5.1.

periods may be either eastward or westward and may consist of varying percentages of mixed Lake Huron and Lake Michigan water. Because of this characteristic it is difficult to apply an average net flow to transport estimates. The derived net transport values are summarized in Table 3.4-1. The table also includes the estimated phosphorus input associated with the gross flow from Lake Michigan to Lake Huron (5).

ST. CLAIR RIVER

Estimates of output from Lake Huron were based on mean concentration measurements made by the University of Michigan and by the U.S. Environmental Protection Agency in southern Lake Huron in 1973; the data are given in Chapter 5.3. The average 1973-1974 flow of the St. Clair River used in the calculation was 6200 m^3/s (1). Open lake concentrations were used rather than concentrations measured at the head of the St. Clair River because data from the latter location include a contribution from material eroded from the shoreline. This material does not become available to the lake water. Therefore, loadings derived using concentrations measured at the head of the St. Clair River are not suitable for whole-lake material balances. The following loadings were calculated using concentration data (4) measured at the head of the St. Clair River: total phosphorus = 2,450 t/a; total nitrogen = 91,400 t/a; reactive silicate = 157,000 t/a; total dissolved solids = 25,500,000 t/a; chloride = 1,140,000 t/a.

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3.5 ATMOSPHERIC INPUTS

The term "bulk precipitation" is used to describe the total of wet deposition via snow and rainfall, plus dry deposition through particulate fallout and gas adsorption. The effect of this bulk precipitation on lake chemistry has been relatively neglected until recent studies in Scandinavia and selected regions of Canada and the United States. Early studies were primarily concerned with acid rainfall. Recent studies of atmospheric loadings, including the present study of the Upper Lakes, have also considered nutrient, particulate, and metallic loadings. Atmospheric inputs to Lake Huron are likely to be of significant impact since direct lake-surface precipitation accounts for 24% of the Lake Huron water supply. These inputs proceed directly to the euphotic zone, thus having maximum biological impact.

Emissions to the atmosphere are categorized by air pollution source regions. These source regions are used for air pollution assessment by the U.S. Environmental Protection Agency (EPA) and the Ontario Ministry of the Environment (MOE); emissions data were obtained from these two agencies. Twenty-two U.S. source regions and eleven Canadian source regions were considered to have significant impact on loadings to Lake Huron. Percentage loadings of sulphate, phosphate, and trace metals which ultimately reach Lake Huron from each source region are shown in Table 3.5-1(1). The significant contribution of pollutants to Lake Huron from distant source regions is indicative of the extent of long range transport. Contributions from distant source regions often exceed those from nearby sources.

ESTIMATES OF ATMOSPHERIC LOADINGS

Estimates of yearly deposition to Lake Huron are shown in Table 3.5-2. These are best estimates derived primarily from the data collected on the present study. Loadings have been divided into the northern (north of a line from Tawas City to Tiverton) and southern portions of the main lake with separate values shown for Georgian Bay and the North Channel. Comparison of this atmospheric component of loading to the total of all inputs to the lake is found in Chapter 3.1.

Atmospheric samples were collected from four sampling networks operated by 1) Canadian Atmospheric Environment Service, 2) Canada Centre for Inland Waters, 3) Michigan Department of Natural Resources (with chemical analyses done by EPA), and 4) McMaster University (under contract to MOE). These data were used with the atmospheric transport-deposition models prepared by Acres (1) and Moroz (2) to estimate atmospheric loadings.

TABLE 3.5-1

Percent Of Loadings To Lake Huron By Air Pollution Source Region[a]

Air Pollution Source Region[b]	Percent of Total Atmospheric Loading		
	Sulphate	Phosphorus	Trace Metals[c]
Saginaw	9.4	5.0	9.4
Detroit	7.2	9.0	11.7
Port Huron	3.2	1.1	1.3
Lower Michigan	1.0	1.2	2.1
Northern Michigan	0.7	2.7	3.3
St. Louis	3.9	4.5	5.2
Chicago	4.1	13.2	7.8
Central Illinois	2.2	2.5	2.6
Green Bay	1.1	3.1	2.0
Milwaukee	1.2	3.2	2.1
Wisconsin	0.3	2.2	0.9
Duluth	0.2	2.2	0.8
Minneapolis	0.6	1.5	1.3
Toledo	3.0	5.5	7.4
Cleveland	4.0	5.8	7.2
Cincinnati	5.3	9.2	10.5
Ohio	2.8	5.0	7.6
Pittsburgh	5.4	2.4	5.2
Pennsylvania	1.5	2.1	3.8
Rochester	0.2	0.4	0.4
Buffalo	0.2	0.5	0.4
S.W. New York	0.2	0.3	0.5
Montreal	0.2	3.2	0.6
Toronto	2.0	3.7	1.0
Sarnia	3.2	0.3	0.3
Sudbury	32.4	0.5	0.2
Thunder Bay	0.1	0.7	0.3
Nanticoke	0.3	0.1	0.1
Noranda	2.3	0.5	0.2
Sault Ste. Marie	0.2	1.4	1.6
Northern Ontario	0.9	0.1	0.4
Southern Ontario	0.2	2.2	1.5
Manitoba	0.5	4.7	0.3

a. From Reference (1).

b. United States Environmental Protection Agency and Ontario Ministry of the Environment air pollution source regions.

c. Cd, Cu, Fe, Ni, Pb

Locations of sampling stations are shown in Figure 3.5-1. Stations were located in areas chosen to minimize the effect of local contamination sources. Bulk samples of precipitation and dry fallout were collected monthly from October, 1973 through June, 1975.

Buoy-mounted bulk samples were collected at five locations to determine differences between onshore and offshore samples. Modified samplers were installed at three stations to collect samples only during precipitation "events".

Mathematical models were constructed by Acres (1) and Moroz (2). The Acres model is a "box" model to predict bulk atmospheric loadings using actual emissions and meteorological data as a basis. The model developed by Moroz considers only the dry deposition processes (particulate and gaseous inputs) and is constructed based upon a Guassian plume, coupled with Pasquil-Gifford diffusion curves. Both models use EPA and MOE source strength data.

ACCURACY OF ESTIMATES

The quantitative loading estimates (Table 3.5-2) were obtained from a summary of the experimental measurements with exception of particulate data which were derived from model calculations only. Measured data are subject to possible variability because of the nature of the samplers and related methodology, potential contamination, seasonal differences, and the completion of chemical analyses by five laboratories. Several modes of comparison were utilized -- comparison of results from buoy/shore/tower monthly stations, comparison of modeled versus measured results, comparison of winter versus summer results, interlaboratory analytical comparisons, and intercomparison of sample collector types.

Samplers from land and offshore (buoy) locations yield similar results except that filtered sodium and particulates tend to be higher in land samplers. Other land anomalies were related solely to local influences.

Comparison of modeled versus measured results provided excellent agreement where accurate emission data were available for model input. Sulphate and nitrate depositions were the most accurate of predicted values. Model results for other parameters, including chloride and phosphorus, were poorly predicted, likely due to lack of source emissions strength information.

Higher deposition of all parameters occurs during the warm weather periods. This appears to be due to a combination of factors, including the greater scavenging efficiency of rain compared to snow, reduced winter biological activity, and increased re-entrainment of local dust during summer.

The loading data shown for phosphorus in Table 3.5-2 is a modification of measured data summarized by Acres (1). Because summer bulk sampler measurements were subjected to local source errors, the data were not

TABLE 3.5-2

ATMOSPHERIC LOADINGS TO LAKE HURON

Parameter	Loadings, In Tonnes Per Year[a]					
	Main Lake Huron			Georgian Bay	North Channel	Whole Lake Total
	North	South	Total			
Nitrogen ($NO_3 + NH_3$ as N)	22,000	12,000	34,000	14,200	3,780	52,000
Total Phosphorus[b]	255	195	450	134	36	620
Total Dissolved Solids[c]	42,000	30,000	72,000	30,000	7,980	110,000
Chloride	20,000	13,000	33,000	12,700	3,360	49,000
Reactive Silicate (as SiO_2)	4,900	2,600	7,500	1,340	355	9,200
Calcium	30,000	240,000	270,000	7,900	2,100	280,000
Sodium	19,000	23,000	42,000	2,370	630	45,000
Magnesium	4,100	2,600	6,700	1,190	315	8,210
Potassium	21,000	9,000	30,000	1,580	420	32,000
Iron	1,300	900	2,200	1,900	504	4,600
Lead	290	170	460	253	67	780
Copper	220	120	340	332	88	760
Nickel	36	44	80	103	27	210
Cadmium	42	17	59	16	4	79
Particulate Solids	90,000	140,000	230,000	94,800	25,200	350,000

a. All parameters were determined from actual measurements except for particulate solids values which were calculated from mathematical model results (1).

b. Corrected for contamination and further modified by Delumyea (4).

c. Calculated from conductivity measurements by multiplying by 0.65.

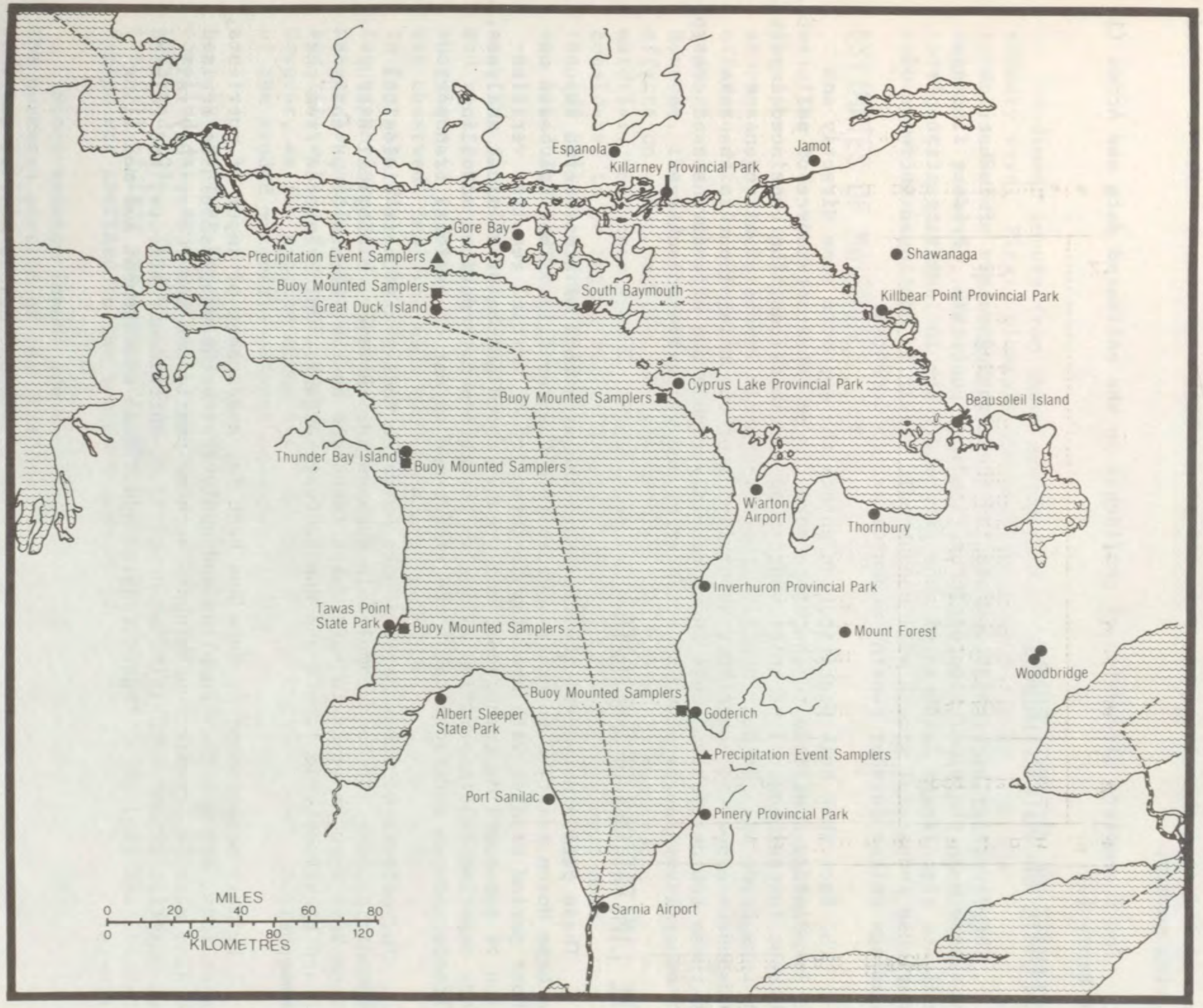


FIGURE 3.5-1 PRECIPITATION CHEMISTRY SAMPLING NETWORK FOR LAKE HURON

considered representative of over-lake deposition. Studies by Delumyea (4) conducted in southern Lake Huron indicate that lake surface deposition in summer amounts to about 40% of the value measured with bulk samplers. Loading estimates for phosphorus were, therefore, derived from direct bulk measurement data recorded during the winter and from 40% of the bulk measurement values recorded during summer.

For a complete discussion of confidence in the estimated data see Acres (1) or Berry (3).

ESTIMATE OF FUTURE TRENDS

The diversity of present sources and the changing nature of industrial processes make the prediction of future loadings uncertain. Present findings indicate significant loadings of many parameters due to long range transport. Continued industrial growth will undoubtedly result in continued increase of loadings unless further control measures are implemented.

The fact that bulk precipitation enters the euphotic zone directly and is immediately available to the biota makes it an important source of pollutants. Without further control of major sources of air emissions, the continued impact on Lake Huron will be detrimental. The atmospheric inputs of nitrogen and phosphorus appear to constitute about 10-30% of the total input to the lake of these two nutrients. This input rate may reduce the effectiveness of control of other input sources such as tributaries and wastewater discharges.

THE LIMITATIONS OF THE DATA

These preliminary estimates indicate the magnitude of atmospheric inputs to Lake Huron relative to other sources (see Chapter 3.1). They are based on short period studies with need for confirmation of initial results, verification of the sampling techniques, and greater coordination of chemical analyses. More experimental information will also strengthen mathematical modelling efforts through verification of the amount and extent of regional transport.

The effects of atmospheric inputs on water bodies and their biological communities have not been completely documented. However, biological disruptions have been observed in soft water lakes due to the effects of pH changes caused by atmospheric inputs and due to toxic organics which entered from the atmosphere.

Primary measurement to date has been for assessment of input of nutrients, major ions, and metals. Sampling and analytical methodology should be revised to also measure organic contaminants such as pesticides and PCB's. Dry fallout quantification, deposition velocities, re-entrainment effects, and related chemical and biological impact require additional measurement and modelling efforts.

3.6 SHORE EROSION AND SEDIMENT INPUTS

Sediment inputs from shore erosion affect water quality in two primary ways. First, minerals and nutrients may dissolve from the eroded sediment. Second, nearshore turbidity may cause biological and aesthetic problems. Erosion from sand and gravel beaches and bank areas is of little concern, but finer grained materials such as clays can cause problems.

ESTIMATES OF MATERIALS INPUTS

The U.S. shore of Lake Huron is subject to local erosion problems for approximately 28% of the mainland shoreline (1, 2). The Michigan shore is characterized by low shore profiles, sandy beaches, and shallow offshore waters. Comparison of early aerial photographs with recent ones shows a number of areas where the shore has receded 10-15 m (2). However, the main concern of such erosion is property loss, rather than effects on water quality, because of the sandy nature of the eroded material. For this reason, chemical inputs from the U.S. side are considered to be negligible at present. Data now being developed under the IJC Pollution from Land Use Activities Reference Group (PLUARG) are scheduled for completion in 1978.

The shoreline of Georgian Bay is primarily sandy pebbly beaches and rock outcrops with occasional marshes and clay banks. Erodible shoreline is restricted. In general, net accretion rather than recession was observed, implying only a marginal contribution of eroded material to Georgian Bay. Shallow water erosion likely is occurring to account for beach formation. Similarly, the Canadian shoreline of Lake Huron proper is mainly bedrock and consists of glacial deposits, sand, gravel, and till with a few rock outcrops. A net recession has been observed. However, as for erosion along the U.S. shoreline, because of the nature of the eroded material, effects on water quality are minimal.

Environment Canada and the Ontario Ministry of the Environment compiled data on the erodible Canadian shoreline of Lake Huron during 1973 and 1974. This was done in response to the high lake levels during the fall of 1972 and spring of 1973. The study indicated that shore damage was confined to the southern portion of Lake Huron (3).

Since erosion inputs are considered negligible for the U.S. shore, the northern portion of the Canadian shore, and Georgian Bay, only the southern portion of the Canadian shore is considered here. Even these studies are limited and somewhat preliminary. They have been carried

TABLE 3.6-1

TRACE METAL CONCENTRATIONS IN CANADIAN LAKE HURON SHORELINE MATERIAL

Element	Concentration in mg/kg (dry weight basis) No. of Samples	Mean	Standard Deviation	Minimum	Maximum	Loadings (t/a)
Mercury	87	0.025	0.020	0.004	0.120	0.05
Lead	116	17	12	7	128	31
Copper	116	19	45	1	350	34
Zinc	116	30	26	7	182	54
Nickel	116	15	9	4	46	27
Cobalt	116	11	6	3	24	20
Chromium	100	25	23	3	189	45
Cadmium	116	1.3	0.5	1	2	2.3
Beryllium[a]	-	-	-	-	-	-
Vanadium	116	38	24	10	116	68
Strontium	116	183	53	102	328	329
Molybdenum	114	3.1	2.7	1	23	5.6
Arsenic[b]	116	3.1	4.1	1	13	5.6
Selenium[a]	-	-	-	-	-	-

a. All samples less than the limit of detection (1 mg/kg)
b. 39 of 116 samples less than the limit of detection (1 mg/kg)

out as part of the PLUARG program and will be finalized and reported later. No data are available for the five material balance parameters. Trace metal analyses and loading estimates from samples along the southern Lake Huron shoreline are summarized in Table 3.6-1. In general, these values represent background levels, although a full interpretation is not yet possible, pending completion of the PLUARG studies. See Chapter 5.2 for a discussion of the chemistry of open water sediments.

METHODS OF ESTIMATION

Aerial photography was used to estimate shoreline erosion between 1952-55 and the spring of 1973. From this information a Coastal Zone Atlas of the Canadian erodible shoreline of Lake Huron was produced. (4).

The Environment Canada studies of 1972-73 also relied heavily on photo-interpretation (3). In addition to using photo-interpretation, erosion rates have been determined from historical land survey data and by more specialized ground survey methods for short-term erosion measurement.

ACCURACY OF THE ESTIMATES

Loadings of trace metals shown in Table 3.6-1 are only indicative of the magnitude of loadings, since lake circulation and littoral drift in the southeastern part of the lake will transport a substantial percentage of these shoreline materials directly to the St. Clair River. Taking into account shoreline erosion in other parts of the lake, subaqueous erosion, and tributary drainage, the loading values quoted appear to be in the right order of magnitude.

3.7 THERMAL INPUTS

The largest single industrial use of Great Lakes water is for cooling steam condensers in electric power plants. Table 3.7-1 lists operational data for existing and committed thermal power plants which discharge cooling water to Lake Huron. In Ontario, the majority of steam electric power generation is located on the Lower Lakes near the greatest electricity demand. However, Lake Huron, Georgian Bay, and the North Channel area are now rapidly being developed for cooling water use.

In Ontario, the Bruce Nuclear Power Development, a major energy and heavy water production centre, began in the early 1960's with the construction of the Douglas Point Generating Station. Presently operational are the single, 220 MW (electric) reactor and the Bruce Heavy Water Plant "A" (design production - 800,000 kg/a of heavy water). The Bruce Generating Station "A" (3,000 MW of electric generating capacity) produced first power in 1976. This plant consists of four-750 MW reactors. Under construction are three additional heavy water plants (B, C, and D) with a nominal rated output of 800,000 kg/a each. Also under construction on this site is Bruce Generating Station "B", a 3,000 MW (four-750 MW reactors) power station expected to produce first power by late 1982 or early 1983.

In Michigan, there are four fossil-fueled plants on Lake Huron with most of the generating capacity found at the mouth of the Saginaw River.

AMOUNT OF HEAT DISCHARGED

As shown in Table 3.7-1, the average total heat discharge to Lake Huron has been about 1,700 MW between 1971 and 1975. Electrical generating plants have to cease operation periodically for routine maintenance and emergency repairs. Therefore, they cannot discharge 100% of their total potential for heat discharge. Realistically, a well operated plant should operate about 70% of the time. Thus, the true maximum potential for the present dischargers is about 2,000 MW. After the new plants start operating, the potential heat discharge will be about 15,000 MW. The large projected increase is due to the Bruce Nuclear Power Development, discussed above.

Although local problems often result from hot water discharges, the effect on the whole lake is small.

TABLE 3.7-1

MAJOR THERMAL DISCHARGERS TO LAKE HURON

Plant Name	Location	Number of Units	Fuel[b]	Total Generating Capacity (MW electric)	Design Δt (C°)	Maximum Design Heat Discharge (MW)	Average Operating Capacity (% Of Maximum) (1971-1975)	Average Heat Discharge (MW)
Ontario								
Douglas Point	Kincardine	1	N	220	7.8	362	32.6[a]	118
Bruce Heavy Water Plants Plant A operational Plants B, C and D under construction	Kincardine	-	-	-	11.1	2600	-	-
Bruce "A" Generating Station (operational 1976-1978)	Kincardine	4	N	3000	10.6	7750	-	-
Bruce "B" Generating Station (operational 1982-1983)	Kincardine	4	N	3000	10.6	7750	-	-
Michigan								
Huron Cement	Alpena	5	F	40.9	6.1	105	85	89
Karn (Units 3 & 4 on cooling towers)	Essexville	4	F	1787	9.4	762	77.3	589
Weadock	Essexville	8	F	678	6.5-9.1	1440	55.3	796
Harbor Beach	Harbor Beach	1	F	121	7.2	173	42.7	75

a. For 1971-1974
b. F = Fossil N = Nuclear

FUTURE INPUTS

In Ontario, the search for thermal power plant sites on Lake Huron and Georgian Bay has accelerated in the last several years. Projections have been made by Ontario Hydro of a growth in peak electricity demand of seven percent per year into the long-term (20-year) future. On Lake Huron and Georgian Bay, it is anticipated that by 1993 there will be an additional 12,000 to 15,000 MW of electric generating capacity in operation. It is likely that 3,000 to 6,000 MW of this will be on the North Channel and 3,000 to 6,000 MW on Georgian Bay. It is also likely that 3,000 to 6,000 MW of generating capacity would be required on the shores of Lake Huron itself. However, the Royal Commission on Electric Power Planning is presently studying power requirements in Ontario to 1993 and beyond. Their conclusions and recommendations could significantly influence the amount of future electrical production.

In Michigan, there are very speculative predictions for expansion of the Detroit Edison System on a site north of Harbor Beach. The size of this facility, the fuel, and the target dates are not known. Consumers Power is considering five sites along Lake Huron. The combined electric generating capacity of these sites is projected to be 7,000 MW by the year 2000. Most of this capacity is expected to be from nuclear plants in the size range of 1,000 to 1,500 MW.

3.8 RADIOACTIVITY INPUTS

PRESENT INPUTS

Radioactivity inputs to Lake Huron arise from four different sources: fallout from nuclear weapons testing, discharge from the Douglas Point nuclear complex, drainage of the Elliot Lake mining area, and weathering of naturally radioactive minerals.

Fallout from nuclear weapons testing provides essentially all of the man-made radioactivity, primarily strontium 90 (^{90}Sr), found in Lake Huron. Inputs are dependent on the amount of atmospheric weapons testing.

Mining activity in the Elliot Lake area and associated surface runoff from tailings ponds result in radium 226 (^{226}Ra) reaching the North Channel via the Serpent River. Approximate loadings to the Serpent River are ^{226}Ra = 1850 μCi/d; Gross α = 15,800 μCi/d; and Gross β = 14,100 μCi/d (1). Considerable quantities of the thorium isotopes are known to enter the waters of the Serpent River Basin but their fate is not known. Loadings to the North Channel have not been calculated *per se*; concentrations reported at the Serpent River mouth are presented and discussed in Chapter 4.1.

Radioactive wastes from chemical laboratories and decontamination facilities at the Douglas Point Generating Station are disposed of by controlled release into the cooling waters. In Ontario, reporting of liquid radioactive effluents is made in two categories: tritium (^{3}H) and gross β-γ. The regulatory limits for lake discharges of these parameters are 83,000 Ci of ^{3}H per month and 4.5 Ci of gross β-γ per month. However, design and operational targets are one percent of these levels, or 830 Ci of ^{3}H per month and 0.045 Ci of gross β-γ per month. Table 3.8-1 summarizes the liquid radioactivity releases from the Douglas Point Generating Station for the years 1968-1970 and 1973-1975.

Stack discharges from a nuclear facility can enter the lake via rainout. Gaseous releases (2) from the Douglas Point Generating Station in 1974 were: particulates = 0.0047 Ci/a; iodine 131 (^{131}I) = 0.047 Ci/a; noble gases = 21,700 Ci/a; and ^{3}H = 5,110 Ci/a. Deposition into the lake has not been measured.

In Michigan, there are no operating nuclear generating plants or plants under construction on the Lake Huron shoreline. The Midland plant is presently under construction. This plant is located on the Tittabawassee River, a tributary of the Saginaw River, and is approximately 80 km upstream from the mouth of the Saginaw River.

TABLE 3.8-1

LIQUID RADIOACTIVE RELEASES FROM DOUGLAS POINT GENERATING STATION [a]

Year	Month	Tritium (curies)	Gross Beta-Gamma (curies)
1968	year	440	5.5
1969	year	986	12.05
1970	year	949	21.17
1973	January	390	0.010
	February	300	0.100
	March	560	0.050
	April	480	0.100
	May	370	0.020
	June	235	-
	July	2270	0.120
	August	1860	0.170
	September	180	0.880
	October	580	0.065
	November	335	0.430
	December	210	0.050
1974	January	450	0.100
	February	320	0.150
	March	250	0.130
	April	505	0.185
	May	90	0.080
	June	95	0.275
	July	95	0.185
	August	75	0.090
	September	355	0.015
	October	590	0.005
	November	385	0.025
	December	230	0.005
1975	January	465	0.022
	February	95	0.009
	March	117	0.208
	April	107	0.063
	May	204	0.027
	June	289	0.031

a. Information from Reference (2).

FUTURE INPUTS

Future inputs of radioactivity from mining activities in the Serpent River Basin are dependent on a number of factors which are discussed in Chapter 4.1.

The projection of future radioactivity waste inputs to Lake Huron from nuclear power generation is dependent on the future growth of electricity demand in Ontario. Regulatory limits for releases from a CANDU reactor with a yearly cooling water flow of $10^9 m^3$, which approximates that of one of the four planned reactors at the Bruce power complex, are 5,500,000 Ci/a of ^3H and 300 Ci/a of gross β-γ. As with all CANDU nuclear power plants, the design and operational targets are one percent of the release limits. Therefore, the targets for the four-reactor Bruce complex would be 220,000 Ci/a of ^3H and 12 Ci/a gross β-γ. No estimate of tritium which may be discharged from the Bruce Heavy Water Plant has been made.

It is expected that 12,000 to 15,000 MW of electric generating capacity will be installed on Lake Huron and Georgian Bay by the year 1993. The nuclear portion of this may be about 9,000 MW, 3,000 MW on Lake Huron, 3,000 MW on the North Channel, and 3,000 MW on Georgian Bay. Table 3.8-2 gives the possible inputs to these areas by 1993.

Although additional generating capacity from nuclear facilities is projected along the Michigan shore of Lake Huron, development of future sites is not considered likely before 1990.

TABLE 3.8-2

Projected 1993 Radioactivity Discharges To Lake Huron

LOCATION	Tritium (curies per year)	Gross Beta-Gamma (curies per year)
Lake Huron Main Body		
Bruce Nuclear Power Development	450,000	24.5
Southern Lake Huron Generating Station	220,000	12
North Channel		
North Channel Generating Station	220,000	12
Georgian Bay		
Georgian Bay Generating Station	220,000	12

3.9 DREDGING INPUTS

The quality of dredged material is quite variable, depending on the source. It may often contain high concentrations of heavy metals, nutrients, and organic materials. Therefore, disposal is of concern.

Dredging is conducted irregularly on Lake Huron to maintain existing navigation channels, build new harbour facilities or construct municipal and industrial intakes and outfalls. Data on the quality and quantity of capital dredging material (from areas dredged for the first time) are not adequate to estimate loadings. The estimates are based on maintenance dredging only.

Sedimentation in channels is caused by three basic mechanisms: silt carried downstream and deposited in the channel when the stream slows, littoral sand drift across the harbour mouth, and materials carried into the channel by storms. Maintenance dredging takes place at the ports listed in Table 3.9-1 and shown on Figure 3.9-1. The shoreline of northern Lake Huron and most of Georgian Bay is rocky; there is little littoral drift and therefore maintenance dredging requirements are minimal. In southern Lake Huron, dredging is required at three-to-ten year intervals. The Saginaw River is a major exception where substantial maintenance dredging is required annually.

Nine-tenths of all polluted sediments on the U.S. side are dredged from the Saginaw River. This material is now disposed of in a diked disposal area rather than into Lake Huron. Therefore, it is not included in the loading calculation.

ESTIMATES OF LOADINGS

The U.S. Environmental Protection Agency (EPA) surveyed all significant U.S. harbours on Lake Huron to determine the chemical quality of maintenance dredgings. The concentrations used in this estimate are compiled from individual reports on each harbour (3). The volumes dredged in U.S. harbours are based on the average for each harbour over a ten-year period (1). Estimated quantities of Canadian maintenance dredging are taken from the report of the IJC Dredging Working Group (2).

Total phosphorus in nonpolluted sediments varies from 50 to 600 mg/kg with a median value around 420 mg/kg (3). It is estimated that 108,000 m^3/a of nonpolluted sediments are disposed of in Lake Huron from U.S. channel maintenance projects. Although the same type of

TABLE 3.9-1

MAINTENANCE DREDGING IN LAKE HURON (1,2)

HARBOURS	VOLUME (m^3/a)	PERCENT POLLUTED	POLLUTED VOLUME (m^3/a)
UNITED STATES			
Alpena	6,100	0	0
Au Sable	23,000	100	23,000
Bay Port	4,600	0	0
Black River	2,300	0	0
Caseville	9,200	0	0
Cheboygan	7,600	0	0
Hammond	7,600	50	3,800
Harbor Beach	3,900	100	3,900
Harrisville	9,200	50	4,600
Les Cheneaux	7,600	100	7,600
Mackinaw City	3,100	0	0
Port Austin	3,100	70	2,200
Port Sanilac	5,500	0	0
Saginaw	535,000	100	535,000
Sebewaing	15,300	30	4,600
St. Marys River	49,700	0	0
Total	692,800		584,700
CANADA			
Bruce G.S.	13,100	-	-
Byng Inlet	2,500	-	-
Collingwood	20,000	-	-
Grand Bend	3,600	-	-
Lake Simcoe	3,300	-	-
Midland	13,100	-	-
Parry Sound	4,600	-	-
Sault St. Marie, Ontario	6,600	-	-
Severn	1,700	-	-
South Baymouth	5,300	-	-
Spragge	4,600	-	-
Stokes Bay	1,900	-	-
Vidal Shoals	2,100	-	-
Total	82,400		

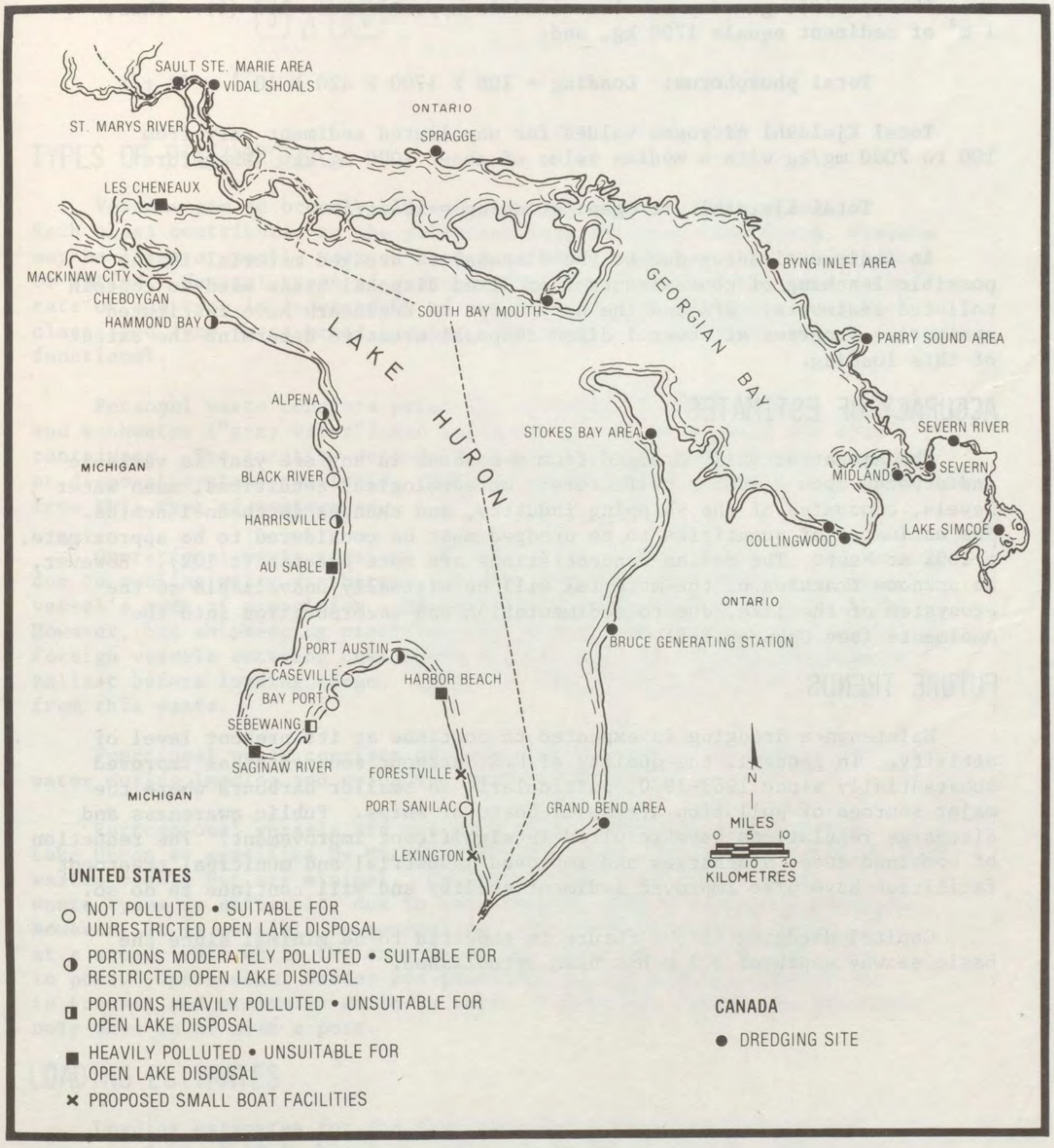


FIGURE 3.9-1 DREDGING SITES ON LAKE HURON

information is not available for Canadian dredging, the following loading calculations have been made for U.S. dredging.

The specific gravity of clean sand is approximately 1.7 (3). Thus, 1 m^3 of sediment equals 1700 kg, and:

$$\text{Total phosphorus: Loading} = 108 \times 1700 \times 420 \times 10^{-6} = 77 \text{ t/a}$$

Total Kjeldahl nitrogen values for unpolluted sediment vary from 100 to 2000 mg/kg with a median value of about 1000 mg/kg. Therefore:

Total Kjeldahl nitrogen: Loading = 184 t/a

An indirect loading due to the disposal of dredged material is the possible leaching of contaminants from diked disposal areas used to contain polluted sediments. EPA and the Army Corps of Engineers have instituted monitoring programs at several diked disposal areas to determine the extent of this loading.

ACCURACY OF ESTIMATES

The amount actually dredged from a harbour in any one year is variable and depends upon a number of factors: meteorological conditions, mean water levels, economics of the shipping industry, and changes in channel depths. The estimates of quantities to be dredged must be considered to be approximate, ± 100% at best. The median concentrations are more precise (± 10%). However, an unknown fraction of the material will be virtually unavailable to the ecosystem of the lake, due to sedimentation and incorporation into the sediments (see Chapter 6.8).

FUTURE TRENDS

Maintenance dredging is expected to continue at its present level of activity. In general, the quality of U.S. harbour sediments has improved substantially since 1967-1970, particularly in smaller harbours where the major sources of pollution are small boats or ships. Public awareness and discharge regulations have resulted in significant improvement. The reduction of combined sewer discharges and improved industrial and municipal treatment facilities have also improved sediment quality and will continue to do so.

Capital dredging in the future is expected to be minimal since the basic seaway depth of 8.2 m has been established.

3.10 VESSEL WASTE INPUTS

TYPES OF DISCHARGES

Vessels can be broadly classed as commercial or recreational. Each class contributes to the pollutant load entering Lake Huron. Vessels may be large or small, more or less transient, and may perform a variety of duties. Several types of waste may be generated, and the generation rate of one type is independent of any other. Types of wastes can be classified into three broad groups: personal, operational, and functional.

Personal waste consists primarily of sewage ("black water"), galley and washwater ("gray water") and solid waste such as plastic and food containers. The quantity depends on housekeeping practices and treatment or disposal systems available. Nutrients and pathogenic organisms originate from this type of wastewater.

Operational waste consists of oily bilge waters, dunnage, and heat due to cooling water discharges. It is generally associated with the vessel's mode of propulsion. Minimal waste discharges are unavoidable. However, bad shipkeeping practices can increase quantities considerably. Foreign vessels entering Lake Huron and Georgian Bay discharge seawater ballast before loading cargo. Chlorides and dissolved solids result from this waste.

Functional waste consists of cargo residues which fall into the water during loading and unloading activities.

Recreational vessels are not permitted to discharge sewage into Lake Huron as specified by Michigan and Ontario statute. Some operational wastes result but are minimal. Estimating the quantity of these three waste types is difficult, due to the changing patterns of ship movement. However, it is possible to generalize. Personal wastes are generated at a steady rate while the ship is on the lake, whether in transit or in port. Operational wastes are generated at the maximum rate while in transit and minimally while in port. Functional wastes are generated only when in or near a port.

LOADING ESTIMATES

Loading estimates for the five material balance parameters are given in Table 3.10-1, based on estimates in Table 3.10-2. These estimates are from black and gray water and salt water ballast. It is impossible to estimate loadings for the material balance parameters for personal

TABLE 3.10-1

ESTIMATED ANNUAL INPUTS FROM VESSELS TO LAKE HURON

PARAMETER	LOADING, IN TONNES PER YEAR				
	CANADA		U.S.		
	Black and Gray Water	Ballast	Black and Gray Water	Ballast	Total
Chloride	6.5	119	36.8	365	527
Total Phosphorus	0.4	--	2.3	--	2.7
Total Nitrogen	1.3	--	7.3	--	8.6
Total Dissolved Solids	44.7	219	254	672	1,190
Reactive Silicate (as SiO_2)	1.2	--	7.0	--	8.2

TABLE 3.10-2

ANNUAL INPUTS OF WASTE CATEGORIES TO LAKE HURON

WASTE CATEGORY	CANADA	U.S.	TOTAL
PERSONAL			
Black and Gray Water	76,500 kℓ	235,200 kℓ	311,700 kℓ
Solid Waste	751 t	244 t	995 t
OPERATIONAL			
Bilges (steamships)	61,400 t	250,000 t	311,000 t
Bilges (motorships)	6,500 t	15,800 t	22,300 t
FUNCTIONAL			
Cargo Spillage	6,500 t	26,800 t	33,300 t

solid waste, operational waste, or functional waste. However, most material balance inputs originate from the black and gray water or salt water ballast.

Other significant parameters discharged are oil, pathogens, and flotsam. It is estimated that 6.66 t of oil is discharged with bilge water annually. Cargo spillage represents 33,300 t discharged to the lake annually. Although not a serious problem for the main lake, much of this material becomes flotsam and causes a nuisance in port areas. Pathogens can be a serious problem, especially in port areas.

BASIS OF ESTIMATION

Assumptions and information used to estimate loadings from vessels to Lake Huron were obtained from References (1) and (2). In addition, discussions with representatives from the United States Coast Guard, Canadian Ministry of Transport, and staff of the Water Quality Division, Michigan Department of Natural Resources provided additional information used as a basis of calculation (3).

It was considered that all vessels entering Lake Huron ports would remain in Lake Huron three days (two days in transit and one day in port) except vessels going to Port Huron which were allowed one day in port.

The calculations were made as follows:

<u>Black & Gray Waters</u>

Volume discharged =

Vessel days x men per vessel x litres of waste per man per day

<u>Solid Waste</u>

Amount discharged =

Vessel days x men per vessel x kilograms per man per day

<u>Bilge Waste</u> (For steamships and motor vessels)

Amount of waste =

Vessel days x percentage of steamships x tonnes of waste discharged

<u>Cargo Spillage</u>

Amount of spilled cargo =

Tonnes of bulk cargo loaded or off loaded x percentage of bulk cargo spilled

Chlorides, Total Phosphorus, Total Nitrogen, Total Dissolved Solids, and Reactive Silicate

Amount discharged =

$$\frac{\text{Vessel days x men per vessel}}{365} \text{ x quantity discharged per person per year}$$

EVALUATION OF ACCURACY OF ESTIMATES

Information regarding the number of vessels was taken from 1974 actual figures and is accurate within ± 10% for 1975. The number of persons per vessel is a U.S. Coast Guard and Ministry of Transport estimate, based on actual counts from several vessels, and has an accuracy of ± 10%. Values used for solid waste, black and gray water, bilge water, and cargo spillage are dependable to a ± 50% range. Per capita inputs of the five material balance parameters were estimated for sewage from Michigan cities and are considered to be acceptable values for sewage from vessels. The range of variation for each of the five parameters is ± 50% for total phosphorus, total nitrogen, and chloride, ± 25% for reactive silicate, and ± 10% for total dissolved solids.

FUTURE INPUTS

Future trends will be influenced by national and regional legislation. It is expected that there will be a 95% reduction in personal waste discharged or dumped over the next three to five years with the enforcement of currently proposed or enacted laws. All solid wastes are presently required to be put ashore for disposal. Raw sewage discharges will cease if legislation to eliminate discharges becomes reality. Operational wastes are regulated to a degree, but further legislation is needed to enforce good shipkeeping practices. Functional wastes, especially those associated with bulk cargoes, will continue to be dumped indiscriminately unless legal constraints are imposed. Thus, future inputs are, in general, expected to decrease.

3.11 SPILLS

Because of their unpredictable nature, it is not possible to accurately estimate specific material inputs which result from spills. For the lake as a whole, inputs from spills are a small portion of the total. However, spills do occasionally have a serious effect on local areas.

There are two primary types of problem spills -- oil or petroleum distillates and other hazardous materials. Spill reports from state, provincial, and federal regulatory agencies indicate that for oil spills, less than 50% of the products spilled to water are actually recovered. Losses of chemicals or other such potentially hazardous materials to water bodies pose a threat to the local environment because such materials generally cannot be recovered. Often in cases of spills involving chemicals, neutralizing agents, which may be considered as polluting substances themselves, are put into the water.

Spills of chemicals, oil, or other toxic materials generally occur near centres of industrial activity or along transportation corridors. The majority of the incidents have taken place near population centres along the shores of Lake Huron or on major tributary watercourses. With the exception of a few isolated incidents, most spills have not caused injury to health or property. However, many spills have caused at least a temporary environmental upset in the immediate vicinity of the spill.

ESTIMATES OF INPUTS

As pointed out above, it is impossible to accurately estimate the amounts of materials spilled into Lake Huron. However, an educated guess can be made as described below.

The U.S. Army Corps of Engineers projected that in 1975 about 443,000 t of petroleum and about 248,000 t of chemicals would be carried to ports in the U.S. portion of Lake Huron. These amounts were expected to increase by 1980 to about 497,000 t of petroleum and about 273,000 t of chemicals (1).

One authority (2) has estimated spillage to be on the order of 0.1% of the total quantity transported. Using the rate of 0.1% of the total material transported as the maximum potential, spills in the U.S. portion of Lake Huron would have been 443 t of petroleum and 248 t of chemicals in 1975.

Although accidental oil spills attract the most public attention, they constitute only about 10% of the total amount of oil entering the lake. The other 90% originates from the normal operation of oil-carrying tankers, other ships, industrial operations, and the disposal of oil-waste materials.

Permanent extension of navigation through the winter season is now being studied. An increased number of spills might result if the navigation period is extended.

3.12 PROJECTED FUTURE WASTE LOADINGS

WASTE LOAD SIMULATION MODEL

DESCRIPTION OF MODEL

In order to examine future trends in loadings from human activities for their possible impact on the lakes, a simulation model was developed. The model that ultimately evolved (and will continue to change) was the product of many things. The questions concerning future loadings required a framework involving a long time horizon (50 years), a large number of human activity variables, and eleven separate basin regions. A great deal of uncertainty is involved in the future projections of the human activity variables and a great number of alternative futures are both plausible and possible. The world we live in and the economic and social processes of which we are a part are constantly undergoing both quantitative and qualitative change. We cannot possibly know, except perhaps in broad outline, what the future holds for certain.

The model, therefore, was designed to allow for a range of choice in the future values of the key variables affecting loadings. In this sense the model possesses simulation capabilities. However, not all variables can be simulated. While verbal descriptions of radically different futures are readily available, no one has yet quantified these and shown how our institutions and value systems would adjust to accommodate such change. The need for internal consistency in the model precludes the articulation of radical change. Aside from this limit, there is still a wide range of simulation capability.

Figure 3.12-1 is a schematic of the model, showing the major variables or parameters. While many variables are illustrated, the two major components are municipal sewage treatment plants which serve the sewered population and industrial activity that discharges its waste directly to surface waters. Unfortunately, and significantly, the treatment and discharge of industrial waste by municipal facilities cannot be modelled separately. The Ontario Ministry of the Environment (MOE) has municipalities monitor their influent and effluent for certain wastes; however, Ministry officials maintain that it is not possible to separate the total waste flow into components identifiable as industrial, commercial, residential, and so on. Projections of municipal waste loadings are very likely biased downwards since they are related only to population growth which is, in general, significantly lower than either industrial or commercial activity growth rates.

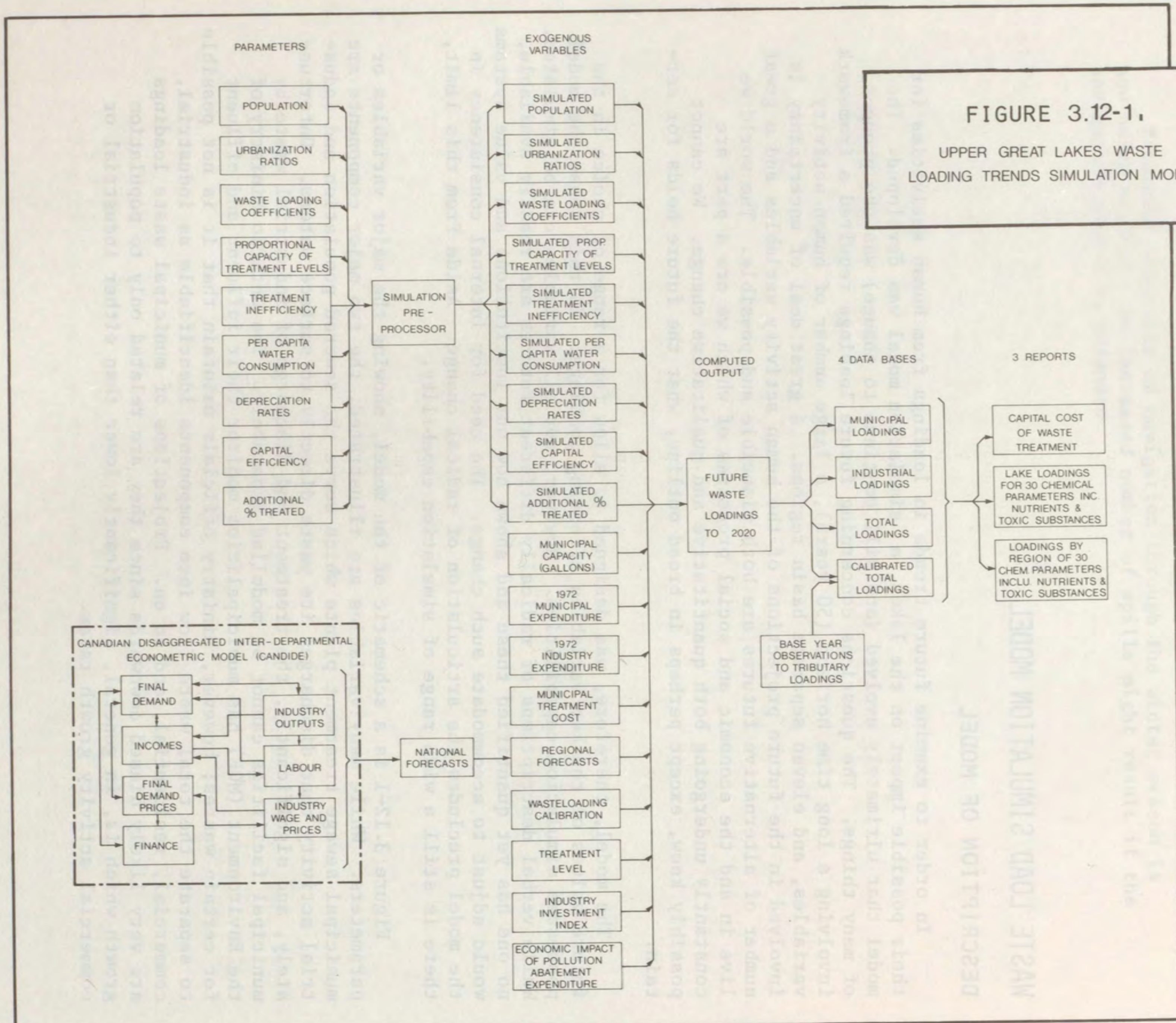


FIGURE 3.12-1.

UPPER GREAT LAKES WASTE LOADING TRENDS SIMULATION MODEL

INFORMATION SOURCES

The basic data requirements can be seen in Figure 3.12-1. Each block represents a set of information which was collected or produced. The sources of such information was varied. The population projections for the Canadian basin were derived from Ontario government sources. The economic activity and population projections for the United States basin was drawn from a unified effort of the Office of Business Economics of the U.S. Department of Commerce and the Economic Research Service of the U.S. Department of Agriculture. This large body of information is identified by the acronym OBERS (19). The Canadian economic activity projections were drawn from a study which utilized a large econometric model of the Canadian economy, known by the acronym CANDIDE (16-18). For the purpose of this project, CANDIDE projections of national activity were related to the watershed regions and extended to the year 2020, well beyond the normally utilized limit of 1985.

Information on industrial waste loadings in the U.S. came from Minnesota, Wisconsin, and Michigan through Region V of the U.S. Environmental Protection Agency. The files of the NPDES system were used to identify individual dischargers, and compliance monitoring reports and/or self monitoring reports were utilized in the calculation of actual loadings. Industrial waste loadings in Canadian basins were supplied by MOE, as were municipal loadings and capacity. Other data and information came from numerous diverse sources which are listed in the bibliography. Values for the simulation variables can be determined by interested model users.

Sociological, technological, and institutional aspects of present and future pollution and pollution abatement were also examined in a separate study which suggested several alternative futures (15). Certain aspects of these futures were used to produce one of the scenarios of future loadings.

MODEL OPERATION

While the data discussed above were oftentimes the product of complex analytical models designed to produce specific data, the waste loadings model is conceptually simple. It is really nothing more than an accounting type representation of the various factors determining loadings and is based on common sense. The data collected represented, as closely as possible, knowledge of the processes by which loadings are created, treated, and discharged. Oftentimes, the lack of detailed information required simplification of complex processes to workable ones. Most often, data availability and timeliness determined the form of process relationships used in the model. Further information and data will continue to become available, necessitating changes in the model data base and processes. The loadings presented below are the product of innumerable model revisions and are certainly not final.

In broad outline, the available data were placed in a computer file and then manipulated according to the chosen representation of the phenomena being considered. Lack of reliable information, necessary simplifications, and uncertainty were accorded their due by allowing for the simulation capabilities discussed above and noted in Figure 3.12-1. For example, the generation of municipal waste loadings by the model is easily followed in Figure 3.12-1. Population, urbanization and sewer connection, per capita waste loadings and water use, and treatment capacity type and inefficiency, for each basin region, were first related according to the model specification, then checked for simulation changes, and finally computed loadings were produced according to the values these variables were assigned. The multidimensional nature of the relationships describing municipal waste production, treatment, and discharge discourages attempts to reproduce them here. The complexity ends, however, at the notational level, as the waste flows are portrayed in a way as close to the real world as quantitative knowledge would allow.

The industrial loadings are calculated in a similar way; however, certain important differences arise. The waste loadings data are based on post-treatment flows, and no information was available to indicate the level of treatment accorded before discharge. For each basin region and industry, loadings were related to a measure of economic output, and the basic projection methodology used this relationship. Again, simulation capabilities allow for a variety of alternative assumptions.

The whole model follows this basic philosophy of simplicity. While a great deal of more complex research and analysis was required to produce the data used in the model, it was not necessary, nor was it at all times possible, to take account of any complexities remaining to be accounted for in this model.

The loadings explicitly examined and modelled were only one source of input to Lake Superior. Actual measurements of total loadings to the lakes, described in the other sections of this chapter, considered tributary, direct municipal and direct industrial, atmospheric, interlake transport, and other sources. Included in tributary loadings, of course, are the discharges of upstream municipal and industrial plants. Net land runoff to the lakes was estimated as the difference between the model calculated sum of all municipal and industrial loadings and the sum of the present measured direct municipal, direct industrial, and tributary loadings. No projections of future loadings from land runoff were attempted. Net land runoff was, therefore, assumed constant into the future. This loading was added to the model projected municipal and industrial loadings to give a "calibrated" total. While it seems clear that land runoff will not remain constant in the future, without more detailed analyses, no other assumption was possible. It was nonetheless, highly unsatisfactory.

ALTERNATIVE POINT SOURCE LOADINGS PROJECTIONS

As described above, the simulation capabilities of the model enable many alternative projections of loadings to be easily produced. Three possible scenarios were developed. The "base scenario" or projection utilized in this report is based upon a continuation of the existing level of treatment. In operational terms, this means that the loadings grow in direct proportion to industrial output and population growth. Philosophically, this scenario implies no relative increase in spending on pollution abatement equipment, no significant technological breakthroughs, and *no increase in public or political concern or commitment to environmental problems.*

A "synergistic scenario" was developed to illustrate the simulation capabilities of the model and to provide one view of a more optimistic future for the environment. This scenario reflects possible impacts of increased public and commercial attention to environmental problems. It includes changes in production processes and treatment technology. This implies that the public and the governments have accepted the need for stringent controls and that the business community develops and utilizes improved processes and treatment technology.

The synergistic scenario is significant and interesting for several reasons, the most important of which is the requirement to specify exactly the changes to current human activity variables that are necessary to achieve a given loadings decrease. While the exercise does not directly indicate how these changes are to be brought about, it does serve to stimulate debate by raising the issues. Secondly, the view held here is that the assumptions themselves are indeed optimistic. They are as follows:

(1) Municipal per capita loadings in 2020 are 40% of the 1974 value.

(2) Industrial unit loadings in 2020 are 40% of the 1974 value.

(3) Per capita domestic water use falls by nearly half by 2020.

(4) By 2020, 80% of sewage treatment plants in the basin will have some form of advanced or tertiary treatment. The balance of capacity will be at least secondary treatment.

(5) Industrial treatment reaches the level of 82% removal by 2020 while the average cost of abatement falls by a total of 21%.

These are combined with several less significant assumptions concerning population size and distribution throughout the basin. This set of assumptions yields a future that gives both decreasing loadings and decreasing or constant real costs of abatement. This seems to be optimistic indeed.

While the potential for the realization of such a scenario exists, it will not actually happen without an increased commitment to this goal on the part of the public, governments, and industry. It is up to them to see that the above assumptions are in fact borne out or more importantly *that a suitable combination of different assumptions (tougher here, easier there) are fulfilled.*

A third scenario incorporating absolute zero loading as a goal for all nutrient and toxic substances shows that the costs are extremely high and disruptive. However, although across-the-board removal may be impractical, selective banning of toxicants and removal of nutrients is a practicable and necessary goal.

PROJECTED LOADINGS

Figure 3.12-2 is a generalized representation of the three loadings scenarios and their relationship with the current (1974) situation. The base scenario produces an obviously expected multiple increase in loadings and is simply no more or no less than the *relative* effort we are exerting today. A growing economy and population will produce more waste each year.

The zero loadings scenario produces a tremendous cost burden because of the rapidly rising cost of achieving ever higher incremental levels of treatment.

The simulation or synergistic scenario depicted here shows the declining loadings and costs as discussed above.

The presentation of actual point estimates of loadings is restricted to the five materials balance parameters. However, information on 25 other parameters that were examined is available (22,23). Trends in these loadings are similar to those presented here.

Table 3.12-1 shows present and projected total loadings to Lake Huron from municipal, industrial, and tributary sources for two different runs of the base scenario (22,23). The differences in the two simulations of projected loadings in 2020 are due in part to an updated information base for the February 1977 output, which reflects the dynamic nature of the model. The two projections also incorporate different assumptions about industrial discharges of nitrogen, chloride, and reactive silicate, which are not completely measured in Canada. Nonetheless, the basic point is inescapable: under the primary assumptions of the base scenario that the existing level of treatment technology and the present level of funding at a fixed percentage of the Gross Basin Product will continue, loadings of each parameter from municipal and industrial sources will increase.

Several considerations prompted the detailed presentation of the base scenario projections only. First, the loadings from the base scenario are the most critical values from the viewpoint of water quality measurements and policy recommendations. Secondly, the zero loadings scenario needs no elaboration except from a cost viewpoint. As illustrated in Figure 3.12-2, these costs escalate rapidly and become very large. While alternative assumptions concerning the behaviour of costs may be considered in the model as zero discharge is approached, the loadings outcome is predetermined. Thirdly, the synergistic scenario loadings reveal the general pattern of the curve in Figure 3.12-2: a steady decline relative to 1974. A considerable effort could be made discussing these loadings; however, this would detract from the ultimate and perhaps only significance the projection has, which is, the synergistic scenario illustrates the simulation capabilities of the model and gives concrete values for key determinants of loadings that, according to the model, will result in lower loadings in the future.

Strictly speaking, a plausible and possible scenario could just as easily be constructed to produce *increases* in loadings and higher average

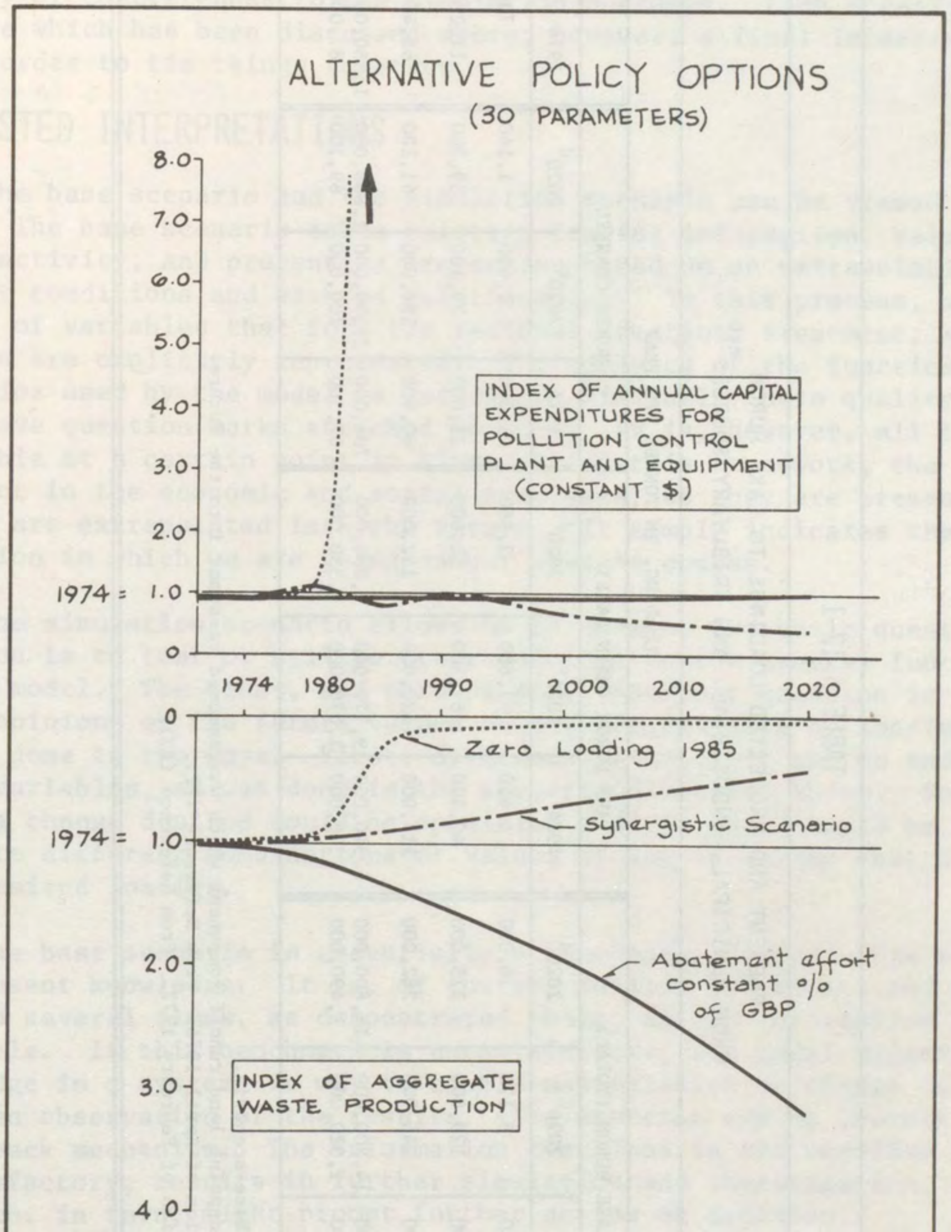


FIGURE 3.12-2.
SCHEMATIC COMPARISON OF RELATIVE CHANGE IN CAPITAL EXPENDITURES AND IN AGGREGATE WASTE PRODUCTION FOR THREE SCENARIOS.

TABLE 3.12-1

PRESENT AND PROJECTED LOADINGS TO LAKE HURON FROM MUNICIPAL, INDUSTRIAL, AND TRIBUTARY SOURCES[a,b]

PARAMETER	LOADING, IN TONNES PER YEAR											
	LAKE HURON (TOTAL)			LAKE HURON (MAIN LAKE)			NORTH CHANNEL			GEORGIAN BAY		
	1974	2020[c]	2020[d]	1974	2020[c]	2020[d]	1974	2020[c]	2020[d]	1974	2020[c]	2020[d]
Total Phosphorus, as P	4,240	5,175	6,030	2,410	2,680	3,960	1,030	1,450	1,140	794	1,045	920
Total Nitrogen, as N	66,500	129,000	125,000	40,100	61,300	51,600	15,000	25,100	59,300	11,200	42,100	13,600
Reactive Silicate, as SiO_2	247,000	444,000	282,000	117,000	120,000	152,000	60,900	187,000	61,100	68,400	136,000	68,500
Dissolved Solids	9,130,000	14,800,000	11,800,000	6,540,000	9,170,000	7,880,000	706,000	2,390,000	1,800,000	1,880,000	3,240,000	2,120,000
Chloride, as Cl	753,000	1,320,000	1,490,000	598,000	1,070,000	1,330,000	67,500	100,000	69,100	87,000	149,000	91,200

a. In accordance with the base scenario.
b. Each value contains a nonpoint land runoff component which was assumed constant into the future.
c. Base scenario - simulation of April 1976. From Reference (22).
d. Base scenario - simulation of February 1977. From Reference (23).

costs of abatement, relative to the base scenario. A close reading of the current situation in the Great Lakes Basin certainly does not inexorably lead to the conclusion that lower future loadings are the most likely outcome. Further, the lack of data on industrial flows to municipal treatment plants introduced the downward bias in municipal loadings projections as noted above. Therefore, one does not want to inadvertently impute a sense of reality or concreteness to the simulation outcomes. Each scenario serves a purpose which has been discussed above; however, a final interpretation might be in order to tie things together.

SUGGESTED INTERPRETATIONS

The base scenario and the simulation scenario can be viewed side by side. The base scenario takes existing loading information, relates it to human activity, and presents a projection based on an extrapolation of these present conditions and assumed relationships. In this process, a large number of variables that form the residual creation, treatment, and discharge process are explicitly represented. The adequacy of the functional relationships used by the model is variable. Similarly, data quality and quantity also have question marks attached to them. It is, however, all that is available at a certain point in time. Using this framework, the trends inherent in the economic and social processes, as they are presently understood, are extrapolated into the future. It simply indicates the general direction in which we are going on our present course.

The simulation scenario allows us to examine two basic questions. One question is to test or utilize other opinions on the general functional form of the model. The other, and perhaps more important question is to test other opinions on the future values of key determinants of loadings. This can be done in two ways. First, different assumptions can be made concerning these variables, as was done in the scenario discussed above. Second, the loading change desired would be specified and the model could be used to indicate different combinations of values of key variables that would yield this desired loading.

The base scenario is essentially a benchmark, derived from the best of our present knowledge. It is, of course, subject to change, and has been changed several times, as demonstrated above, as new information became available. If this benchmark is unsatisfactory, the model organizes data and knowledge in a systematic way to enable manipulation or change in the system and then observation of the results. The exercise can be loosely compared to a feedback mechanism. The information contained in the baseline case, if unsatisfactory, results in further simulation and investigation, the results of which, in turn, might prompt further action or decision.

AREAS FOR FUTURE CONSIDERATION

In any undertaking covering as many areas of study and taking as long a time to complete, there are innumerable things that one would have liked to have done better. This model is no exception. The numerous working papers describing various aspects of the modelling effort are listed in the bibliography. No effort at detailing shortcomings, deficiencies, and so forth will be undertaken here.

Modelling such as that done here is an ongoing effort. The conceptualization and construction of such models is as helpful in identifying problem areas in other research fields as is progression in the opposite direction. The potential future uses of the present model have been discussed above and some interest has been shown in this direction. It is also clear that conceptual and empirical problems still remain, and work continues in these areas.

CHAPTER 4

WATER QUALITY CHARACTERISTICS OF THE NEARSHORE WATERS, HARBOURS, AND EMBAYMENTS

4.0 INTRODUCTION

Chapter 4 deals with the studies of the nearshore waters of Lake Huron. The study program contained a two-phased approach. The first phase dealt with the documentation of water quality along those stretches of the nearshore area relatively unaffected by man's activities. The second aspect dealt with the assessment of water quality degradation in locations where significant waste inputs originate. It relates the material loading data contained in Chapter 3 to the effects on water quality in the immediate offshore areas where water use is most intensive. Accordingly, Chapter 4 is divided into the following sections:

4.1 Lake Huron Coastal and Embayments
4.2 Saginaw Bay
4.3 St. Marys River
4.4 Nearshore-Offshore Exchange

The first three subchapters each contain a description of the limnological characteristics - physical, chemical, and biological - plus a summary of existing and developing problems. Chapter 4.4 is a commentary on the nearshore-offshore exchange of materials, leading up to the description of the open waters of Lake Huron in Chapter 5.

4.1 NEARSHORE WATERS AND EMBAYMENTS

DESCRIPTION OF THE STUDY AREA

The nearshore area, a small portion of the lake volume, is the focal point of a limnological study. These littoral zones are the site of complex interactions between the watershed and the deepwater, or limnetic zone. Littoral zone physical processes, such as wave-induced mixing, coastal currents, and thermal bars, act in the dispersion, containment, or redirection of tributary and other watershed influences.

The surface area of Lake Huron is 59,570 km^2; the shoreline, including islands, is 6,159 km (1). For this study, nearshore waters were defined as those within 3 km of shore or extending offshore to a water depth of ∿ 15 m and encompassing roughly 7,578 km^2, or 13% of the total surface area of the lake.

GEOLOGY AND TOPOGRAPHY

The mainland and submerged geology of Lake Huron is quite diverse, ranging from erosion-resistant granites of the Precambrian Shield region in the north, to Phanerozoic rocks along the southern portion of the drainage basin. The landscape of the basin has been dramatically modified by recent glacial erosion, resulting in the present topographical features. A more detailed discussion of Lake Huron geology and topography is to be found in Chapter 1.

WATER USE

The coastal zone of Lake Huron is extensively utilized for a wide variety of water uses, including water supply, waste disposal, recreation, navigation, and commercial fishing (Figures 1-9, 1-10, and 1-11). Chapter 3 details the materials input to Lake Huron from municipal, industrial, and tributary sources including loadings from the five major materials balance variables: total nitrogen, total phosphorus, dissolved solids, reactive silicate, and chloride. Further statistics on water use indicate that ∿ 2 x 10^6 m^3 of water are drawn daily from Lake Huron by Canadian and United States municipal water works. Additional information regarding water use in the study area is detailed in Chapter 1.

METHODS

STUDY PLAN

Surveys of the nearshore regions of Lake Huron were undertaken by the Province of Ontario and the State of Michigan in 1974 and 1975.

The Ontario Ministry of the Environment (MOE) examined water quality to document the impact of existing materials inputs and to provide a baseline for measuring the environmental influence of additional shoreline development. Monitoring cruises which included Georgian Bay and the North Channel were carried out between May 7 and November 25, 1974 and from April 21 to May 9, 1975 (2,3) using a sampling grid of approximately 120 stations for which the province has accumulated water quality data since 1967 (Figure 4.1-1). In conjunction with this monitoring program, short-duration intensive studies were undertaken at Goderich, Douglas Point, Southampton, Port Elgin, Tobermory, Owen Sound, Collingwood, Penetanguishene, Midland, Parry Sound, Spanish River mouth, and Serpent Harbour (Figure 4.1-1) to assess the status of enrichment and the extent of local water quality impairment.

The Michigan Department of Natural Resources (DNR) selected a total of nine locations along the coast of Lake Huron for water quality documentation during 1974 (Figure 4.1-1). These locations were divided into groups designated as intensive, or those areas affected by cultural sources; and non-intensive, or those areas relatively unaffected by man's activities. Each location was sampled during the spring and the fall of 1974, using an array of seven sampling stations per location. Additional intensive local water quality studies were also completed at Cheboygan, Alpena, and Harbor Beach (Figure 4.1-1)(9).

Extensive information was collected on physical, chemical, and biological characteristics (Table 4.1-1).

DATA PRESENTATION

To reflect regional differences in water quality and to facilitate the presentation of findings, the Reference Group divided both nearshore and open water areas of Lake Huron into segments. The nearshore waters of Lake Huron are geographically segmented into eight segments A to I in addition to Saginaw Bay (segment H) which is dealt with in Chapter 4.2 (Figure 4.1-1). In this section, seasons were delimited as spring 1974 (April, May, June), summer 1974 (July, August, September); fall 1974 (October, November, December). Statistical summaries are shown in Figures 4.1-3 to 4.1-8 and 4.1-12 to 4.1-15 for each segment and season.

Geographical division of nearshore and open water areas was justified on a number of grounds. First, the water chemistry and biology in different parts of a lake are frequently different. Therefore, it would be misleading to combine measurements from different parts of a lake into one average value. Such an overall average might mask an unusually

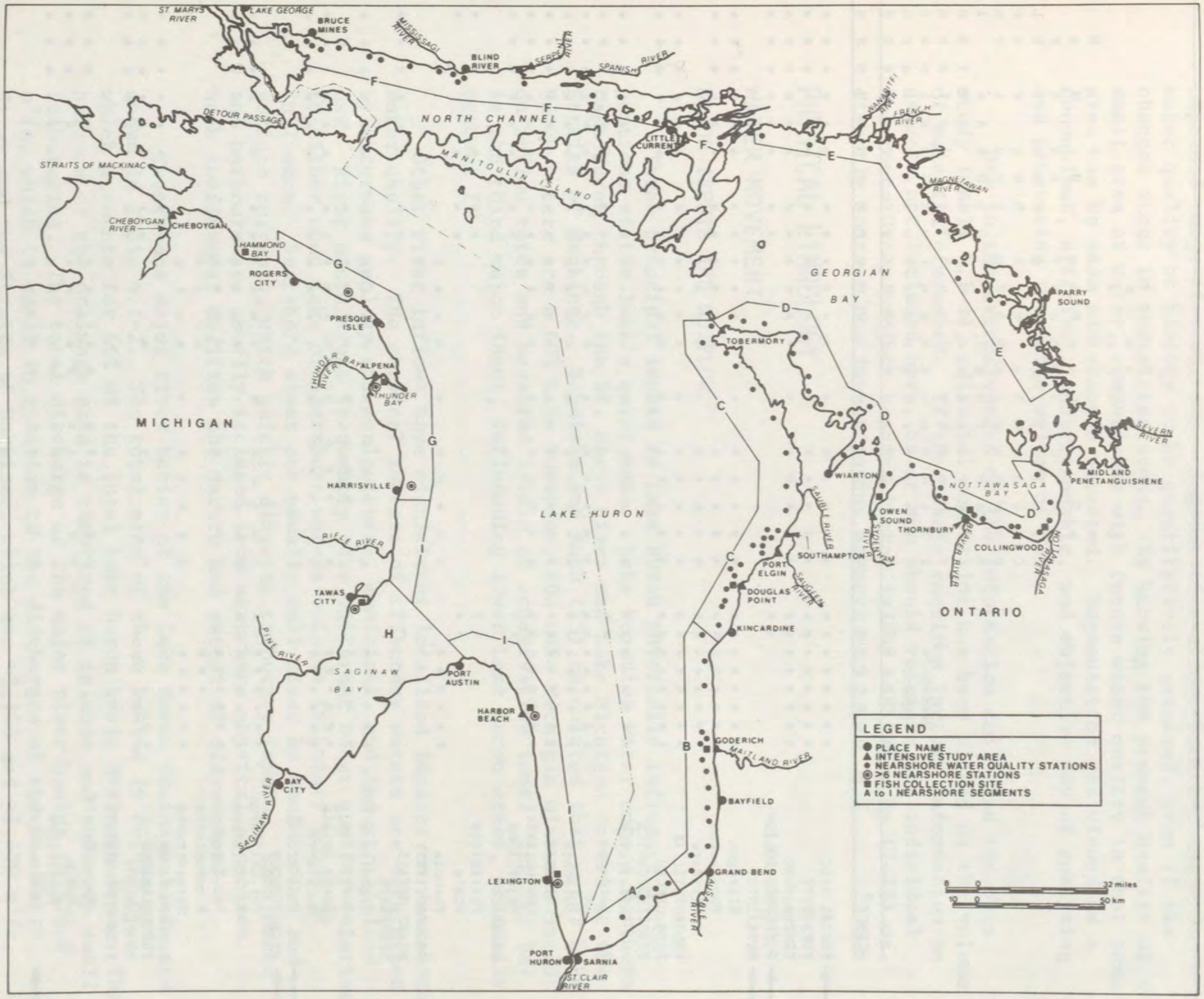


FIGURE 4.1-1 NEARSHORE SEGMENTS, STUDY AREAS, AND STATION LOCATIONS. The nearshore zone generally extends offshore about 3 km or to a water depth of about 15 m. Widths are not to scale.

TABLE 4.1-1

NEARSHORE STUDY PROGRAM

	Nearshore Segments	A	B	C	D	E	F	G	I	Goderich	Douglas Point	Southampton	Tobermory	Owen Sound	Thornbury	Collingwood	Nottawasaga Bay	Penetang Midland	Parry Sound	Spanish R. Mouth	Serpent Harbr	De Tour	Cheboygan	Hammond Bay	Presque Isle	Alpena	Harrisville	Tawas	Harbor Beach	Lexington
	AGENCY[a]	O	O	O	O	O	O	M	M	O	O	O	O	O	O	O	O	O	O	O	O	M	M	M	M	M	M	M	M	M
Physical Limnology	SECCHI DISC	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	TURBIDITY	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	TEMPERATURE	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	SUSPENDED SOLIDS							*	*													*	*		*	*	*	*	*	*
Chemical Limnology	NUTRIENTS																													
	Nitrogen	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Phosphorus	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Silicate	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*									
	CHLOROPHYLL α	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	DISS.OXYGEN	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	DISS.INORGANICS																													
	Alkalinity	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Hardness							*	*													*	*		*	*	*	*	*	*
	pH	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Sulphate	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Chloride	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Conductivity	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Major Ions							*	*													*	*		*	*	*	*	*	*
	ORGANICS																													
	Pesticides							*	*													*	*		*					*
	PCB's							*	*													*	*		*					*
	Phenols	*	*	*	*	*	*			*	*	*	*	*		*		*	*	*	*									
	RADIOACTIVITY										*										*									
	HEAVY METALS							*	*													*	*		*	*	*	*	*	*
	SEDIMENTS																													
	Organics & PCB's	*	*	*	*	*	*					*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Pesticides	*	*	*	*	*	*					*	*	*		*		*	*	*	*		*			*			*	
	Heavy Metals	*	*	*	*	*	*			*		*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Nutrients	*	*	*	*	*	*			*		*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Radioactivity																				*									
Aquatic Biology	MICROBIOLOGY																													
	Tot.Coliforms	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Fec.Coliforms	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*		*	*	*	*	*	*
	Fec.Streptococci	*	*	*	*	*	*			*	*	*	*	*		*		*	*	*	*									
	P.aeruginosa				*	*	*											*		*	*									
	Heterotrophs	*	*	*	*	*	*			*	*	*	*	*		*		*	*	*	*									
	BENTHIC FAUNA																					*	*		*	*	*	*	*	*
	PHYTOPLANKTON	*	*							*				*		*		*				*	*		*	*	*	*	*	*
	ZOOPLANKTON																					*	*		*	*	*	*	*	*
	FISH CONTAMINANTS																													
	Heavy Metals									*	*			*	*		*	*		*	*			*		*		*	*	*
	PCB's									*	*			*	*		*	*		*	*			*		*		*	*	*
	Pesticides									*	*			*	*		*	*		*	*			*		*		*	*	*
	Radioactivity									*	*			*	*		*	*		*	*									

a. Agency - O Ontario Ministry of the Environment
M Michigan Department of Natural Resources

high or low value in one area of a lake. Segmentation also allows quantitative tests to be made to determine if apparent differences between areas of a lake are statistically real or simply within the expected range of variation. Segmentation allows future changes in water quality or biology to be quantitatively assessed, even if the changes occur in restricted areas. By knowing the present quality of a small area of water, comparisons with future water quality in that same area can be made and changes detected. Segmentation was viewed as a convenient, efficient, understandable, and objective way of analyzing and presenting the large volume of data.

Due to the extensiveness of the information collected for this study (Table 4.1-1), editorial constraint has been placed on the volume of material presented. If the reader requires further information on aspects not included here, he or she should refer to the individual Reference Group project reports listed in the bibliography (2-12) or directly contact the investigating agency.

PHYSICAL LIMNOLOGY

WATER MOVEMENT

MAJOR INPUTS AND OUTFLOW

Three principal inputs to Lake Huron physically influence large portions of the lake's water mass. Lake Superior water enters northern Lake Huron through the St. Marys River and Lake Michigan enters at the Straits of Mackinac. Schelske and Roth (13) calculated that upper Lake Huron waters are a 60% Lake Superior, 40% Lake Michigan mixture, based on inflow rates and measured levels of conservative ions. Saginaw Bay is the third major input, influencing lower Lake Huron areas, primarily segment I.

Other river inflows have significant localized impacts on nearshore water quality. The chemical aspects of tributary waters are determined by watershed geology and agricultural, municipal, and industrial land use. River mouth areas frequently have different water quality relative to either open lake or nearshore waters outside tributary zones of influence. Nearshore areas are usually well mixed by wind action and surface currents, which quickly disperse tributary inputs. Embayments and harbours are usually isolated from nearshore physical processes. Such confinement modifies the nature and extent of dispersion.

Twenty-one major river basins of the Lake Huron drainage basin are shown in Table 4.1-2. The total area of these basins is 86,899 km^2, which accounts for 66% of the total Lake Huron basin drainage area. The balance of the drainage area is comprised of islands and numerous small tributaries. The total discharge of the major river basins is 976.8 m^3/s, which is small in relation to the discharges of the St. Marys River and the Straits of Mackinac, which are $\sim$2,100 and $\sim$1,400 m^3/s, respectively. Four larger rivers, the French, Mississagi, Saginaw, and

TABLE 4.1-2

MAJOR RIVER BASINS IN THE LAKE HURON WATERSHED

RIVER BASIN	Basin Area (km^2)	Mean Annual Discharge (m^3/s)
SEGMENT A		
No major river inputs		
SEGMENT B		
Ausable	865	9.3
Maitland	2,137	23.3
SEGMENT C		
Saugeen	4,066	55.4
Sauble	927	13.0
SEGMENT D		
Sydenham	181	2.7
Beaver	572	7.2
Nottawasaga	1,181	9.2
SEGMENT E		
Severn	5,853	49.4
Magnetawan	624	10.6
French	13,908	172.4
Wannapitei	3,134	37.0
SEGMENT F		
Spanish	12,069	179.4
Aux Sable	1,357	18.5
Mississagi	9,298	127.7
Serpent	1,349	24.2
SEGMENT G		
Thunder Bay	3,238	26.3
SEGMENT I		
Au Sable	5,377	51.3
Rifle	1,002	10.5
OTHER RIVERS		
Pine	629	6.0
Cheboygan	3,776	36.3
Saginaw	15,356	107.1
TOTAL	86,899	976.8

Spanish, comprise 60% of the total tributary discharge shown in Table 4.1-2.

Lake Huron flows into the St. Clair River at the southern end of the lake, with a mean annual flow of 5,070 m^3/s.

CIRCULATION PATTERNS

Ayers, *et al.* (14) detected a general southward movement of surface waters along western Lake Huron segments G and I and along southeastern Lake Huron segment A (Figure 4.1-2). The surface currents at these locations are modified by short-term wind stresses, but the general southerly flow is maintained. Schelske and Roth (13) reported the occasional movement of Saginaw Bay waters northward to the Thunder Bay area. Both studies (13,14) show that the Saginaw Bay water mass usually flows from Port Austin southward through segment I to the St. Clair River. Sloss and Saylor (15) presented current patterns similar to those of Ayers, *et al.* (14) with a general southward movement of water through segments A, B, and I, and a counter-clockwise movement in the northern two-thirds of the lake, which includes segments C, G, and the northern portion of segment I.

Based on current estimates of Ayers, *et al.* (14), Georgian Bay waters have restricted mixing with the main body of Lake Huron. The isolation of Georgian Bay is an important influence on the water quality of segments D and E.

THERMAL REGIMES

Water temperature is an important environmental variable, controlling the potential of a water body to support biological processes. The rates of all metabolic functions are directly proportional to temperature, determining both the quality and productivity of aquatic communities.

Thermal stratification, when present, separates the water mass into thermally distinct layers, restricting vertical circulation. Deep-water areas of Lake Huron stratify seasonally. Littoral areas, however, were found to be well mixed and frequently isothermal. Deep-water stations at DeTour and segment F showed decreasing surface-to-bottom thermal gradients, without recognizable thermal strata. Statistical comparisons of physical water quality variables in surface and bottom waters showed no significant differences in many cases.

Temperatures in nearshore segments A to I during spring sampling ranged from 2.4 to 18.1°C (Figure 4.1-3). Embayment/harbour areas, which are shallower and influenced by tributary inputs, had spring temperatures ranging from 4.2 to 21°C. Summer nearshore temperatures ranged from 4.5 to 23°C, while embayment/harbour values were 17 to 20°C. During fall, nearshore temperatures ranged from 4.9 to 20°C and embayment/harbour temperatures ranged from 12 to 20°C. The overlap of seasonal temperature ranges indicates large regional differences.

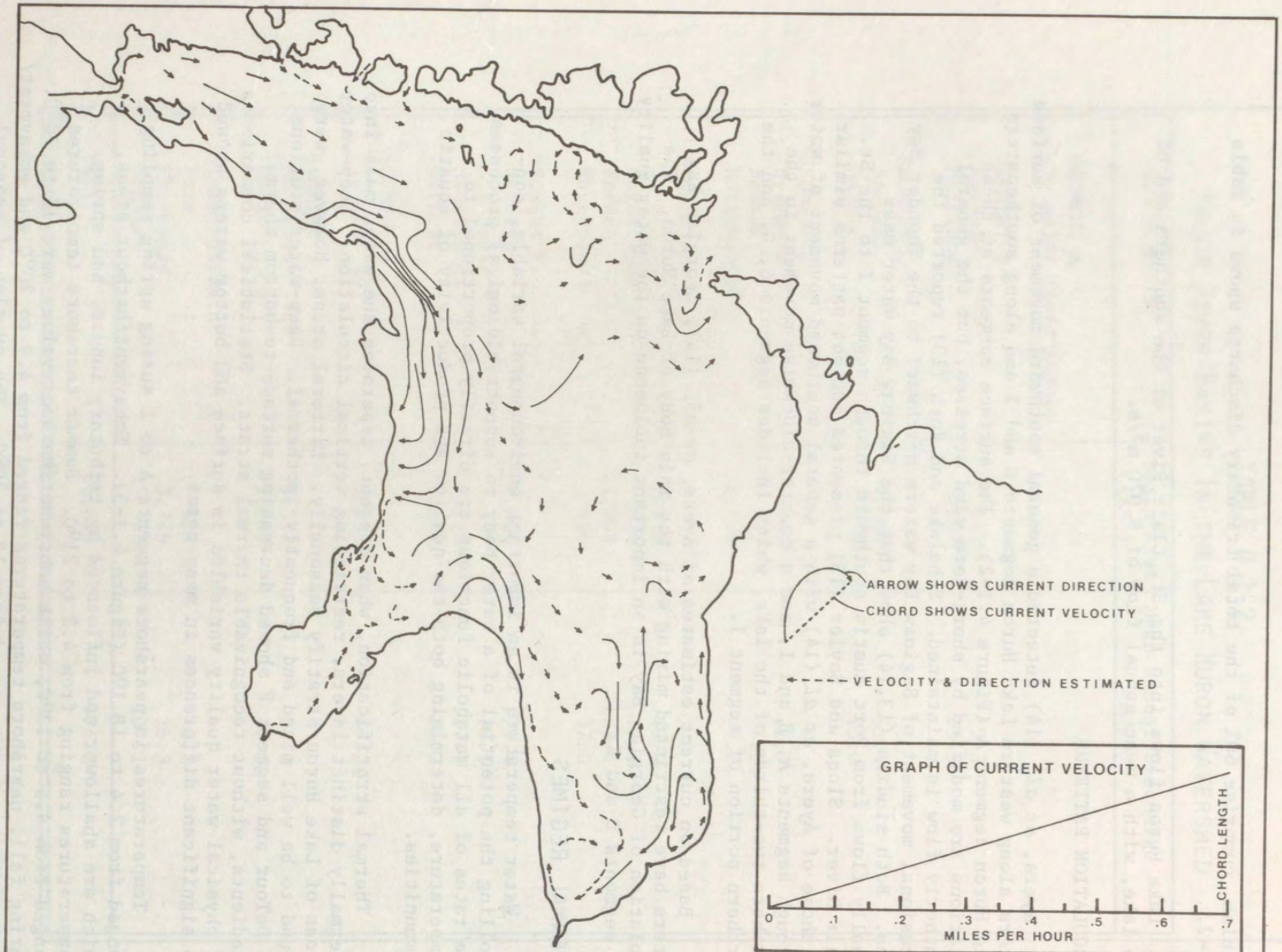


FIGURE 4.1-2 TYPICAL LAKE HURON SURFACE CURRENTS.
Adapted from Reference (14).

The thermal regimes of Lake Huron nearshore areas are influenced by three major factors: solar radiation, temperature of inflowing waters, and wind-induced mixing. Peak solar radiation occurred in June; however, peak water temperatures were observed in late summer. This resistance to warming is due to the high specific heat of water and to the relatively low surface area to volume ratio of the water mass. Tributary inflows are usually more reflective of ambient air temperatures than is the main lake, causing them to warm the nearshore waters in spring and cool them in late fall. Wind energy inputs induce thorough mixing of shallow zone waters resulting in occasional upwelling and sinking of thermally distinct water masses (14). The presence of a thermal bar during spring in the Douglas Point area has been documented by Rodgers (16).

TRANSPARENCY

Materials in suspension influence water clarity by reducing the depth of light penetration and depth of the photic zone in a lake. A Secchi disc is used to measure the depth to which direct sunlight or the diffusive skylight penetrates water. The depth of light penetration to 1% of the incident light level was assumed to be twice the Secchi depth in Lake Huron during present nearshore studies.

A comparison of water clarity (Secchi depth) among all nearshore areas is made in Figure 4.1-4. Except for segments A and B, all areas showed high Secchi readings (4 to 10 m). Low Secchi depths (0.1 to 5 m) and moderately high turbidities (2 to 16 FTU) in segments A and B reflect the influence of suspended particulate matter rather than the presence of a biomass. High suspended solids in segments A and B were associated with spring tributary drainage and locally derived particulate matter that was intermittently resuspended by wave action and strong currents.

CHEMICAL LIMNOLOGY

NUTRIENTS AND CHLOROPHYLL *a*

TOTAL PHOSPHORUS

The mean annual total phosphorus level was usually <0.02 mg P/ℓ in all nearshore segments (Figure 4.1-5). The lowest values were observed in segment G in spring, fall, and on an annual basis. Segments A and B had the highest mean annual levels of total phosphorus followed by F, C, I, E, and G in decreasing order. Greatest spatial variations in total phosphorus were noted in segments A and B which is attributed to coastal erosion and tributary drainage.

TOTAL NITROGEN

Annual mean total nitrogen concentrations in segments A to I ranged from 0.356 to 0.647 mg N/ℓ (Figure 4.1-6). These levels ranged from

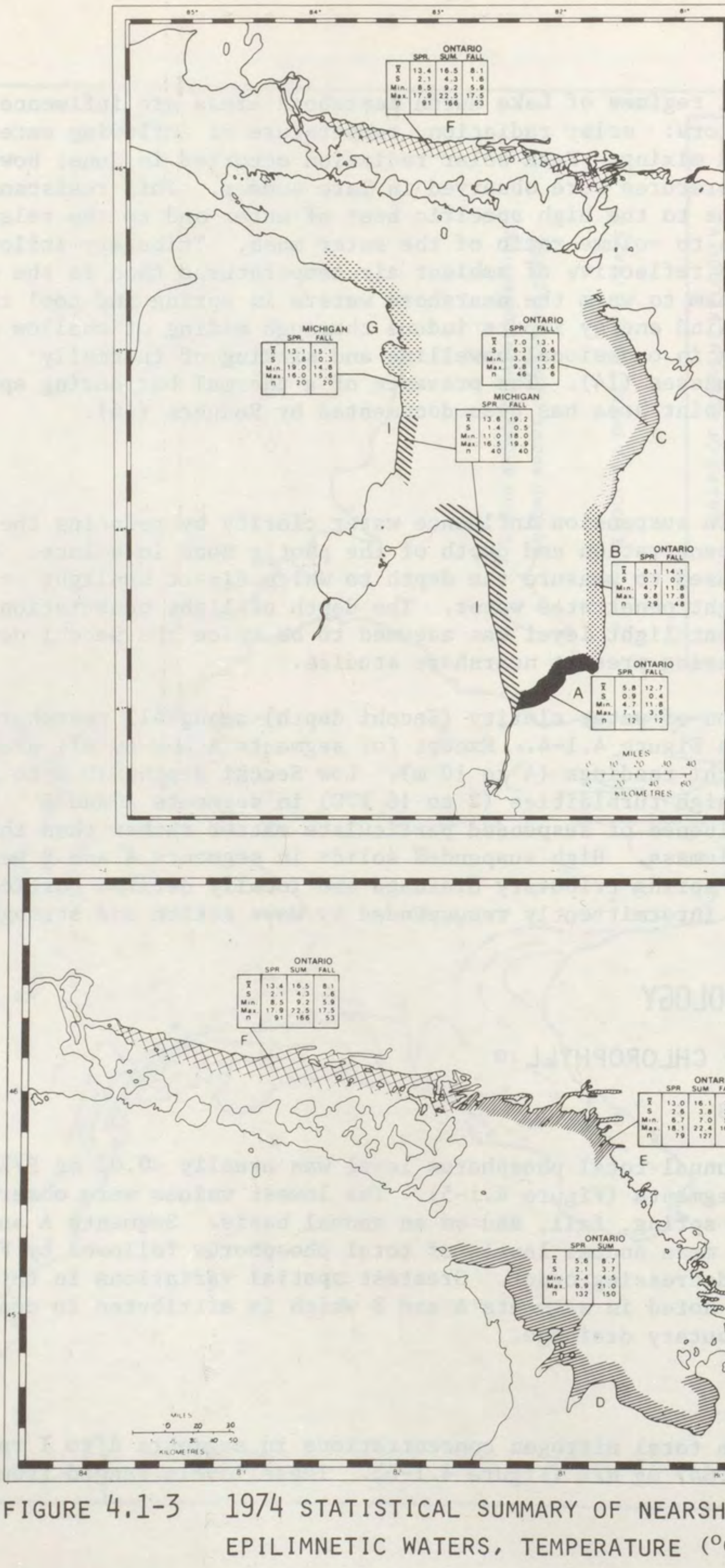


FIGURE 4.1-3 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, TEMPERATURE (°C).

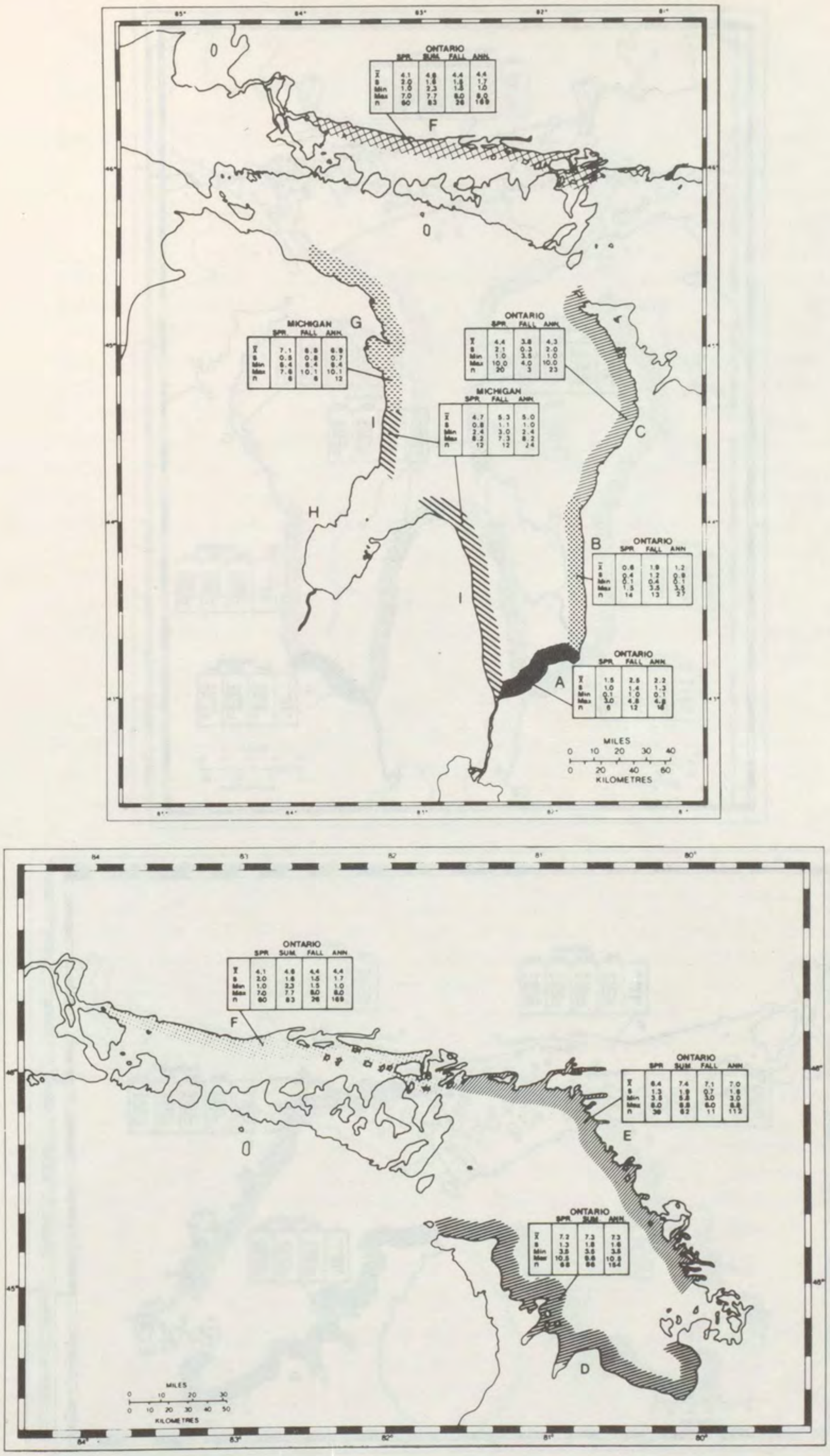


FIGURE 4.1-4 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, SECCHI DEPTH (metres).

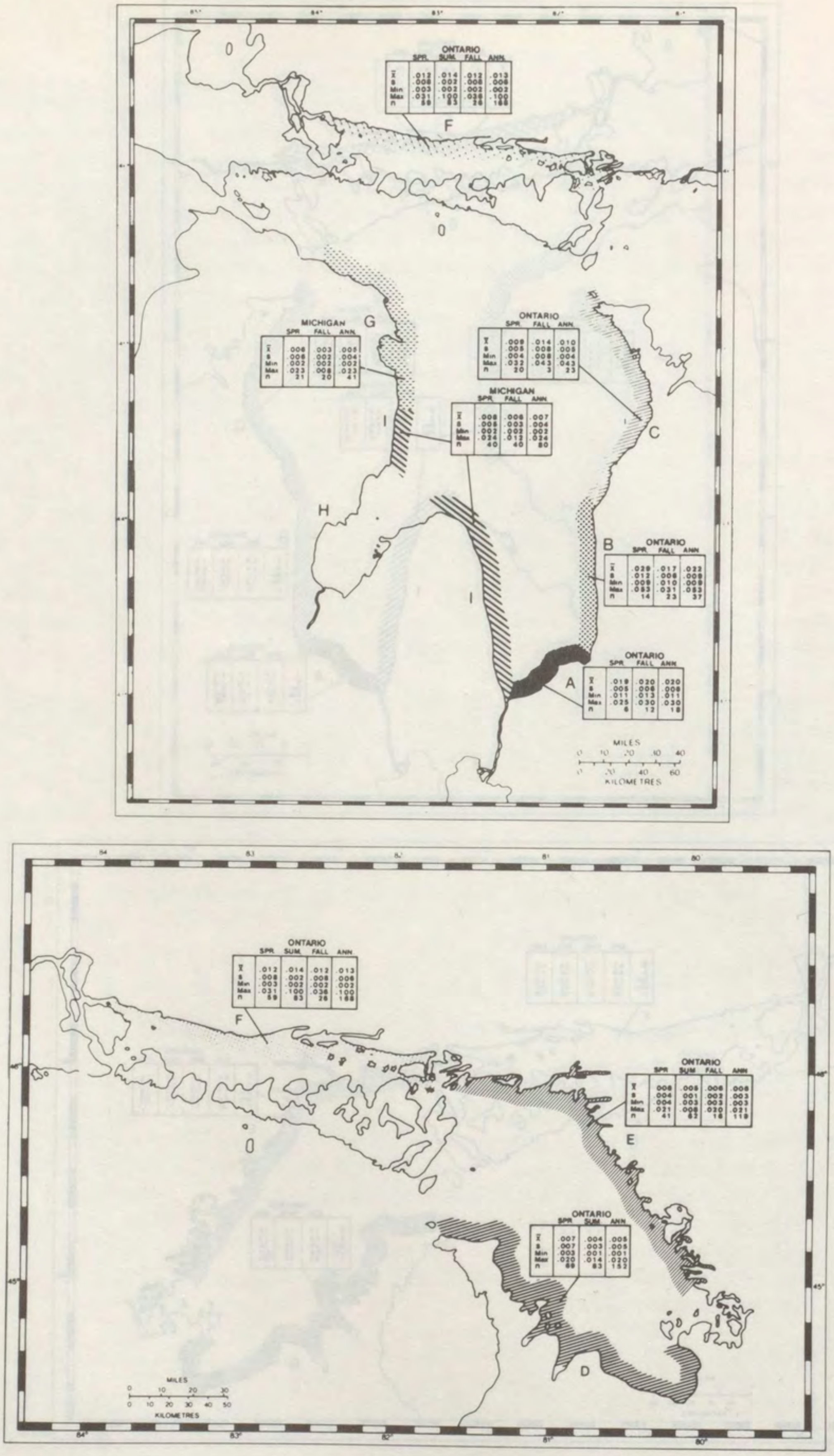
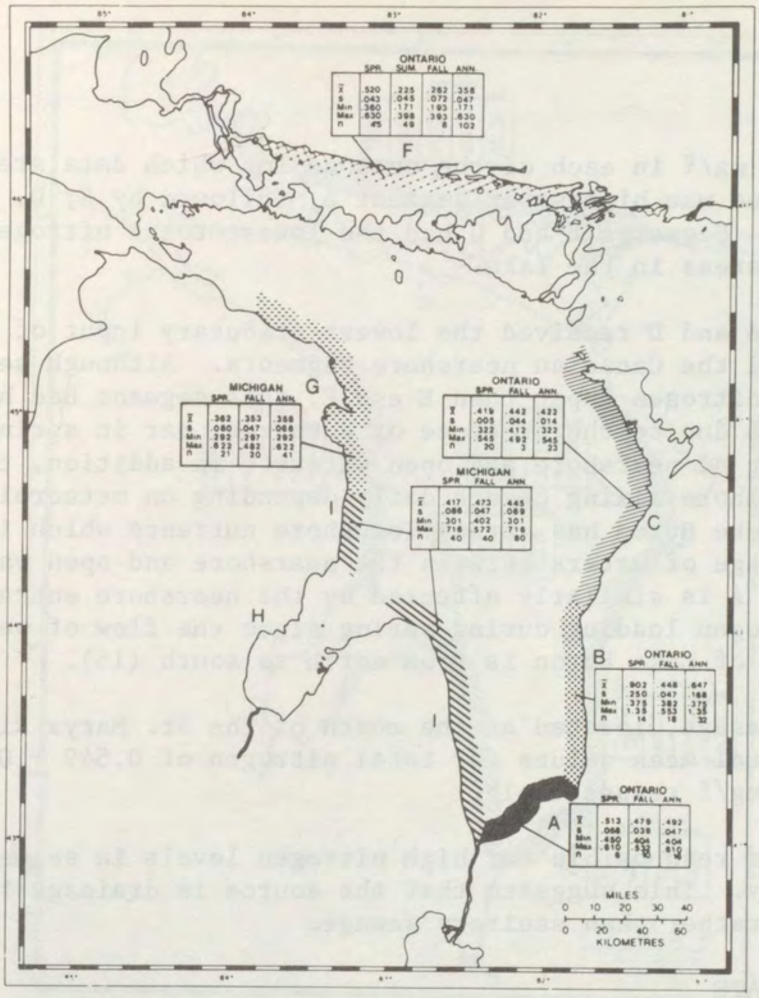


FIGURE 4.1-5 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, TOTAL PHOSPHORUS (mg P/ℓ).



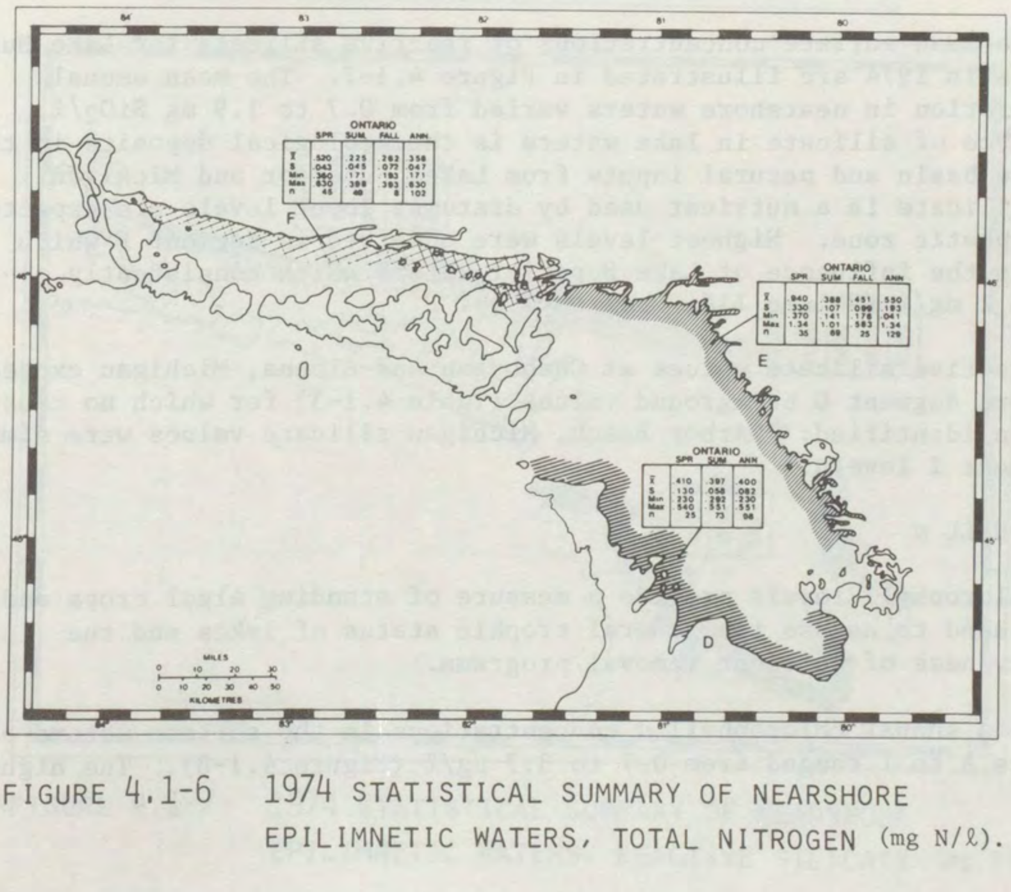


FIGURE 4.1-6 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, TOTAL NITROGEN (mg N/ℓ).

0.225 to 0.940 mg/ℓ in each of the seasons for which data are available. The annual value was highest in segment B, followed by E, D, A, I, and C in that order. Segments F and G had the lowest total nitrogen levels of all nearshore areas in the lake.

Segments A and D received the lowest tributary input of total nitrogen of all the Canadian nearshore segments. Although segment B received less nitrogen input than E and F, this segment had higher total nitrogen levels due to the presence of a thermal bar in spring which inhibits mixing of nearshore and open waters. In addition, the characteristics of nearshore mixing change daily depending on meteorological conditions. Lake Huron has strong longshore currents which interfere with the exchange of waters between the nearshore and open waters of the lake. Segment A is similarly affected by the nearshore entrapment of tributary nitrogen loading during spring since the flow of water along the east coast of Lake Huron is from north to south (15).

DeTour Passage, located at the mouth of the St. Marys River, had spring and annual mean values for total nitrogen of 0.549 ± 0.095 and 0.507 ± 0.087 mg/ℓ respectively.

Nitrate is responsible for high nitrogen levels in segments D and E in Georgian Bay. This suggests that the source is drainage from agricultural land rather than sanitary sewage.

REACTIVE SILICATE

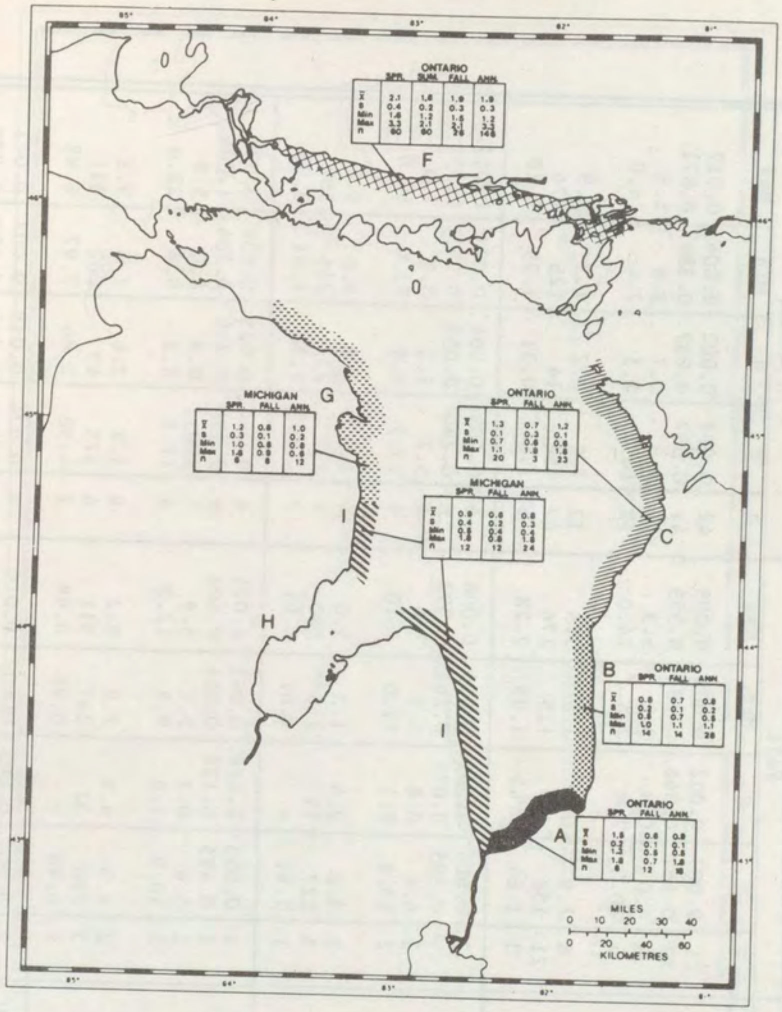
The mean surface concentrations of reactive silicate for Lake Huron segments in 1974 are illustrated in Figure 4.1-7. The mean annual concentration in nearshore waters varied from 0.7 to 1.9 mg SiO_2/ℓ. The source of silicate in lake waters is the geological deposits in the drainage basin and natural inputs from Lakes Superior and Michigan. Since silicate is a nutrient used by diatoms, lower levels are expected in the photic zone. Highest levels were observed in segment F which reflects the influence of Lake Superior waters which consistently average 2 mg/ℓ (Volume III, Chapter 4.1).

Reactive silicate values at Cheboygan and Alpena, Michigan exceeded nearshore segment G background values (Table 4.1-3) for which no cause has been identified. Harbor Beach, Michigan silicate values were similar to segment I levels.

CHLOROPHYLL *a*

Chlorophyll levels provide a measure of standing algal crops and can be used to assess the general trophic status of lakes and the effectiveness of nutrient removal programs.

Mean annual chlorophyll *a* concentrations in the surface waters of segments A to I ranged from 0.7 to 3.7 µg/ℓ (Figure 4.1-8). The highest



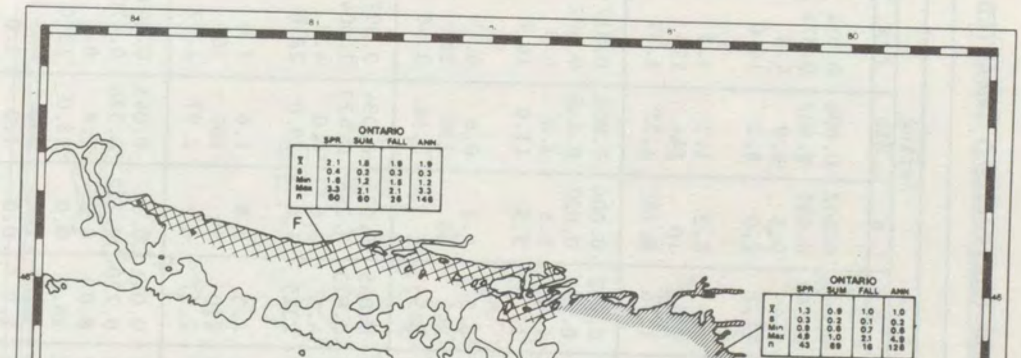
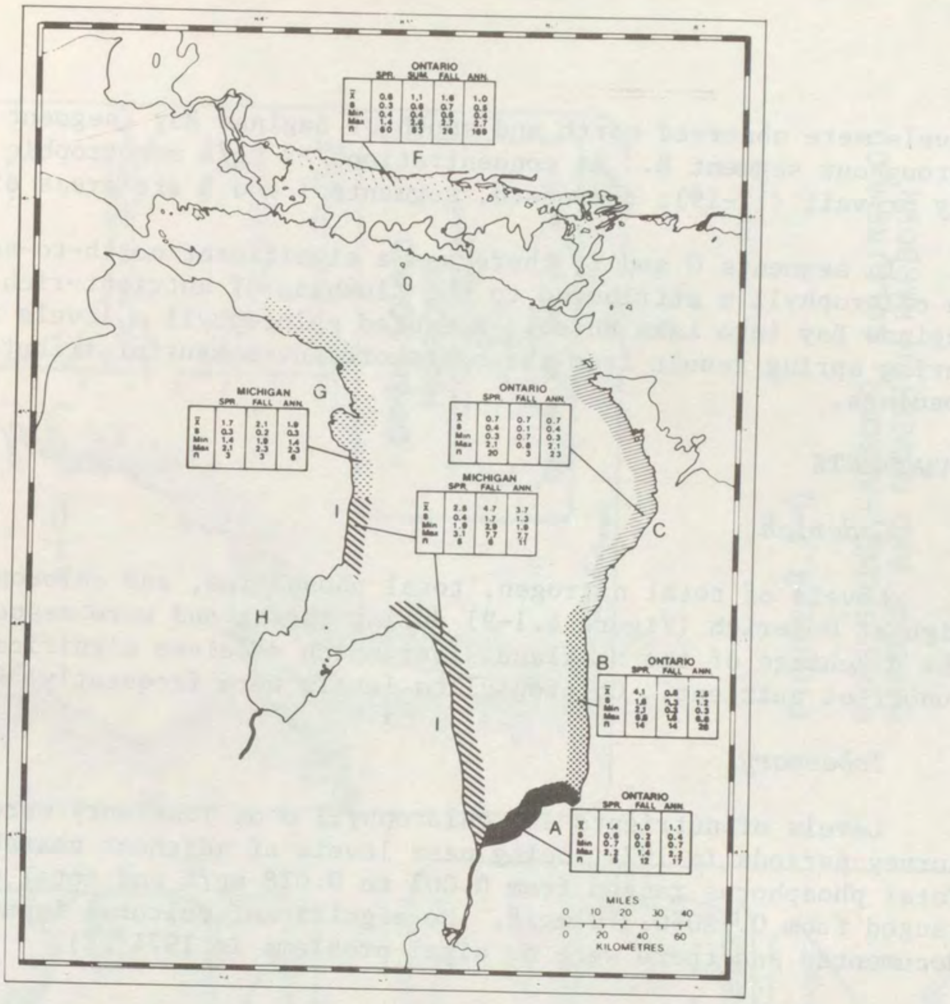


FIGURE 4.1-7 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, REACTIVE SILICATE (mg SiO_2/ℓ).

TABLE 4.1-3

Seasonal Values for Control and Impacted Areas in Lake Huron Michigan Waters

Area	Parameter	Units	SEASONAL VALUES														
			Spring					Fall					Annual				
			n	$\overline{x}$	s	Min	Max	n	$\overline{x}$	s	Min	Max	n	$\overline{x}$	s	Min	Max
DeTour (Control)	Total P (P)	mg/ℓ	21	0.007	0.002	0.004	0.012	21	0.007	0.002	0.005	0.009	42	0.007	0.002	0.004	0.012
	Total N (N)	mg/ℓ	21	0.549	0.095	0.402	0.871	20	0.462	0.046	0.384	0.553	41	0.507	0.087	0.384	0.871
	Chloride (Cl^-)	mg/ℓ	6	3.6	0.5	2.9	4.3	6	4.0	0.8	3.2	5.3	12	3.8	0.7	2.9	5.3
	Sulphate (SO_4^{2-})	mg/ℓ	6	11.1	2.0	8.3	14.0	6	10.3	2.8	7.4	14.0	12	10.7	2.5	7.4	14.0
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	6	1.5	0.2	1.3	1.8	6	1.8	0.1	1.6	1.9	12	1.6	0.2	1.3	1.9
	Conductivity	µS/cm	21	155	10	144	175	21	152	17	125	176	42	154	14	125	176
	Chlorophyll *a*	µg/ℓ	3	1.76	0.18	1.55	1.89	3	1.86	0.45	1.39	2.28	6	1.81	0.31	1.39	2.28
Cheboygan	Total P (P)	mg/ℓ	3	0.012	0.004	0.008	0.017	3	0.006	0.001	0.005	0.008	6	0.009	0.004	0.005	0.017
	Total N (N)	mg/ℓ	3	0.274	0.027	0.248	0.302	3	0.305	0.075	0.262	0.392	6	0.290	0.053	0.248	0.392
	Chloride (Cl^-)	mg/ℓ	2	4.9	1.6	3.8	6.0	2	6.4	0.8	5.8	7.0	4	5.7	1.3	3.8	7.0
	Sulphate (SO_4^{2-})	mg/ℓ	2	13.5	3.5	11.0	16.0	2	13.5	2.1	12.0	15.0	4	13.5	2.4	11.0	16.0
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	3.5	4.1	0.6	6.4	2	3.2	2.6	1.3	5.0	4	3.3	2.8	0.6	6.4
	Conductivity	µS/cm	3	248	30	230	282	3	227	12	216	240	6	237	23	216	282
	Chlorophyll *a*	µg/ℓ	1	3.56	-	3.56	3.56	1	1.61	-	1.61	1.61	2	2.59	1.38	1.61	3.56
Alpena	Total P (P)	mg/ℓ	3	0.055	0.035	0.034	0.097	3	0.053	0.018	0.041	0.074	6	0.054	0.025	0.034	0.097
	Total N (N)	mg/ℓ	3	0.673	0.288	0.473	1.004	3	0.485	0.118	0.364	0.601	6	0.496	0.298	0.364	1.004
	Chloride (Cl^-)	mg/ℓ	2	4.5	0.6	4.0	4.9	2	5.6	0.5	5.2	5.9	4	5.0	0.8	4.0	5.9
	Sulphate (SO_4^{2-})	mg/ℓ	2	23.5	6.4	19.0	28.0	2	10.9	1.6	9.8	12.0	4	17.2	8.2	9.8	28.0
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	4.3	3.8	1.6	7.0	2	6.0	4.5	2.8	9.2	4	5.2	3.6	1.6	9.2
	Conductivity	µS/cm	3	270	59	202	308	3	280	32	247	311	6	275	43	202	311
	Chlorophyll *a*	µg/ℓ	1	2.97	-	2.97	2.97	1	6.98	-	6.98	6.98	2	4.98	2.84	2.97	6.98
Harbor Beach	Total P (P)	mg/ℓ	2	0.041	0.0	0.041	0.041	2	0.008	0.002	0.007	0.010	4	0.024	0.018	0.007	0.041
	Total N (N)	mg/ℓ	2	0.720	0.212	0.570	0.870	2	0.382	0.001	0.382	0.383	4	0.551	0.230	0.382	0.870
	Chloride (Cl^-)	mg/ℓ	2	8.0	0.2	7.8	8.1	2	6.7	0.4	6.4	6.9	4	7.3	0.8	6.4	8.1
	Sulphate (SO_4^{2-})	mg/ℓ	2	18.0	0.0	18.0	18.0	2	16.0	0.0	16.0	16.0	4	17.0	1.2	16.0	18.0
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	1.0	0.0	1.0	1.0	2	0.6	0.1	0.5	0.6	4	0.8	0.3	0.5	1.0
	Conductivity	µS/cm	2	213	4	210	215	2	195	3	193	197	4	203	10	193	215
	Chlorophyll *a*	µg/ℓ	1	6.42	-	6.42	6.42	2	8.21	1.79	6.94	9.47	3	7.61	1.63	6.42	9.47



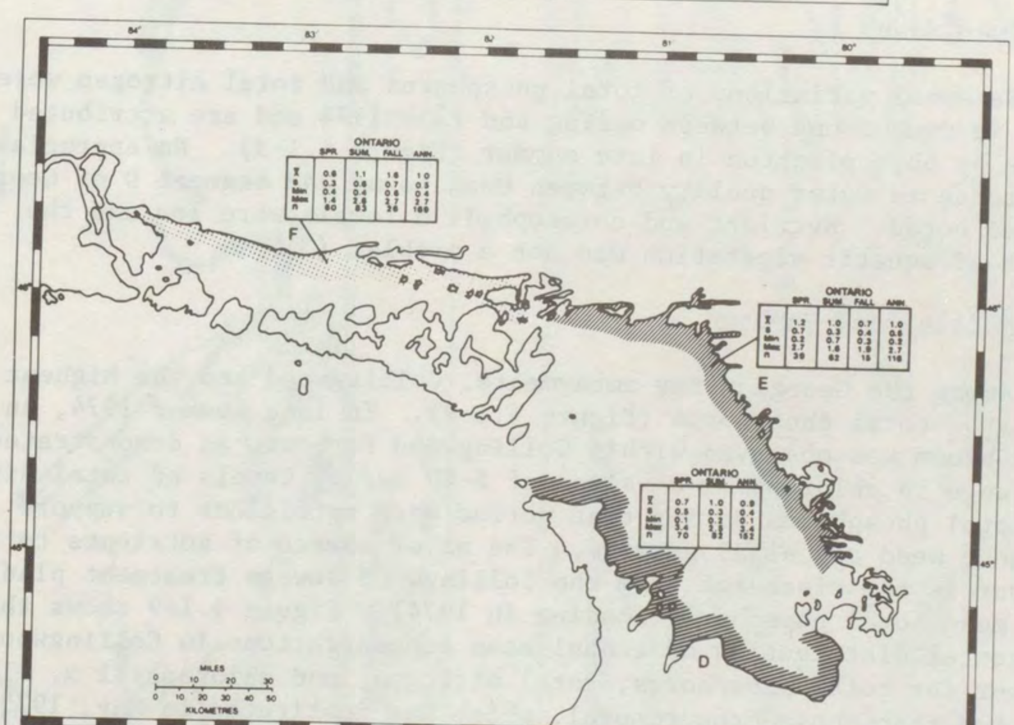


FIGURE 4.1-8 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, CHLOROPHYLL α (μg/ℓ).

levels were observed north and south of Saginaw Bay (segment I) and throughout segment B. At concentrations >2 μg/ℓ mesotrophic conditions may prevail (17-19); therefore, segments I and B are areas of concern.

In segments G and I, there was a significant north-to-south increase in chlorophyll α attributed to the flushing of nutrient-rich waters from Saginaw Bay into Lake Huron. Elevated chlorophyll α levels in segment B during spring result from the nearshore entrapment of tributary nutrient loadings.

EMBAYMENTS

Goderich

Levels of total nitrogen, total phosphorus, and chlorophyll *a* were high at Goderich (Figure 4.1-9) during spring and were associated with the discharge of the Maitland River which receives significant spring runoff of nutrient. Chlorophyll α levels were frequently >2 μg/ℓ (3).

Tobermory

Levels of nutrients and chlorophyll α at Tobermory were low for survey periods in 1974, being near levels of adjacent nearshore waters. Total phosphorus ranged from 0.002 to 0.018 mg/ℓ and total nitrogen ranged from 0.120-0.372 mg/ℓ. No significant cultural inputs were documented and there were no algal problems in 1974 (3).

Owen Sound

Seasonal variations of total phosphorus and total nitrogen were noted in Owen Sound between spring and fall 1974 and are attributed to uptake by phytoplankton in late summer (Figure 4.1-9). No appreciable difference in water quality between Owen Sound and segment D of Georgian Bay was noted. Nutrient and chlorophyll α levels were low and the growth of aquatic vegetation was not a problem (3).

Collingwood Harbour

Among the Georgian Bay embayments, Collingwood had the highest levels of total phosphorus (Figure 4.1-9). In late summer 1974, an algal bloom was observed within Collingwood Harbour, as demonstrated by the range in chlorophyll α values of 8-29 μg/ℓ. Levels of total nitrogen and total phosphorus during that period were sufficient to support nuisance weed and algal growths. The major source of nutrients to the harbour is the discharge from the Collingwood sewage treatment plant (70 kg/d mean total phosphorus loading in 1974). Figure 4.1-9 shows the horizontal distribution of annual mean concentrations in Collingwood Harbour for total phosphorus, total nitrogen, and chlorophyll α. It is expected that phosphorus removal, which was instituted in May, 1975 will effect a reduction in nuisance algal and aquatic plant growths within the harbour (3).

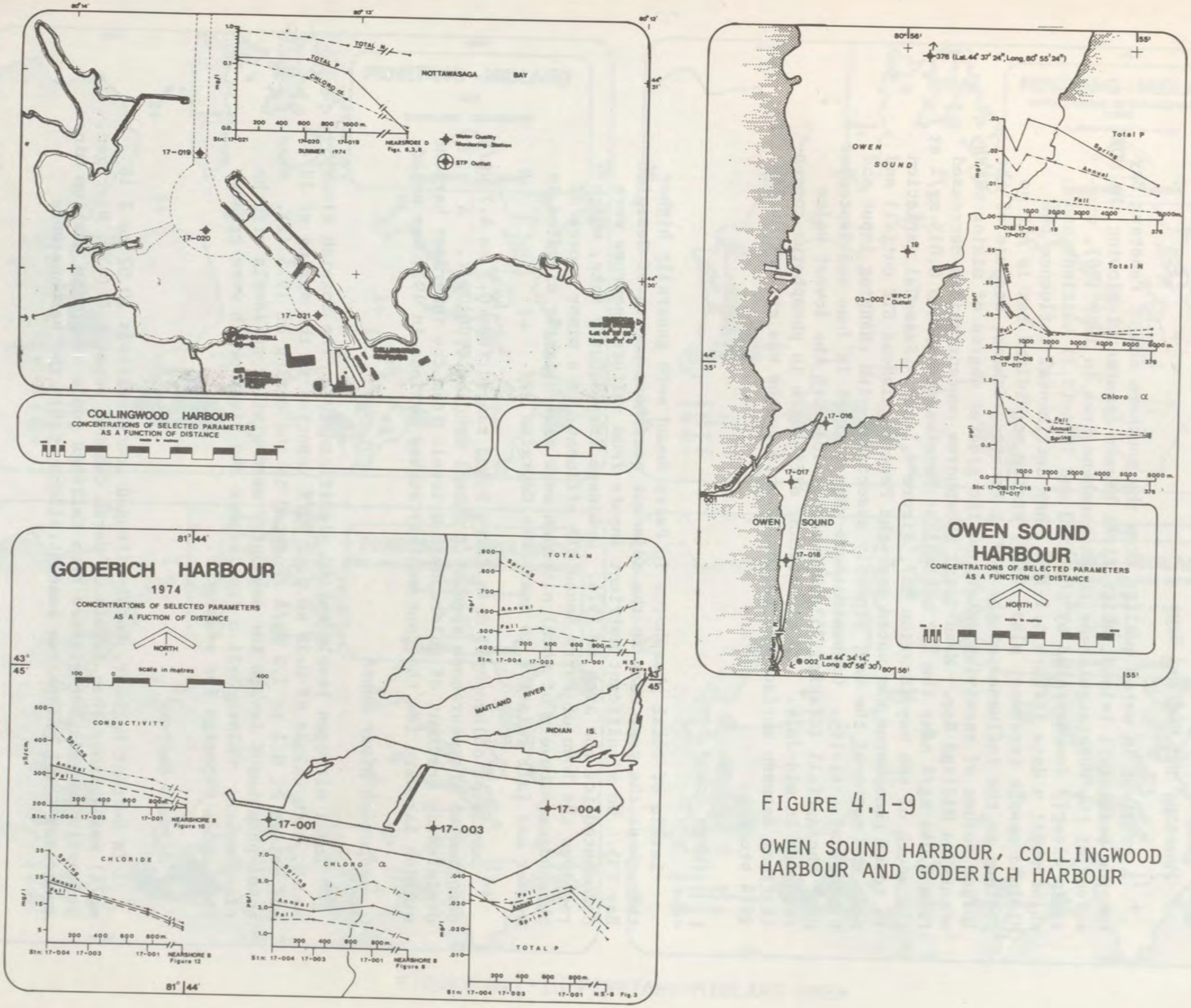


FIGURE 4.1-9

OWEN SOUND HARBOUR, COLLINGWOOD HARBOUR AND GODERICH HARBOUR

Penetang and Midland Bays

A gradient in water quality from the southern end of Penetang Bay towards Beausoleil Island, which first became apparent following the MOE survey of the Penetanguishene to Waubaushene area in 1969 (20), was again clearly demonstrated by the 1973 and 1974 (5,7) nutrient and chlorophyll α data (Figure 4.1-10). Any detrimental influence the Midland sewage treatment plant (STP) exerts on Midland Bay is not so obvious as the influence of the STP at Penetanguishene, because of the larger volume of receiving water and the greater degree of mixing which occurs in Midland Bay. Mean total phosphorus concentrations decreased from 0.044 mg/ℓ near the STP outfall at Penetanguishene to 0.015 mg/ℓ at the mouth of the bay (Station 357, Figure 4.1-10). Seasonal variation in total phosphorus was noted near the Penetanguishene STP outfall and near the mouth of the bay, probably associated with changing input and biological activity. Concentrations were highest in June and September near the outfall (Station 353, Figure 4.1-10) with the lowest value recorded in mid-July. No significant difference in phosphorus concentrations between surface and bottom sample depths was evident during 1974 studies.

Parry Sound

Levels of total phosphorus in Parry Sound were generally higher throughout the year than in the adjacent nearshore waters of Georgian Bay (3). No significant nutrient inputs from cultural sources were documented for the area in 1974. Drainage from McCurry Lake, which receives the Town of Parry Sound STP effluent, is a minor source of phosphorus. Levels of total nitrogen were also slightly elevated in summer and fall relative to nearshore Georgian Bay.

Levels of chlorophyll α in Parry Sound ranged from 0.5 to 4.7 μg/ℓ compared to the nearshore segment E annual mean of 0.96 μg/ℓ. A diminishing gradient of chlorophyll α levels from the innermost harbour station lakeward for the four monthly survey periods in 1974 was noted.

Spanish River Mouth

Total nitrogen levels varied significantly at the Spanish River mouth, with values of 0.38 to 0.62 mg/ℓ reported in the spring of 1974 and values of 0.1 to 1.0 mg/ℓ reported in the spring of 1975 (2). Mean total phosphorus levels for segment F were similar to levels off the river mouth. Chlorophyll α levels near the river mouth were greater than those reported for segment F.

Serpent Harbour

In Serpent Harbour, total nitrogen concentrations (0.52 to 2.10 mg/ℓ) were higher than levels of North Channel segment F (4). Nitrogen, primarily ammonia, originates from tailings ponds at active uranium mines upstream. Total phosphorus concentrations within the harbour were

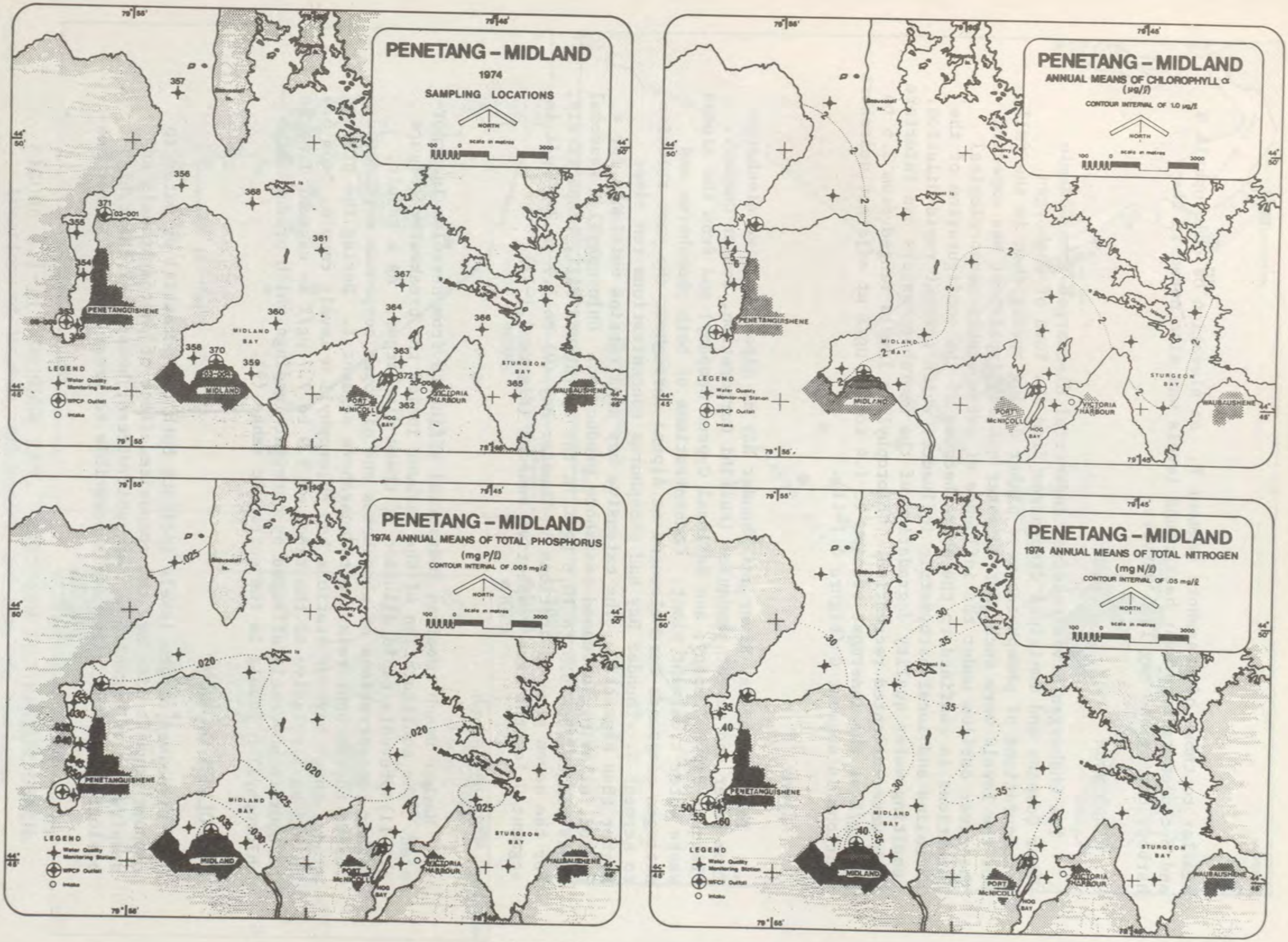


FIGURE 4.1-10 PENETANG-MIDLAND AREA

similar to those of nearshore segment F. An elevation of chlorophyll α and β concentrations over background levels was also noted in the harbour during the May 1975 survey.

Cheboygan

The Cheboygan River receives industrial discharges from Charmin Paper Company and municipal discharges from the Town of Cheboygan. Concentrations of phosphorus were higher during spring than in the fall, but the levels were such that no water quality impairment was expected. The river outflow under the influence of unfavourable meteorological conditions is confined to the shore because of the configuration of the shoreline and local bathymetric influences which prevent rapid dilution. Resulting water quality degradation of the nearshore waters can interfere with water-oriented recreation. Chlorophyll α levels ranged from 1.6 to 3.5 µg/ℓ at the innermost station to 1.4 to 2.3 µg/ℓ at adjacent nearshore stations in segment G (Figure 4.1-11).

Alpena

The Thunder Bay River and Thunder Bay at Alpena receive discharges from paper and cement companies (Abitibi Corporation, Besser Company, Fletcher Paper Company, and National Gypsum Company) and from the Alpena waste water treatment plant. Concentrations of both phosphorus and nitrogen compounds were elevated at Alpena throughout the year relative to segment G. Thunder Bay had phosphorus concentrations ten times higher than segment G. The extensive bay area retains nutrients for a period, allowing increased nearshore production. Chlorophyll α seasonal means ranged from 6.5 to 10.6 µg/ℓ in the spring and fall, respectively, for the seven grouped stations in Thunder Bay (9) to 1.7 to 2.1 µg/ℓ in segment G for the same respective seasons (Figure 4.1-11).

Harbor Beach

Harbor Beach receives industrial effluents from Hercules Incorporated. The configuration of the harbour inside the breakwater (Figure 4.1-11) prevents rapid dilution of these discharges. As a result, higher concentrations of phosphorus and nitrogen compounds were noted inside the harbour relative to nearshore segment I. During the present study, inner harbour stations had chlorophyll α levels ranging from 6.4 to 9.5 µg/ℓ relative to the range of 1.9 to 7.7 µg/ℓ in segment I. The harbour is adversely affected by nutrient loadings which produce high chlorophyll α levels in the eutrophic range (9).

DISSOLVED OXYGEN

Dissolved oxygen levels indicate both the potential of water to support aquatic life and the composite effect of photosynthesis and respiration of organisms. Eutrophic waters, because of their high biological productivity, are susceptible to great diurnal and/or sea-

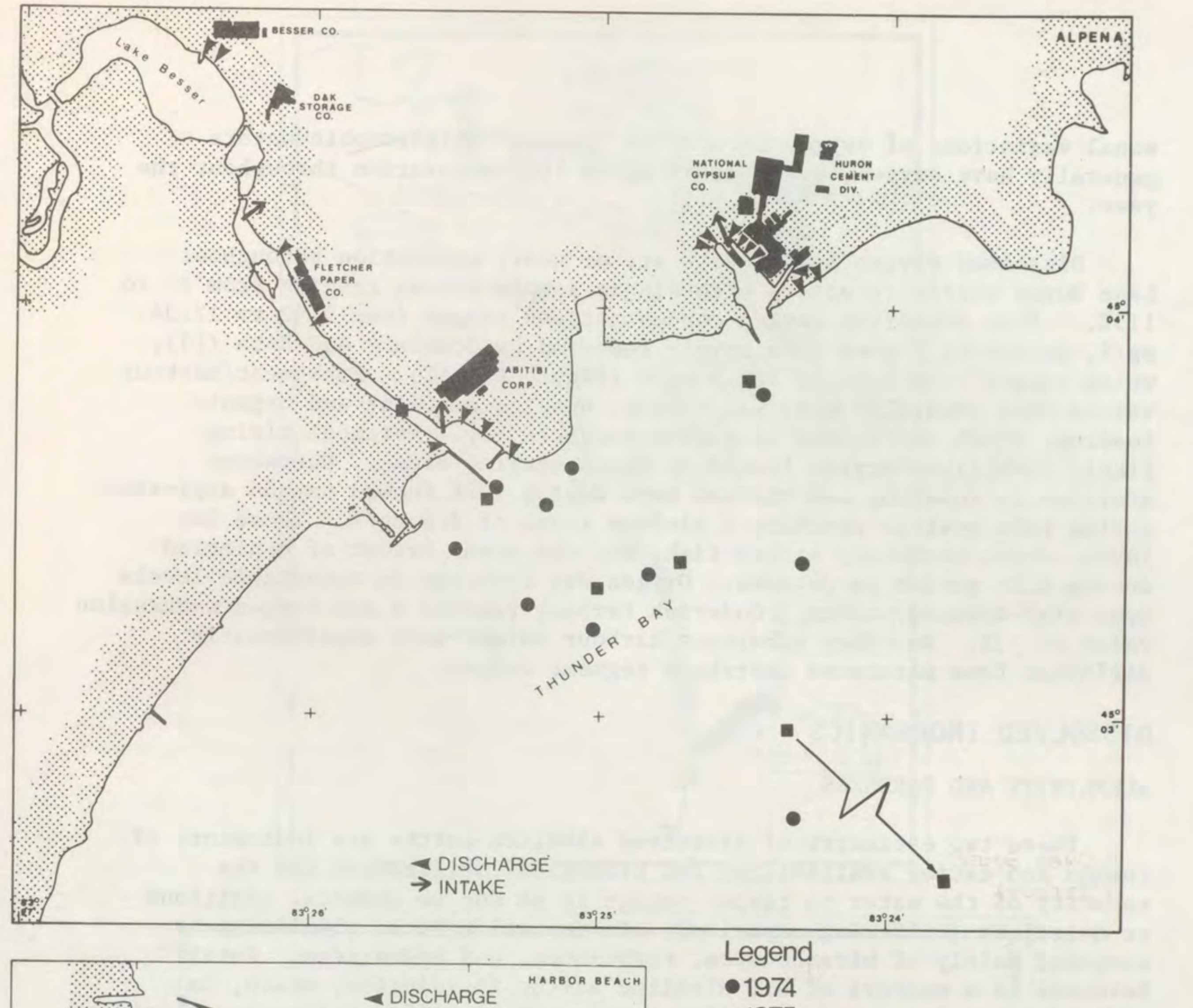


FIGURE 4.1-11 THUNDER BAY, CHEBOYGAN AND HARBOR BEACH.
Locations of intakes, discharges, and sampling stations.

sonal variations of oxygen saturation levels. Oligotrophic waters generally have oxygen levels at or above 100% saturation throughout the year.

Dissolved oxygen levels were at, or near, saturation throughout Lake Huron nearshore waters with single sample values ranging from 80 to 115%. Mean dissolved oxygen concentrations ranged from 9.92 to 12.34 mg/ℓ, generally higher than levels reported by Schelske and Roth (13), which ranged from 9.53 to 10.70 mg/ℓ (Figure 4.1-12). Embayment/harbour values were generally near saturation, despite nutrient and organic loadings which contribute to higher productivity. Vertical mixing likely stabilized oxygen levels in these shallow areas. Deepwater stations in Penetang and Midland Bays during 1974 showed oxygen depletion during calm weather reaching a minimum level of 2.6 mg/ℓ. These low levels would certainly stress fish, but the areal extent of depletion during this period is unknown. Oxygen was restored to acceptable levels upon wind-induced mixing. Goderich Harbour reached a low oxygen saturation value of 73%. No other embayment/harbour values were significantly different from saturated nearshore segment values.

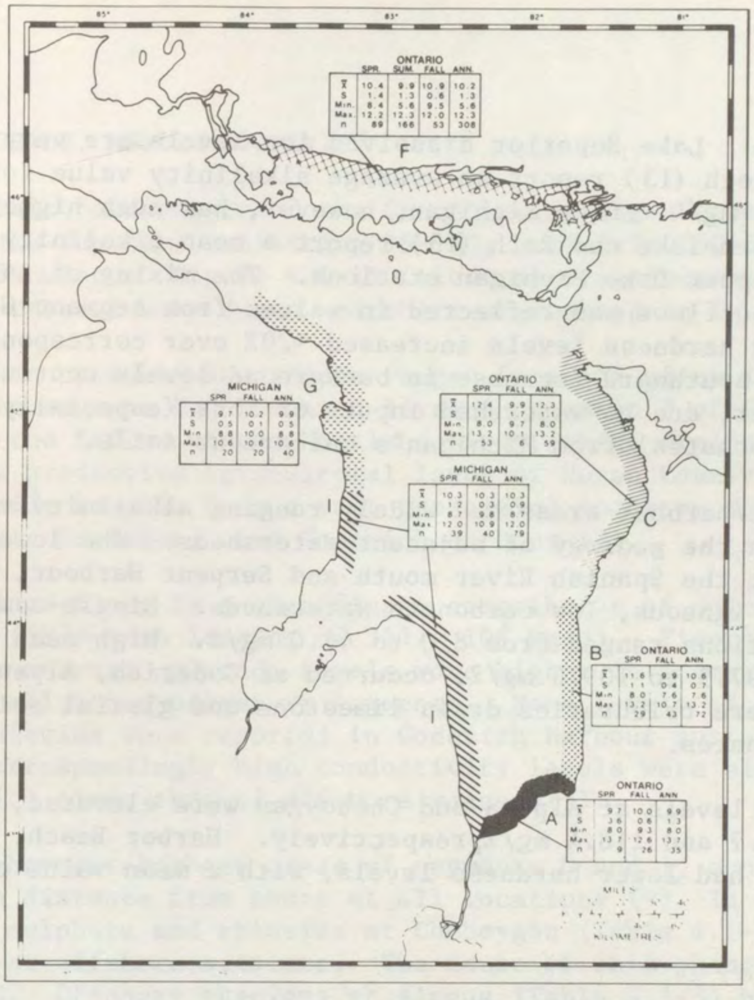
DISSOLVED INORGANICS

ALKALINITY AND HARDNESS

These two estimates of dissolved alkaline earths are indicators of carbon and cation availability for biological utilization and the capacity of the water to resist change in pH due to chemical additions or deletions (buffering capacity). In natural waters, alkalinity is composed mainly of bicarbonates, carbonates, and hydroxides. Total hardness is a measure of all alkaline earths in solution, which, in addition to calcium and magnesium carbonates, includes sulfates, chlorides, and other salts. Soil and bedrock are sources of these ions in natural waters. Igneous rock formations release small amounts of alkaline earths, while sedimentary formations and glacial-derived soils are very rich sources. Lake Superior receives very small amounts of alkaline earths from its igneous watershed (13). Lake Huron's watershed is largely composed of limestone, dolomite, and glacial soils, a rich supply of alkaline earths to lake waters (1).

Alkalinity values in nearshore segments A to C were high, with annual means ranging from 91.5 to 102.1 mg $CaCO_3$/ℓ. These values were much higher than the open water lakewide mean of 78.6 mg/ℓ reported by Weiler and Chawla (22) and were related to watershed inputs of carbonates. Segments D to F were lower in alkalinity, ranging from 62.6 to 78.0 mg/ℓ, but were quite variable, having both igneous and sedimentary drainage basin inputs.

DeTour Passage alkalinity and hardness values were the lowest for western Lake Huron coastal segments, 65 and 85 mg/ℓ, respectively. These low values reflect the movement of Lake Superior water through the



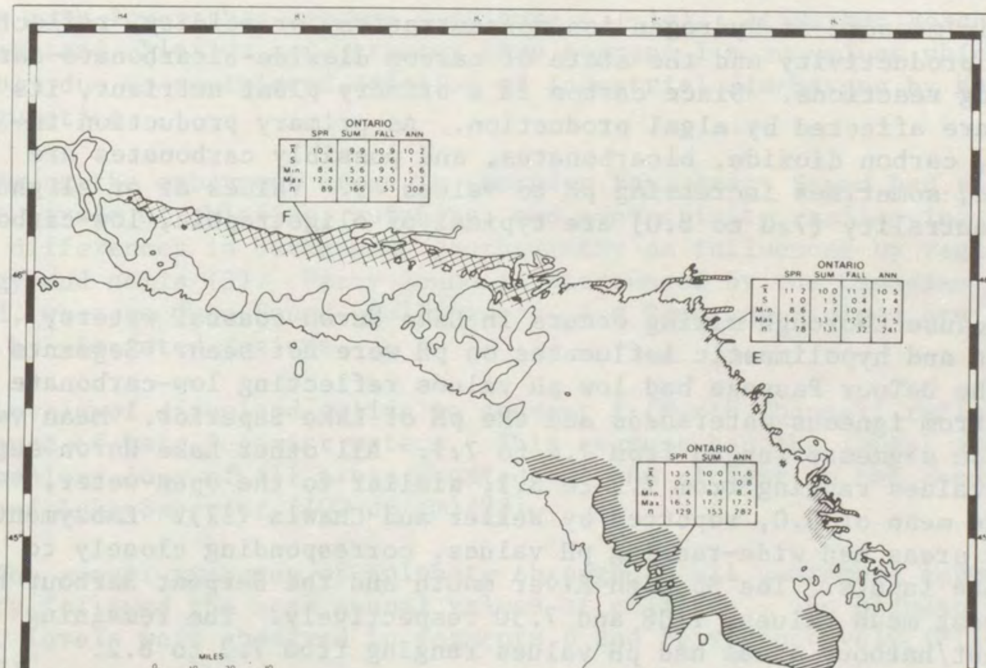


FIGURE 4.1-12 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, DISSOLVED OXYGEN (mg O_2/ℓ).

DeTour Passage. Lake Superior dissolved ion levels are very low; Schelske and Roth (13) report an average alkalinity value for Lake Superior of 44 mg/ℓ. Lake Michigan, however, has much higher dissolved ion levels. Schelske and Roth (13) report a mean alkalinity value of 109 mg/ℓ for upper Lake Michigan stations. The mixing of Lakes Michigan and Superior outflows was reflected in values from segment G, where alkalinity and hardness levels increased ∿20% over corresponding DeTour values. This southward increase in background levels continued to the St. Clair River, due to watershed inputs of ions (especially calcium and magnesium carbonates) from Michigan's calcareous soils.

Embayment/harbour areas had widely ranging alkalinity values, dependent upon the geology of adjacent watersheds. The lowest reported levels were at the Spanish River mouth and Serpent Harbour, which are influenced by igneous, low carbonate watersheds. Single-sample values at these locations ranged from 8.0 to 44.0 mg/ℓ. High mean values ranging from 97.9 to 109.6 mg/ℓ, occurred at Goderich, Alpena, and Cheboygan, where tributaries drain limestone and glacial soil regions, rich in carbonates.

Hardness levels at Alpena and Cheboygan were elevated, with mean values of 116.7 and 118.4 mg/ℓ, respectively. Harbor Beach, which has no river inflow, had lower hardness levels, with a mean value of 103.0 mg/ℓ.

pH

This measure of hydrogen ion concentration, or acidity, reflects primary productivity and the state of carbon dioxide-bicarbonate-carbonate buffering reactions. Since carbon is a primary plant nutrient, its levels are affected by algal production. As primary production increases, carbon dioxide, bicarbonates, and possibly carbonates are consumed, sometimes increasing pH to values >9. Values at or slightly above neutrality (7.0 to 8.0) are typical of oligotrophic, low-carbonate waters.

Because thorough mixing occurs in Lake Huron coastal waters, sediment and hypolimnetic influences on pH were not seen. Segments D to F and the DeTour Passage had low pH values reflecting low-carbonate inputs from igneous watersheds and the pH of Lake Superior. Mean values for these segments ranged from 7.4 to 7.7. All other Lake Huron segments had pH values ranging from 7.9 to 8.1, similar to the open-water, lakewide mean of 8.0, reported by Weiler and Chawla (22). Embayment/harbour areas had wide-ranging pH values, corresponding closely to carbonate inputs. The Spanish River mouth and the Serpent Harbour had the lowest mean values, 7.08 and 7.30 respectively. The remaining embayment/harbour areas had pH values ranging from 7.7 to 8.2.

SULPHATE, CHLORIDE, AND CONDUCTIVITY

The specific conductance of the Great Lakes ranges from 100 to 350 µS/cm, with Lake Superior exhibiting 95-100, Lake Erie 250-300, and Lake Ontario 325-350 µS/cm. Figure 4.1-13 illustrates conductivity levels in the surface waters of Lake Huron nearshore segments A to I.

Annual mean conductivity values ranged from 156 µS/cm in segment F to 227 µS/cm in segment B. The high level in segment B of Lake Huron is attributed to the inflow of the Maitland River, which drains a large portion of the productive agricultural lands of Huron County as well as carrying chloride loading from a salt processing industry (Domtar Chemicals Ltd., Sifto Salt Division) near Goderich Harbour (3).

The Maitland River is a significant contributor of chloride loading to Lake Huron (1973 mean loading of 347×10^3 kg/d). Figure 4.1-14 indicates that average chloride levels were higher in segment B (6.9 mg/ℓ) than in all other nearshore segments. Mean levels of 22.2 mg/ℓ and 17 mg/ℓ chloride were reported in Goderich Harbour during spring and fall 1974. Correspondingly high conductivity levels were also noted in the harbour (1.3 times that of offshore values)(3).

In the embayment/harbour areas of segments G and I, conductivity decreased with distance from shore at all locations (9). In contrast to conductivity, sulphate and chloride at Cheboygan (Table 4.1-3) showed higher levels at offshore stations. The cause of this phenomenon was not identified. Offshore stations at Alpena (Table 4.1-3) had chloride values much lower than segment G (Figure 4.1-14). At Harbor Beach, sulphate and chloride were greater than segment I mean values which is probably due to restricted dilution of industrial discharges by harbour configuration.

Among the embayment areas in Georgian Bay, Parry Sound had the lowest levels of chloride, sulphate, and conductivity, reflecting the major differences in background geochemistry as influenced by regional geology and soils (3). Parry Sound is surrounded by the Canadian Shield, whereas Owen Sound, Collingwood, and Penetang-Midland are influenced by glaciated regions.

Levels of dissolved solids in segment F (North Channel) reflect the influence of Lake Superior waters. This segment had the lowest amount of dissolved ions of all areas studied and was closest to the conductivity level of Lake Superior (100 µS/cm)(23).

The annual averages of sulphate throughout all nearshore segments closely followed the mean annual values of chloride. The highest and lowest levels were observed in segments B and F, respectively (Figure 4.1-15).

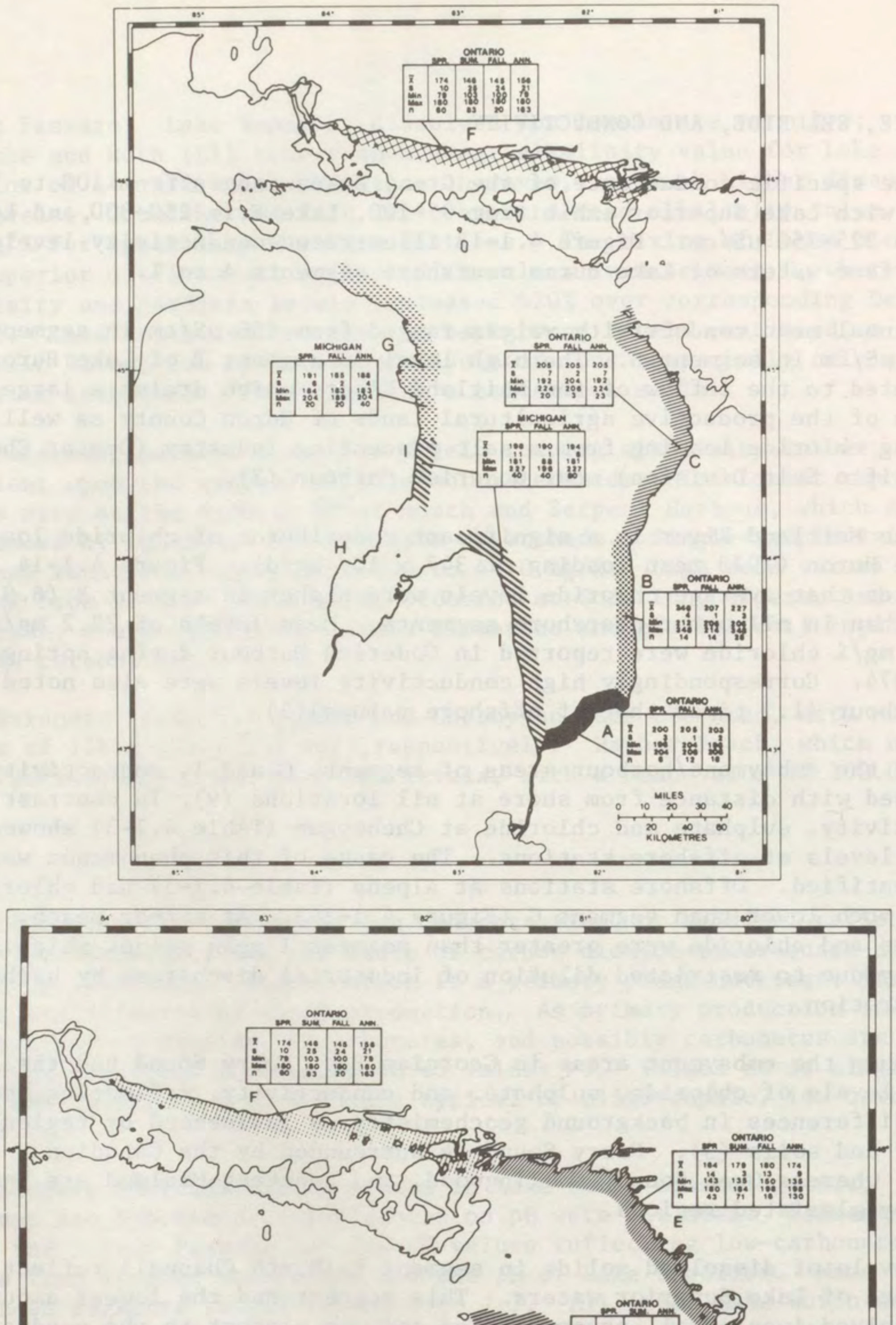


FIGURE 4.1-13 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, CONDUCTIVITY (μS/cm).

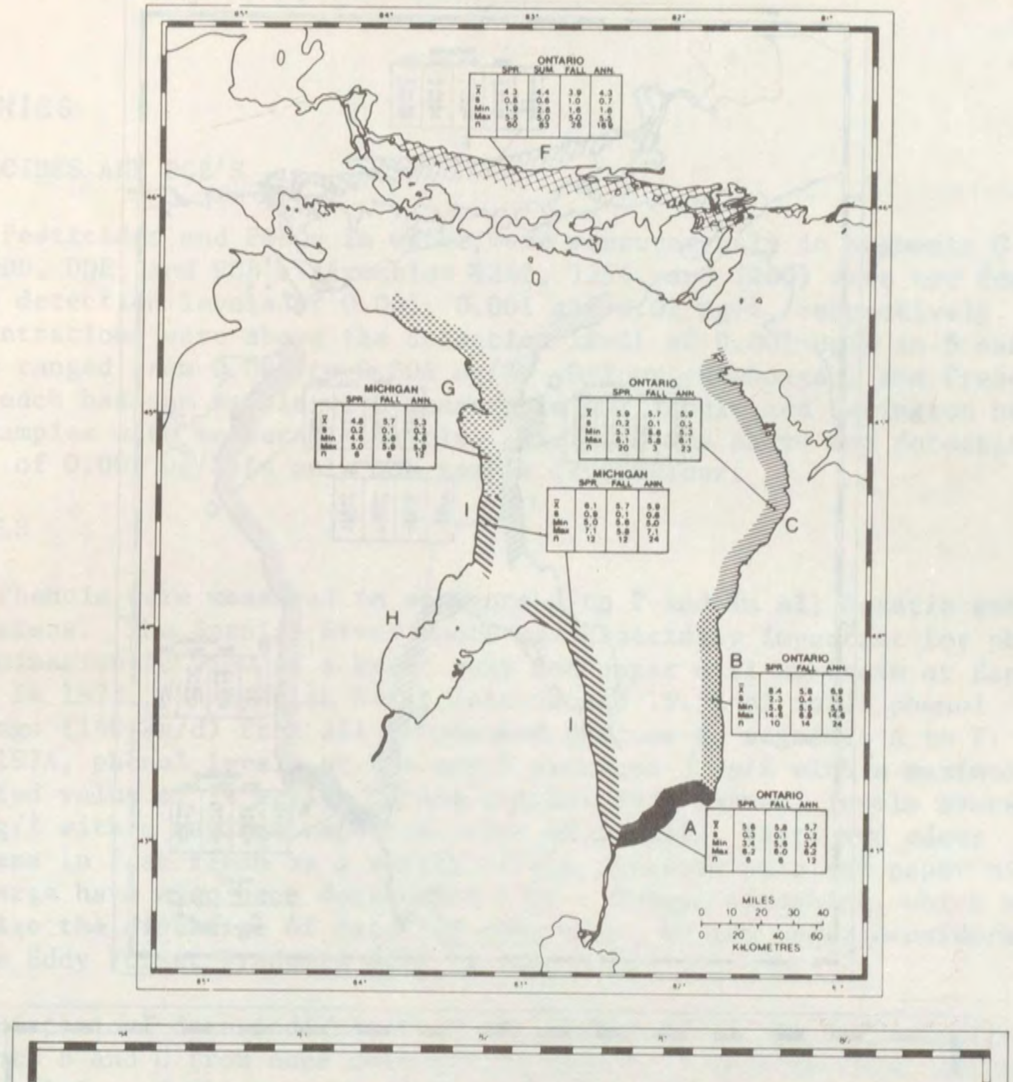


FIGURE 4.1-14 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, CHLORIDE (mg Cl/ℓ).

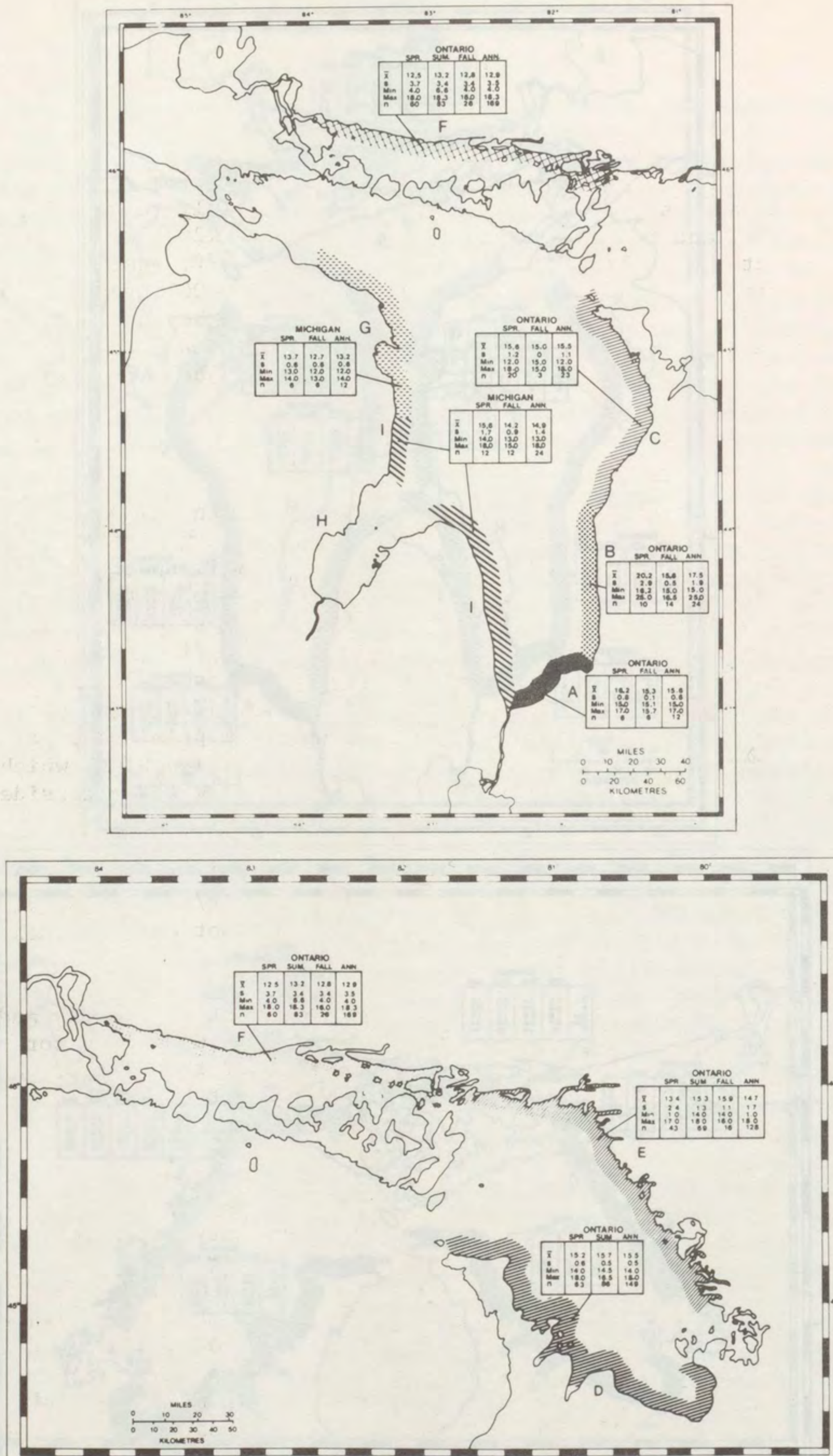


FIGURE 4.1-15 1974 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, SULPHATE (mg SO_4/ℓ).

ORGANICS

PESTICIDES AND PCB'S

Pesticides and PCB's in water were measured only in segments G and I. DDD, DDE, and PCB's (Arochlor 1242, 1254, and 1260) were not found above detection levels of 0.001, 0.001 and 0.01 μg/ℓ, respectively. DDT concentrations were above the detection limit of 0.001 μg/ℓ in 5 samples which ranged from 0.001 to 0.004 μg/ℓ. DeTour, Cheboygan, and Presque Isle each had one sample with measurable DDT levels and Lexington had two samples with measurable levels. Dieldrin was above the detection limit of 0.001 μg/ℓ in only one sample from DeTour.

PHENOLS

Phenols were measured in segments A to F and in all Ontario embayment areas. The Spanish River mouth was especially important for phenol determination in view of a kraft pulp and paper mill upstream at Espanola (2). In 1973, the Spanish River contributed 15.5% of total phenol loadings (140 kg/d) from all documented sources to segments A to F. In June 1974, phenol levels at the mouth averaged 3 μg/ℓ with a maximum reported value of 14 μg/ℓ. During the May 1975 survey, levels averaged 1.3 μg/ℓ with a maximum reported value of 2 μg/ℓ. Taste and odour problems in fish flesh as a result of the upstream pulp and paper mill discharge have also been documented (10). Oxygen bleaching, which would minimize the discharge of tainting compounds, is now under consideration at the Eddy Forest Products mill in Espanola.

Historical data indicate that the phenol level has increased in segments B and C from none detected in 1967 to 1 μg/ℓ in 1974, although the precision of the test at such low levels may not warrant such a conclusion.

Parry Sound had phenol levels within Agreement objectives and Ontario's domestic water supply criteria (Appendix C) except for two different occasions at a station near the mouth of the harbour where levels of 2 and 5 μg/ℓ were reported in 1974 (2 out of 13 samples) (3). No source of these levels has been identified.

RADIOACTIVITY

In general, the overall levels of radioactivity entering Serpent Harbour, as measured at Highway 17 on Serpent River (Table 4.1-4), have decreased since the late 1960's, e.g. ^{226}Ra, gross α, and gross β had averaged 9, 27, and 35 pCi/ℓ, respectively during the period 1966-70. During the period 1971-76, levels of ^{226}Ra, gross α, and gross β averaged 5.7, 16, and 19 pCi/ℓ, respectively. The reduction of radioactivity levels in water can be attributed to a decrease in mining activity, reuse of process waters, natural decreases in streamflows, and the use of barium chloride treatment.

TABLE 4.1-4

ANNUAL SUMMARIES FOR SERPENT HARBOUR, NORTH CHANNEL[a]

YEAR	^{226}Ra pCi/ℓ	GROSS α pCi/ℓ	GROSS β pCi/ℓ	^{238}U μg/ℓ
1966	11.7	40.3	29.3	10.0
1967	8.8	22.1	31.2	10.3
1968	8.8	33.8	35.5	10.0
1969	7.3	30.9	35.4	10.0
1970	8.7	32.9	38.9	10.1
1971	6.5	27.9	30.2	10.0
1972	5.7	14.6	22.4	10.0
1973	6.1	15.6	20.4	10.5
1974	5.5	13.2	13.5	10.0
1975	5.4	8.2	15.9	-
1976	5.3	15.0	14.3	<10.

a. From References (21) and (49).

During two 1975 surveys, ^{226}Ra levels >3 pCi/ℓ, the permissible criterion for surface water supply (Appendix C), were noted within Serpent Harbour. On May 30, 1975, an area within the harbour extending 5 km from Serpent River mouth had ^{226}Ra levels greater than the criterion. During the September 23, 1975 survey ^{226}Ra levels in excess of the criterion were noted for an area extending 2.7 km from the river mouth (4).

Radiological water sampling has been done off the Douglas Point nuclear reactor since 1967, at the same time as conventional water sampling. In general, the measured parameters at lake sampling points used have not indicated the presence of reactor waste products at measurable levels (Table 4.1-5). Elevated ^{3}H values recorded during July 1973 coincided with equipment malfunction at the station; see Chapter 6.11 for further discussion. Tritium releases, which account for the largest number of curies of radioactivity from CANDU reactors, are within the release limits set by the Atomic Energy Control Board and do not result in any appreciable increase in radioactivity dose over the background from atmospheric fallout.

HEAVY METALS

During the present study, heavy metals in water were measured only at selected sites in segments G and I.

Total nickel levels were detectable ($\geq$5 µg/ℓ) in 3 samples from Harbor Beach and in one sample each from Alpena and Presque Isle. None of the values exceeded the proposed Agreement objective for the protection of fish and wildlife (Appendix C).

Manganese was measurable ($\geq$1.0 µg/ℓ) in all samples with no locations having levels >20 µg/ℓ, except at Alpena where the values ranged from 4 to 60 µg/ℓ. The highest level at Alpena exceeded the U.S. Drinking Water Standard of 50 µg/ℓ (Appendix C). The source of this contaminant has not been identified.

Iron levels were variable, ranging from below the detection limit (5 µg/ℓ) to 1,000 µg/ℓ. At Harbor Beach and Alpena several samples exceeded both the U.S. Drinking Water Standard and the proposed Agreement objective for fish and aquatic life (300 µg/ℓ, Appendix C). The sources of contamination have not been determined at these sites.

Individual copper values ranged from below detection limits (1 µg/ℓ) at Alpena to 70 µg/ℓ at Presque Isle. Mean levels at individual locations in segments G and I ranged from 1.54 µg/ℓ at Lexington to 8.33 µg/ℓ at Tawas City. All measured copper levels were within acceptable limits according to U.S. water quality criteria for raw water but several individual samples exceeded the proposed Agreement objective of 5 µg/ℓ for the protection of fish and aquatic life.

Zinc levels ranged from below the detection limit (1 µg/ℓ) at Tawas City and Lexington to 120 µg/ℓ at DeTour Passage. The proposed Agreement

TABLE 4.1-5

DOUGLAS POINT - BRUCE INSHORE SURFACE WATER[a]

STATION	LOCATION		SAMPLING	ANNUAL AVERAGE IN pCi/ℓ			
	NORTH LAT.	WEST LONG.	DATE	GROSS α	GROSS β	^{3}H	^{226}Ra
113	44°18'24"	81°38'12"	1967	<1	6	-	0.2
			1969	<1	5	<1700	-
			1970	<1	4	<1700	-
			1971	<1	4	<1700	1
			1972	<1	5	<1700	-
			1973	<1	2	<1700	-
			1974	<1	2.7	<1700	-
			1975	<1	2.0	<1700	-
			1976	<1	3.0	<300	-
114	44°19'42"	81°37'24"	1967	<1	5	-	0.3
			1969	<1	6	<1700	-
			1970	<1	4	<1700	-
			1971	<1	6	<1700	1
			1972	1	5	<1700	-
			1973	<1	2	<1700	-
			1974	<1	3.7	<1700	-
			1975	1	2.3	<1700	-
			1976	<1	4.4	<300	-
115	44°20'48"	81°36'08"	1967	1	5	-	0.3
			1971	<1	3	<1700	<1
			1972	<1	5	<1700	-
			1973	<1	2	<1700	-
			9 July 1973[b]	<1	2	9300	-
			1974	<1	3	<1700	-
			1975	1	2.7	<1700	-
			1976	<1	5.2	<300	-
116	44°18'24"	81°36'42"	1967	<1	7	-	0.4
			1970	<1	5	<1700	-
			1971	<1	3	<1700	1
			1972	1	4	<1700	-
			1973	<1	2	<1700	-
			1974	<1	3	<1700	-
			1975	<1	1.3	<1700	-
			1976	<1	2.3	<300	-
117	44°20'09"	81°35'42"	1967	2	7	-	0.1
			1970	-	4	2040	-
			1971	<1	4	<1700	<1
			1972	<1	5	<1700	-
			1973	<1	1	<1700	-
			9 July 1973[b]	<1	1	46200	-
			1974	<1	3	<1700	-
			1975	1	2.7	<1700	-
			1976	<1	3.4	<300	-
121	44°19'33"	81°36'50"	1971	<1	3	<1700	1
			1972	<1	5	<1700	-
			1973	<1	2	<1700	-
			9 July 1973[b]	<1	2	11100	-
			1974	<1	3.3	<1700	-
			1975	1.3	3.0	<1700	-
			1976	<1	2.3	<300	-
122	44°20'02"	81°36'45"	1971	<1	4	<1700	3
			1972	<1	5	<1700	-
			1973	<1	2	<1700	-
			9 July 1973[b]	<1	2	30300	-
			1974	<1	3	<1700	-
			1975	1	3	<1700	-
			1976	<1	2.2	<300	-
123	44°20'55"	81°34'36"	1971	<1	4	<1700	1
			1972	<1	4	<1700	-
			1973	<1	2	<1700	-
			7 July 1973[b]	<1	1	8500	-
			1974	<1	3	<1700	-
			1975	<1	2	<1700	-
			1976	<1	2.7	<300	-
364	44°19'03"	81°36'50"	1972	<1	8	<1700	-
			1973	<1	2	<1700	-
			9 July 1973[b]	<1	2	25900	-
			1974	<1	3.7	<1700	-
			1975	<1	2.7	<1700	-
			1976	<1	3.7	<300	-
368	44°18'45"	81°36'45"	1975	2	3.7	<1700	-
369	44°18'42"	81°37'09"	1975	1	2.7	<1700	-
370	44°19'18"	81°37'06"	1975	<1	2.3	<1700	-
371	44°19'33"	81°36'27"	1975	1	3.0	<1700	-
			1976	<1	4.0	<300	-
373	44°20'54"	81°35'21"	1975	1	2.7	<1700	-
			1976	<1	2.8	<300	-

a. From References (21) and (49).
b. Special set of samples.

objective is 30 μg/ℓ; however, no location mean exceeded this value. Location means were lowest at Alpena (6.6 μg/ℓ) and highest at DeTour (19.5 μg/ℓ).

Total arsenic, selenium, cadmium, and mercury were not detected at or above the detection limits of 1.0, 1.0, 2.0, and 0.2 μg/ℓ, respectively.

Lead was frequently below the detection limit (5 μg/ℓ) and the highest level was recorded at Alpena (12 μg/ℓ). All measured lead levels were within the U.S. Drinking Water Standard (50 μg/ℓ) and the proposed Agreement objective for fish and wildlife in Lake Huron (20 μg/ℓ) (Appendix C).

Most total chromium levels were below detection (1 μg/ℓ), with 2.0 μg/ℓ the highest level reported and all levels were well within the limits of the proposed Agreement objective (Appendix C).

SEDIMENTS

Samples of the top 5 cm of surficial sediment were collected between May 1974 and May 1975, from Lake Huron segments A to I, major harbours, and local impacted areas (Table 4.1-6) and were analyzed for PCB's, pesticides, and total metals (zinc, cadmium, lead, mercury, copper, chromium, nickel, and iron).

HEAVY METALS

Mean concentrations and simple statistics of zinc, cadmium, lead, mercury, copper, chromium, nickel, and iron are presented in Table 4.1-6; the regional differences in sediment characteristics for these metals are depicted elsewhere (2-4,9). Because of the apparent similarity of the type of sediments and small sample size, Lake Huron segments A and B are discussed together as one nearshore segment.

The predominant surficial sediments in the nearshore regions of Lake Huron are comprised of sand and gravel derived from erosional processes operating on the underlying glacial tills (24) and are low in organic matter. Nearshore segments E and F lie in Precambrian rock of the Canadian Shield. The southern part of Lake Huron lies wholly within Paleozoic rocks, mostly dolomites. The lowest levels of all the heavy metals, except cadmium, were found in the surficial sediments of Lake Huron segments A to C, compared to segments D and E of Georgian Bay, segment F of the North Channel, and harbours. Sediment samples from segment F, which ranged from sand to clay, contained the highest levels of zinc, lead, mercury, copper, chromium, and nickel. Most of the heavy metal concentrations in segment D were higher than the adjacent segment E. Heavy metal levels in non-industrialized nearshore areas reflect natural levels due to soil weathering and geochemical processes. It is also possible that these segments may be affected by the transport of sediment from industrialized areas.

TABLE 4.1-6

HEAVY METALS IN SURFICIAL SEDIMENTS OF LAKE HURON

Area	Sample Size	CONCENTRATION IN mg/kg: Zinc Min. Max.	Zinc Mean	Zinc Std. Dev.	Cadmium[a] Min. Max.	Cadmium[a] Mean	Cadmium[a] Std. Dev.	Lead[a] Min. Max.	Lead[a] Mean	Lead[a] Std. Dev.	Mercury[a] Min. Max.	Mercury[a] Mean	Mercury[a] Std. Dev.
Lake Huron A & B	8	12.0 25	17.75	4.46	<1.9 2.9			9.4 29.0	16.55	6.3	<0.01 <0.01		
Lake Huron C	6	3.93 16.0	9.02	4.5	<2.0 12.0			1.3 28.5	15.5	11.0	0.006 0.011		
Goderich Harbour	3	15.7 47.6	29.7	16.3	<2.0 2.96			33.1 65.1	49.9	16.1	0.019 0.082	0.059	0.035
Georgian Bay D	12	7.5 115	65.1	35.1	<2.0 2.9			6.04 47	28.2	12.8	0.005 0.064		
Georgian Bay E	6	4.99 98.1	54.6	31.9	<1.0 2.97			<6.0 46.0			<0.01 0.045		
Tobermory Harbour	3	81.6 99.0	90.5	8.7	2.85 2.97	2.91	0.06	60.7 104.0	75.6	24.6	0.042 0.056	0.051	0.008
Owen Sound Harbour	6	57.2 187.0	103.7	47.7	<2.0 3.95			26.4 174.0	75.6	53.1	0.026 0.435	0.166	0.143
Collingwood Harbour	3	99.1 127.0	116.4	15.1	3.92 4.46	4.19	0.27	85.8 274.0	162.3	98.9	0.084 0.189	0.146	0.06
Penetang-Midland	8	89.0 228.0	130.5	42.6	<1.9 2.84			30.6 104.0	57.2	24.2	0.052 0.52	0.18	0.16
Parry Sound Harbour	20	25 290	107.9	73.7	0.5 3.98			9 160	41.6	35.7	0.02 0.534	0.12	0.14
North Channel F	19	17.8 233.0	95.29	71.42	<2.0 3.95			2.5 99.2	31.31	24.94	<0.01 0.149		
Spanish Harbour	19	17.5 213.0	83.8	49.25	0.50 3.98	2.53	1.14	1.8 82.0	26.38	18.18	0.01 0.127	0.055	0.034
Serpent Harbour	20	44 226	155.9	52.3	<1.0 2.0			11 83	52.2	21.99	0.04 0.12	0.077	0.040
DeTour	1	5.4			<0.4			<1			<0.1		
Cheboygan	5	5.6 140	40.7	55.8	<0.4			<1 10	4.7	3.7	<0.1		
Presque Isle	1	34			<0.4			19			<0.1		
Alpena	6	24 44	31.0	7.3	<0.4			8 30	15.0	8.0	<0.1		
Harrisville	1	26			<0.4			4			<0.1		
Tawas City	6	12 26	19.6	5.5	<0.4			5 16	10.0	4.3	<0.1		
Harbor Beach	4	44 170	126.0	57.2	<0.4			12 36	26.5	10.5	<0.1		
Lexington	1	70			<0.4			13			<0.1		

Area	Sample Size	CONCENTRATION IN mg/kg: Copper[a] Min. Max.	Copper[a] Mean	Copper[a] Std. Dev.	Chromium[a] Min. Max.	Chromium[a] Mean	Chromium[a] Std. Dev.	Nickel[a] Min. Max.	Nickel[a] Mean	Nickel[a] Std. Dev.	Iron % Min. Max.	Iron % Mean	Iron % Std. Dev.
Lake Huron A & B	8	2.9 25	10.2	7.6	5.5 20.0	12.5	4.6	3.0 19.0	11.9	4.9	0.4 1.1	0.71	0.25
Lake Huron C	6	<5.0 7.5			4.5 16.5	11.7	3.9	<4.5 21.0			0.4 1.1	0.56	0.27
Goderich Harbour	3	12.8 25.9	18.0	6.9	15.2 28.3	20.9	6.7	10.8 23.4	16.67	6.34	0.55 1.35	0.92	0.40
Georgian Bay D	12	<5.0 52.0	25.1	16.7	<7.0 55	25.5	16.4	11.8 58.0	36.7	17.9	0.40 4.0	2.28	1.36
Georgian Bay E	6	<5.0 32.3			<5.0 35.6			<5.0 78.0			0.73 2.4	1.75	0.58
Tobermory Harbour	3	28.2 37.7	32.4	4.8	39.9 45.7	43.1	2.9	35.4 47.9	42.4	6.4	1.23 1.56	1.4	0.17
Owen Sound Harbour	6	20.0 62.7	38.6	14.7	14.0 20.0	17	4.2	27.0 45.0	31.4	6.9	1.18 2.5	1.5	0.49
Collingwood Harbour	3	37.2 50.6	44.7	6.85	23.8 26.3	24.7	1.29	28.3 33.3	31.3	2.7	1.08 1.21	1.14	0.07
Penetahg-Midland	8	15.3 43.9	28.5	10.9	28.7 156.0	65.4	40.7	19.1 88.0	36.7	22.4	1.3 3.28	2.47	0.62
Parry Sound Harbour	20	6.0 42.0	24.5	9.9	4.0 53.5	19.9	13.0	4.0 32.0	18.21	9.48	0.3 6.7	2.33	1.50
North Channel F	19	<5.0 489.0			7.92 68.9	37.08	21.92	19.8 562	109.6	142.8	0.57 4.85	2.06	1.069
Spanish Harbour	19	-	-	-	10 62	35.11	15.06	-	-	-	0.84 2.42	1.46	0.45
Serpent Harbour	20	14.0 68.0	40.45	15.34	13 46	29.95	9.15	20 335	103.5	95.84	0.89 2.88	1.88	0.51
DeTour	1	1.2			<0.2			2			0.26		
Cheboygan	5	1.0 16.0	4.60	3.99	2.0 18.0	6.72	6.48	<1 12	4.7	4.4	0.20 0.86	0.392	0.279
Presque Isle	1	11.0			7.8			20			0.48		
Alpena	6	3.8 12.0	6.53	3.24	3.0 7.2	5.26	1.66	6 15	10.0	3.2	0.32 0.60	0.460	0.128
Harrisville	1	1.8			2.8			5			0.62		
Tawas City	6	3.0 12.0	6.86	3.82	0.6 14.0	7.50	5.11	7 20	13.0	5.6	0.22 0.80	0.533	0.248
Harbor Beach	4	14.0 24.0	20.00	4.30	11.0 19.0	14.20	3.50	24 38	30.5	5.7	1.70 7.80	3.400	2.970
Lexington	1	4.6			3.4			10			0.52		

a. If mean and Std. Dev. are not shown, less than values were found for more than 15% of the samples.

Ontario guidelines for heavy metals in sediment apply only to the disposal of dredging spoils in open water. Dredging takes place at Goderich, Bayfield, and Grand Bend and for these areas, sediments were not found to be polluted in excess of the Ontario guidelines.

The nearshore sediments at locations on the Michigan side of Lake Huron were characterized by low levels of heavy metals (Table 4.1-6). Zinc levels at Cheboygan and Harbor Beach exceeded the U.S. Environmental Protection Agency (EPA) dredge spoils guidelines (Appendix C). Iron and chromium were also found at elevated levels in the Harbor Beach sediments.

PCB'S AND PESTICIDES

Only two out of 17 samples from the stations in segments A to C, i.e. at the Ausable River mouth and near Bayfield contained detectable amounts of PCB's (36 to 94 μg/kg). Pesticides were either below the detection level or were present in trace amounts. Detectable PCB levels in 19 sediment samples from Georgian Bay segments D and E (out of a total of 52 samples) ranged from 15 to 900 μg/kg with concentrations >100 μg/kg being detected in the sediments at Owen Sound and Collingwood Harbour. These embayments also contained small amounts of DDT and its metabolites in sediment samples (Table 4.1-7).

An average of 68 μg/kg of PCB's and small amounts of pesticides (5 μg/kg) were found in sediment samples from the Spanish River mouth. Trace amounts of PCB's and pesticides were found in some sediment samples from the North Channel segment F while most samples contained non-detectable amounts. Except for the few stations in Collingwood Harbour and Owen Sound, these results suggest that the surficial sediments of Lake Huron segments A to F are devoid of any detectable hazardous PCB's and pesticides contamination.

The nearshore sediments of Lake Huron segments G and I were characterized by low levels of pesticides and PCB's. However, measurable DDT residues were found in samples at two control areas, Presque Isle (16.3 μg/kg total DDT) and Harrisville (3.0 μg/kg total DDT).

Alpena, Cheboygan, and Harbor Beach generally had higher concentrations. Cheboygan averaged 7.2 μg/kg total DDT in sediment. Alpena had total DDT concentrations ranging from 3.9 to 30.7 μg/kg in sediments. Levels of PCB's in the sediments at Harbor Beach (18 to 27 μg/kg), the only U.S. location at which PCB's were found in sediment at concentrations above detection levels, interfered with the analysis of pesticides.

OILS AND GREASE

At Cheboygan, Alpena, and Harbor Beach sediment was found to exceed the EPA dredge spoil guideline for oils and grease.

TABLE 4.1-7

Concentrations of PCB'S and Pesticides in the Nearshore Surficial Sediments of Lake Huron

Area	Sample Size[d]	CONCENTRATION IN µg/kg PCB	DDE	Dieldrin	DDD	pp DDT	op DDT
Lake Huron A & B	8	65 (2)	a	a	a	a	a
Lake Huron C	6	a	a	a	a	a	a
Georgian Bay D	12	46.6 (5)	2.5 (4)	1.6 (3)	2.8 (6)	1.5 (6)	a
Georgian Bay E	6	40 (1)	b	a	a	a	a
Tobermory Harbour	1	40	4	a	a	2	2
Owen Sound Harbour	6	267.5 (4)	13.6	4.5 (2)	14.3	4.2	a
Collingwood Harbour	3	853	8.3	a	14	5	c
Penetang-Midland	8	32 (4)	2.2 (2)	1.1 (4)	5 (2)	b	a
Parry Sound Harbour	19	a	a	a	a	a	a
North Channel F	19	a	3.5 (6)	a	4.3 (5)	6.7 (4)	7 (2)
Spanish Harbour	18	56.8 (16)	.4 (16)	a	1.9 (16)	1.8 (16)	a
Serpent Harbour	16	a	1.3	a	a	a	a

a. Non-detectable.
b. Trace.
c. Not Analyzed.
d. Parentheses denote the number of samples above detection limit.

AQUATIC BIOLOGY

Biological communities react measurably to subtle changes in water quality, thereby permitting an assessment of water quality integrated over time. Long-term changes in the biological community permit evaluation of changes in water quality that would not be readily detectable by routine water chemistry measurements.

The present structure and composition of phytoplankton, zooplankton, and benthic invertebrate communities in the nearshore waters of Lake Huron, when compared with past data, yield estimates of changes of populations which can correlate with present water quality and recent water quality trends. Analysis of the population of the species present and their known pollution tolerance indicates the trophic status or enrichment of the water body. Additionally, coliform bacteria levels in water and the presence of toxic materials in fish tissue point out areas where inputs may be potentially hazardous to human health.

MICROBIOLOGY

Information which complements the description of nearshore bacteriological water quality, given below, is presented in Chapter 5.5.

MICHIGAN

In Michigan, data were collected in Segments G and I and at DeTour and Cheboygan (25)(Table 4.1-1). Elevated total coliform counts were observed at Cheboygan, Alpena, Tawas City, and Harbor Beach, where municipal wastes are discharged to tributaries flowing into Lake Huron (Table 4.1-8). Maximum total coliform densities were recorded at river mouth stations. The mouths of the Cheboygan, Thunder Bay, and Tawas Rivers had total coliform counts >1,000/100 mℓ. Water at the mouth of the Thunder Bay River had total coliform counts up to 18,000/100 mℓ. Total coliform densities in 29% of the samples from Alpena exceeded the Agreement objective (Appendix C). In the spring, Cheboygan and Harbor Beach total coliform densities exceeded objectives and in the fall objectives were exceeded at Tawas City and Lexington (Segment I). All samples from DeTour and Presque Isle had total coliform densities <200 counts/100 mℓ.

All fecal coliform densities at DeTour, Harrisville, and Lexington were below detection limits (10 counts/100 mℓ)(Table 4.1-9). Fourteen percent of the samples from Cheboygan and Alpena had fecal coliform counts >200 organisms/100 mℓ during the spring. During the fall 14% of the Tawas City samples had fecal coliform counts >200 organisms/100 mℓ. As with total coliforms, fecal coliform densities were highest at river mouth stations. Maximum fecal coliform densities (470 counts/100 mℓ) were found at the mouth of the Cheboygan River.

Fecal streptococci densities were generally at or below the detection limit (10 counts/100 mℓ)(Table 4.1-10). Tawas City samples exceeded 100 counts/100 mℓ during the spring. During the fall, all locations had <50 counts/100 mℓ. When detected, maximum fecal streptococci densities were found at or near river mouth stations.

TABLE 4.1-8

Total Coliform Densities in the Surface Waters of Lake Huron, 1974 and 1975[a]

PERCENT OF SAMPLES IN COUNT RANGE

LOCATION	MAY - JUNE, 1974			JULY - SEPTEMBER, 1974				OCTOBER - DECEMBER, 1974				APRIL - MAY, 1975			
ONTARIO	≤1	2-99	100-999	≤1	2-99	100-999	≥1000	≤1	2-99	100-999	≥1000	≤1	2-99	100-999	≥1000
Segment A	70	20	10					17	58	25		82	9	9	
Segment B	25	64	11					10	60	17	14	25	60	10	5
Segment C	80	18	2					83	17			80	20		
Segment D	93	7		15	75	10									
Segment E	54	46		18	58	21	3	65	26	9					
Segment F	61	25	14	43	43	14		80	12	8					

MICHIGAN	JUNE - JULY, 1974			SEPTEMBER, 1974		
	<100	100 - 999	≥1000	<100	100 - 999	≥1000
DeTour	83	17		83	17	
Cheboygan	64	21	14	64	36	
Segment G	100			67	33	
Alpena	7	64	29		71	29
Tawas City	86	14		57	21	21
Segment I	67	33		17	50	33
Harbor Beach	29	50	21	14	86	

a. All analyses done by Millipore filter method. Data reported by Ontario Ministry of the Environment (2) and the Michigan Water Resources Commission (25).

TABLE 4.1-9

FECAL COLIFORM DENSITIES IN THE NEARSHORE WATERS OF LAKE HURON, 1974 AND 1975[a]

LOCATION	PERCENT OF SAMPLES IN COUNT RANGE									
ONTARIO	MAY - JUNE, 1974		JULY - SEPTEMBER, 1974		OCTOBER - DECEMBER, 1974				APRIL - MAY, 1975	
	≤1	2 - 99	≤1	2 - 99	≤1	2 - 99	100-199	≥200	≤1	2 - 99
Segment A	90	10			58	42			82	18
Segment B	82	18			76	16	4	4	65	35
Segment C	98	2			100				100	
Segment D	100		91	9						
Segment E	95	5	100		100					
Segment F	89	11	79	21	92	8				

MICHIGAN	JUNE - JULY, 1974			SEPTEMBER, 1974			
	<10	10 - 99	≥200	<10	10 - 99	100-199	≥200
DeTour	100			100			
Cheboygan	86		14	71	29		
Segment G	93	7		100			
Alpena	50	36	14	64	21	14	
Tawas City	93	7		86			14
Segment I	100			100			
Harbor Beach	57	43		79	21		

a. All analyses done by Millipore filter method. Data repoted by Ontario Ministry of the Environment (2) and the Michigan Water Resources Commission (25).

TABLE 4.1-10

Fecal Streptococci Densities in the Nearshore Waters of Lake Huron, 1974 and 1975[a]

LOCATION	PERCENT OF SAMPLES IN COUNT RANGE										
ONTARIO	MAY - JUNE, 1974			JULY - SEPTEMBER, 1974			OCTOBER - DECEMBER, 1974		APRIL - MAY, 1975		
	≤1	2-19	20 - 99	≤1	2 - 19	20 - 99	≤1	2 - 19	≤1	2 - 19	≥100
Segment A	70	30					75	25	82	9	9
Segment B	57	7	36				96	4	40	45	15
Segment C	97	3					100		83	17	
Segment D	93	7		89	11						
Segment E	79	21		42	55	3	100				
Segment F	85	15		7	93		97	3			

MICHIGAN	JUNE - JULY, 1974				SEPTEMBER, 1974		
	<10	10 - 19	20 - 99	≥100	<10	10 - 19	20 - 99
DeTour	100				100		
Cheboygan	86		14		93	7	
Segment G	83	17			92	8	
Alpena	64	14	21		100		
Tawas City	79		14	7	86		14
Segment I	100				83		17
Harbor Beach	64	21	14		79	21	

a. All analyses done by Millipore filter method. Data reported by Ontario Ministry of the Environment (2) and the Michigan Water Resources Commission (25).

No consistent seasonal trends were apparent for total and fecal coliforms or fecal streptococci populations.

ONTARIO

Ontario microbiology data were collected in segments A-F and selected embayments (Table 4.1-1)(2,3). The nearshore waters of segments A-F were generally free of fecal contamination with the majority of total coliform, fecal coliform, and fecal streptococci counts within Agreement objectives and agency water use criteria (Appendix C).

For total coliforms, the objective and criteria were exceeded for 3% of the samples collected during July-September, 1974 in segment E, 14% of the samples collected during October-December, 1974 in segment B, and 5% of the samples collected during April-May, 1975 for segment B (Table 4.1-8). During October-December 1974, 4% of fecal coliform samples collected in segment B exceeded the Agreement objective (200 counts/100 mℓ) (Table 4.1-9) and 8% of fecal coliform samples exceeded agency recreational use criteria (100 counts/100 mℓ). The Ontario recreational water use criterion for fecal streptococci (20 counts/100 mℓ) was exceeded in 36% and 15% of the samples from segment B during spring 1974 and 1975, respectively. Bacterial contamination in segment B was localized and confined to inshore stations in the vicinity of Goderich.

Bacterial levels in embayment/harbour areas were generally higher than nearshore segment levels. Monthly geometric means of the indicator bacteria in Goderich Harbour were within Agreement objectives and agency criteria during three surveys in 1974 and 1975.

Individual total coliform samples for stations in the vicinity of the Saugeen River mouth at Southampton were moderately high on two occasions in 1974. However, levels of fecal coliforms and fecal streptococci were low, suggesting that bacterial contamination was non-fecal in origin. The Agreement objective for fecal coliforms and the Ontario criteria for fecal coliforms and fecal streptococci were exceeded during May 1974 for two stations in the inner portion of Owen Sound Harbour. Localized fecal contamination was due to combined sewer overflow for which remedial measures are now being investigated.

During the summer of 1974 the Agreement objective for total coliforms was exceeded at stations in the inner portion of Penetang Bay. These levels were attributed to urban drainage and the discharge of inadequately disinfected waste; in addition, heavy recreational use may have been a contributing factor.

Monthly geometric means of the health-oriented indicator bacteria for individual stations within Parry Sound, Parry Sound Harbour, and specifically off McCurry Lake outlet (the site of the Parry Sound sewage treatment plant secondary discharge) were within Agreement objectives and provincial criteria during five monthly surveys in 1974. In the vicinity of Blind River during June 1974 elevated fecal coliform and

Pseudomonas aeruginosa were found. These levels were attributed to the discharge of sanitary waste. A remedial program consisting of a new treatment plant and sewerage system is now underway. During the summer and fall of 1974 elevated total and fecal coliform densities were noted in the vicinity of Spanish River.

PHYTOPLANKTON

Studies on the phytoplankton communities in Lake Huron are relatively sparse. Vollenweider *et al.* (26) reported a 1971 survey of portions of Lake Huron. Low biomass characterized the offshore stations, and the diatoms *Cyclotella, Tabellaria, Stephanodiscus, Melosira,* and *Synedra* dominated, although various phytoflagellates and cryptomonads, including *Cryptomonas erosa* and *Rhodomonas minuta,* sometimes accounted for 20% of the biomass. Information which complements the description of the nearshore phytoplankton community, given below, is presented in Chapter 5.4.

MICHIGAN

Michigan waters were sampled at DeTour, Cheboygan, Alpena, Harrisville, Tawas City, Harbor Beach, and Lexington (25). The dominant phytoplankton in the nearshore waters of Lake Huron are shown in Table 4.1-11. Generally, diatoms were the dominant algal group, except in Thunder Bay at Alpena during June when blue-greens, basically *Dactylococcopsis fascicularis,* were dominant. There appears to be an overall north-to-south increase in algal abundance in Lake Huron, but this trend was masked, in part, by location variability.

ONTARIO

Ontario waters were sampled at municipal intakes located at Collingwood, Owen Sound, Goderich, Grand Bend, Penetang, Midland, and Sarnia (6). Diatoms were the dominant group throughout the year, but during late summer and early fall, chrysophytes, blue-green, and green algae contributed to the flora. The mesotrophic nature of southern Lake Huron and the oligotrophic character of Georgian Bay were indicated by these data. Maximum algal densities at Sarnia, Goderich, and Grand Bend were usually 3 to 10 times greater than comparable densities at Owen Sound and Collingwood. Although short-term in nature, the high densities are considered excessive for oligotrophic waters (6). *Aphanizomenon flos-aquae* and *Anabaena flos-aquae,* species common to eutrophic waters, were virtually absent except in Penetang Harbour and Midland Bay where they were abundant on several occasions. Although the classical bimodal pattern of phytoplankton development occured, the lack of intensity and short duration of the spring and fall maxima indicated the relative oligotrophic nature of both northeastern Lake Huron and Georgian Bay.

ZOOPLANKTON

Very few studies of Lake Huron zooplankton have been published. Schelske and Roth (13) found many genera of *Diaptomus, Bosmina,* and *Cyclops* in Lake Huron north of Saginaw Bay. Patalas (27) found 23

TABLE 4.1-11

ABUNDANT OR DOMINANT PHYTOPLANKTON IN NEARSHORE LAKE HURON WATERS, 1974[a]

LOCATION	GROUP (PHYLUM)	GENERA OR SPECIES	COMMENTS
MICHIGAN	Diatoms (Bacillariophyta)	*Cyclotella glomerata*, *Cyclotella comensis*, *Tabellaria fenestrata*, *Fragelaria crotonensis*, *Asterionella formosa*	*Cyclotella* sp. was often dominant by numbers.
	Blue-greens (Cyanophyta)	*Dactylococcopsis fascicularis*, *Aphanocapsa delicatissma*	*D. fascicularis* was dominant in Thunder Bay in June samples.
	Cryptophyta	*Rhodomonas minuta*	*R. minuta* was often the most abundant species.
	Yellow-browns (Chrysophyta)	*Dinobryon* spp.	*Dinobryon* was often very abundant.
	Greens (Chlorophyta)	*Chrysosphaerella longispina*	
ONTARIO	Diatoms (Bacillariophyta)	*Tabellaria* spp., *Fragilaria* spp. *Rhizosolenia* spp., *Asterionella* spp.	These four genera were dominant throughout the year.
	Yellow-browns (Chrysophyta) Blue-greens (Cyanophyta) Greens (Chlorophyta)	*Dinobryon* spp. *Oscillatoria* spp. *Oocystis* sp., *Chlamydomonas* spp., *Ankistrodesmus* spp., *Scenedesmus* spp.	All six genera in these three phyla were abundant during the early fall.

a. Data for Ontario (6) and Michigan (25) are summarized from specific project reports.

crustacean species with *Cyclops bicuspidatus thomasi*, *Diaptomus sicilis*, *D. ashlandi*, and *D. minutus* the abundant copepods, while *Holopedium gibberum* and *Bosmina longirostris* were the most abundant cladocerans. Patalas related a decreasing ratio of cyclopoid copepods to other entomostraca to increased enrichment of the Great Lakes, except Lake Erie. Nauwerck (28) reported approximately 30 species of rotifers from Lake Huron. *Kellicottia*, *Conochilus*, and *Gastropus* were considered oligotrophic genera while *Brachionus*, *Filinia*, and *Keratella* were considered eutrophic. Information which complements the description of the nearshore zooplankton community, given below, is presented in Chapter 5.4.

MICHIGAN

In Michigan, data were collected in Segments G and I and at DeTour and Cheboygan (25). The shallow nearshore waters provide a more productive habitat for rotifers with the stations nearest to shore or in river mouths having the highest counts. There are no generic differences observed among stations. Eight genera of rotifers were identified. Both the lowest and the highest rotifer abundance occurred in the fall: $381/m^3$ at DeTour and $9{,}494/m^3$ at Harbor Beach.

The most abundant crustacean zooplankton are given in Table 4.1-12. The number of species ranged from 6 at Harbor Beach to 11 at DeTour. *Daphnia retrocurva*, often found in enriched water, was present at all stations in the fall as opposed to 7 of 9 locations in the spring, and was most abundant in the fall. Overall crustacean abundance in Lake Huron ranged from 2,146 organisms/m^3 in the fall at Cheboygan to a high of 41,554 organisms/m^3 at Harbor Beach in the spring.

Crustacean zooplankton numbers were generally higher at stations nearest shore or in river mouths. Stations nearest shore had a different species composition than stations further offshore. *Daphnia galeata mendotae* and *Bosmina coregoni* were found only at the former, and *Diaptomus ashlandi* was not.

Zooplankton abundance was greater (13,444 $\pm$ 14,331 organisms/m^3) in the spring than in the fall (4,545 $\pm$ 2,164 organisms/m^3). Impacted locations appeared to have greater numbers than the control locations.

There was a significant north-south increase in zooplankton abundance in the spring, which indicates a north-south increase in enrichment.

The ratio of calanoid copepods to other entomostraca and rotifers has been related to trophic state (29). This ratio, at all times, was >0.3 at DeTour, Presque Isle, and Harrisville. In the spring, when the highest proportion of calanoid copepods occurred, Harbor Beach and Tawas City were the only locations with a ratio <0.20. Cheboygan, Alpena, and Lexington had intermediate ratios. The low ratios at Tawas City and Harbor Beach may reflect significant enrichment. Both locations are subject to currents from Saginaw Bay which is highly enriched (30).

TABLE 4.1-12

ABUNDANT OR COMMON ZOOPLANKTON IN NEARSHORE LAKE HURON WATERS, 1974[a]

LOCATION	GROUP	GENERA OR SPECIES	COMMENTS
MICHIGAN	Rotifers	*Keratella, Polyarthra, Asplanchna, Filinia*	All four genera were abundant at all locations.
		Kellicottia, Conochilus, Brachionus, Gastropus	*Gastropus* was found at 5 of 8 locations whereas the others were found at all.
	Crustaceans Cladocera	*Bosmina longirostris, Daphnia retrocurva*	*B. longirostris* was one of the two most abundant crustacean species present.
	Calanoid Copepods	*Diaptomus oregonensis, Diaptomus minutus, Diaptomus sicilis, Epischura lacustris*	*D. minutus* was the most abundant calanoid copepod.
	Cyclopoid copepod	*Cyclops bicuspidatus thomasi*	*C. bicuspidatus* was one of the two most abundant crustacean zooplankton.

a. Data fully reported in Reference (25).

BENTHOS

Substantial data have been collected on the benthic macroinvertebrate communities in Lake Huron during the past decade. Teter (31), Schuytema and Powers (32), Schelske and Roth (13), Shrivastava (33), and Mozley (34) have documented the benthos in the main basin of the lake. Schneider *et al.* (35) surveyed the benthic community in shallow eutrophic Saginaw Bay, and Brinkhurst (36) reported on oligochaetes from the same samples. The benthic community of Georgian Bay was studied by Brinkhurst *et al.* (37). The benthos found in Lake Huron, except in Saginaw Bay, is an oligotrophic community generally dominated by the *Pontoporeia affinis* - oligochaete-chironomid-sphaeriid association. However, Shrivastava (33) suggests that Lake Huron is in an early stage of mesotrophy. Information which complements the description of the nearshore benthic community, given below, is presented in Chapter 5.4.

MICHIGAN

Michigan nearshore waters were sampled for benthos at DeTour, Presque Isle, Harrisville, Tawas City, Lexington, Cheboygan, Alpena, and Harbor Beach (25). At depths <25 m, the benthic communities at the control locations were dominated by oligochaetes and chironomids while the amphipod, *P. affinis*, dominated at depths >25 m (Figure 4.1-16 and Table 4.1-13).

The dominant taxa at DeTour were the oligochaete, *Stylodrilus heringianus*, and the chironomid, *Heterotrissocladius sp.*, which together formed 81% of the total population.

The benthic community at Presque Isle is unique in Lake Huron nearshore waters. This location had an exceptionally large population dominated by *P. affinis* and *Pisidium sp.* Pollution-tolerant tubificids, *Limnodrilus hoffmeisteri* and *Potamothrix vejdovski*, were also present.

The benthic communities at Harrisville, Tawas City, and Lexington were composed of nearly equal percentages of chironomids and oligochaetes. However, the species composition at Tawas City was substantially different from the other two locations due to the influence of Saginaw Bay, reflected in the increased diversity and predominance of mesotrophic and eutrophic indicator benthic forms. *Pontoporeia affinis*, although present, has been generally replaced by the pollution-tolerant amphipods, *Gammarus sp.* and *Hyallela azteca.*

The oligochaete and chironomid communities at Harrisville and Lexington were characterized by low total numbers, indicating relatively unenriched conditions. However, Lexington was dominated by mesotrophic and eutrophic indicator species and the primary oligotrophic indicator species were not found. This indicates enrichment from Saginaw Bay. Harrisville was dominated by oligotrophic indicator species.

At Alpena and Harbor Beach, oligochaetes dominated the benthic community while other taxa dominated the Cheboygan community. Oligotrophic indicator forms were virtually absent at both locations. *Pontoporeia*

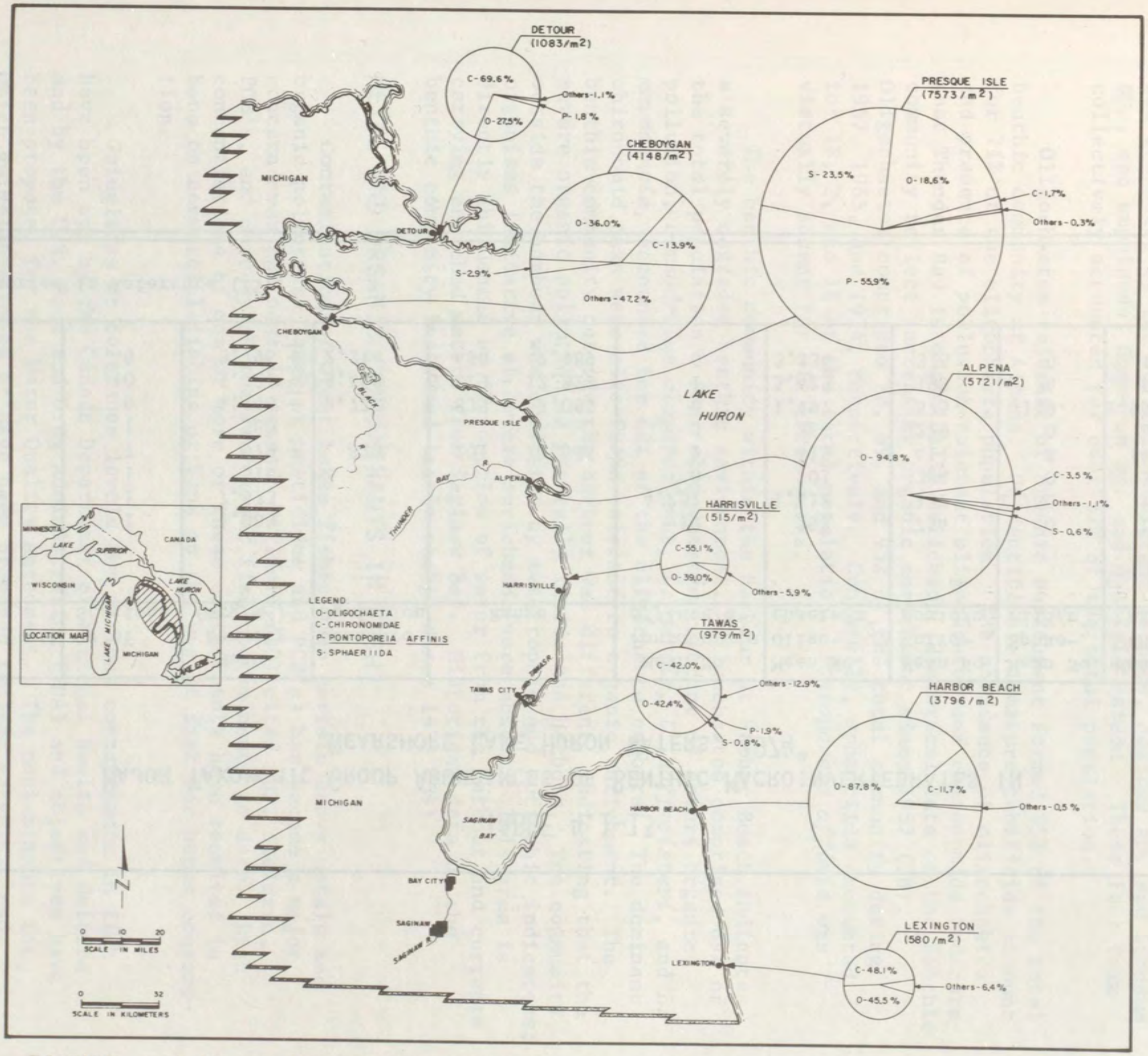


FIGURE 4.1-16 : COMPOSITION AND DENSITY OF BENTHIC FAUNAL COMMUNITIES IN MICHIGAN NEARSHORE WATERS OF LAKE HURON, 1974 .

TABLE 4.1-13

MAJOR TAXONOMIC GROUP ABUNDANCES OF BENTHIC MACROINVERTEBRATES IN NEARSHORE LAKE HURON WATERS, 1974[a]

LOCATIONS	# of Stations	Mean Density (org/m^2)	Standard Deviation	Range	Mean No. *Pontoporeia affinis*/m^2	Mean No. Oligo-chaete/m^2	Mean No. Chiro-nomid/m^2	Mean No. Sphae-riid/m^2	Mean No. Other taxa/m^2	No. of Taxa
MICHIGAN										
DeTour	1	1,083			19	298	754	0	12	12
Presque Isle	1	7,573			4,231	1,412	132	1,780	18	14
Harrisville	1	515			0	201	284	0	30	21
Tawas City	7	979 ±	820	201 - 2,684	2	415	411	8	143	56
Lexington	1	580			0	264	279	0	37	24
Cheboygan	6	4,148 ±	2,722	833 - 9,085	0	1,497	575	119	1,957	81
Alpena	10	5,721 ±	3,468	2,223 - 12,323	1	5,423	199	34	65	55
Harbor Beach	8	3,796 ±	2,214	486 - 7,189	0	3,334	375	0	19	36

a. Data reported in Reference (25).

affinis was not found at Cheboygan or Harbor Beach and was found at Alpena in extremely low numbers.

The taxa present at Cheboygan indicate organic enrichment, apparently from municipal water, paper mill, and stormwater discharges. The community was dominated by the pollution-tolerant isopods, *Asellus sp.* and *Lirceus sp.*, and amphipods, *Gammarus sp.* and *Hyallela azteca*. These four taxa collectively accounted for over 37% of the total population.

Oligochaetes tolerant of organic enrichment formed 95% of the total benthic community at Alpena. Unidentifiable immature tubificids account for 71% of the oligochaete population. The abundance of oligochaetes and presence of pollution-tolerant oligochaetes and chironomids indicate that Thunder Bay is organically enriched. Historical data on the benthic community reflect increasing organic enrichment since 1957 (38). Oligochaetes comprised 72, 89, and 95% of the total community during 1957, 1965, and 1974, respectively. Conversely, sphaeriids accounted for 18, 2, and 1% of the total population. *Pontoporeia affinis* was virtually absent for all three dates.

The benthic community within the harbour at Harbor Beach indicates a severely degraded benthic environment. Oligochaetes comprised 89% of the total population. Four oligochaetes tolerant of severe organic pollution, *Limnodrilus claparedianus, L. cervix, L. hoffmeisteri,* and *L. maumeensis,* accounted for 62% of the oligochaete numbers. The dominant chironomid taxa were also forms tolerant to organic enrichment. The benthic community outside the harbour was different, indicating that the severe organic pollution is generally inside the harbour. The community outside the harbour was dominated by mesotrophic and eutrophic indicators; organisms indicative of severe enrichment were absent. This area is directly influenced by the outflow of water from the harbour and currents carrying enriched waters from Saginaw Bay. Historical data on the benthic community indicated little change since 1958 (39).

METAL AND ORGANIC CONTAMINANTS IN FISH

Contamination of Great Lakes fishes with certain heavy metals and organic pollutants (such as pesticides and PCB's) has become a major concern over the past 10 years. Willford (40) cited DDT, dieldrin, PCB's, and mercury as the four major fish contaminants to date. High concentrations of one or more of these contaminants have resulted in bans on commercial fishing or bans on the use of fish for human consumption.

Guidelines or tolerance levels for various contaminants in fish have been set by the Canada Department of National Health and Welfare and by the U.S. Food and Drug Administration (FDA) and objectives have been proposed for the Water Quality Agreement. The contaminants for which guidelines exist or have been proposed include arsenic, lead, mercury, PCB's, aldrin, dieldrin, endrin, heptachlor epoxide, and DDT and its metabolites. The limits are summarized in Appendix C.

Little literature is available on contaminants in fishes from Lake Huron. Reinert (41) reported relatively low levels of total DDT and dieldrin in various species of fish from Lake Huron. The Great Lakes Environmental Contaminant Survey (42) reported generally low concentrations of DDT, dieldrin, PCB's, and mercury in Lake Huron fishes. These 1973 and 1974 data indicated DDT, PCB's, and mercury generally did not exceed guidelines in Lake Huron fish. Previous studies of heavy metal contamination of Great Lakes fishes have been reported by Lucas and Eddington (43), Uthe and Bligh (44), and Beal (45); however, no Lake Huron data were presented, so these studies can only be used for comparison purposes.

MICHIGAN

Michigan collected fish during 1974 and 1975 from five nearshore locations in Lake Huron: Hammond Bay, Alpena, Tawas City, Harbor Beach, and Lexington (Figure 4.1-1). Whitefish (*Coregonus clupeaformis*), rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), chinook salmon (*Oncorhynchus tshawytscha*), walleye (*Stizostedion vitreum*), and yellow perch (*Perca flavescens*) were sampled. Analyses were performed on skinless fillets of individual fish and, in the case of yellow perch, on composites of four to fifteen fillets. All samples were analyzed for DDT and its isomers, dieldrin, PCB's, and mercury (Table 4.1-14) and about two-thirds of the samples were analyzed for 17 additional contaminants. All data were calculated on a wet weight basis.

Pesticides and other organic contaminants in all species were low. Chlordane, lindane, methoxychlor, hexachlorobenzene, hexachlorobutadiene, dibutyl-n-phtalate, 2,2-diethylhexylphthalate, and polybrominated biphenyls were not found at detectable levels in any fish analyzed. Total DDT was generally found above detectable levels (Table 4.1-15) with the highest location mean (0.97 mg/kg) occurring in chinook salmon at Alpena. The lowest location mean was in yellow perch composites from Hammond Bay, where total DDT was not detected in any sample. All the salmonids, including whitefish, had mean location levels >0.2 mg/kg, while the percids, yellow perch and walleye, generally had means <0.07 mg/kg.

PCB's were generally very low in the Lake Huron fish. However, brown trout and chinook salmon had elevated values. The mean for chinook salmon from Alpena was 2.31 mg/kg while brown trout from Hammond Bay and Alpena had mean values of 1.13 and 1.10 mg/kg, respectively. The FDA guideline for PCB's (5.0 mg/kg) was not exceeded in any individual fish.

Means of PCB's in perch illustrate geographic variation of PCB residues. PCB's appear higher in the southern zone of the lake. The highest mean location value (0.30 mg/kg) was found at Harbor Beach while in the northern location of Hammond Bay, four composite samples contained no detectable (<0.01 mg/kg) PCB's.

Heavy metal concentrations were generally very low in all areas and all species sampled in Michigan. Only mercury values approached the guidelines; all other metals concentrations were <10% of the limits.

TABLE 4.1-14

CONTAMINANTS MEASURED IN FISH FROM NEARSHORE LAKE HURON WATERS[a]

	Ontario	Michigan
Heptachlor-heptachlor epoxide	*	
Dieldrin	*	*
Aldrin	*	
Lindane	*	*
Endrin	*	
DDT	*	*
DDD	*	*
DDE	*	*
Chlordane	*	*
Methoxychlor		*
Polychlorinated biphenyl (PCB)	*	*
Polybrominated biphenyl		*
Hexachlorobutadiene		*
Hexachlorobenzene		*
Dibutylphthalate		*
Diethylhexylphthalate		*
Copper	*	*
Nickel	*	*
Lead	*	*
Zinc	*	*
Cadmium	*	*
Manganese	*	
Arsenic	*	*
Chromium	*	*
Selenium	*	
Mercury	*	*
Gross α	*	
Gross β	*	
Individual fish		*
Composite	*	*
Fillets	*	*

a. Information from References (8) and (42).

TABLE 4.1-15

Mean Concentrations (mg/kg wet weight basis) of Selected Trace Contaminants in Fish Collected from Nearshore Lake Huron Waters, 1974 and 1975 [a]

LOCATION	SPECIES	DDT	PCB	DIELDRIN	Hg	Cu	Zn	Pb	Cd
MICHIGAN									
Detection Limit		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Hammond Bay	Brown Trout	0.57	1.13	0.02	0.13	0.74	3.46	0.11	0.03
	Perch	b	b	b	0.31	0.56	4.60	0.26	0.10
	Rainbow Trout	0.32	0.94	0.03	0.10	0.61	3.78	0.07	0.03
	Walleye	0.03	b	b	0.17	0.28	3.80	0.23	0.30
	Whitefish	0.26	b	0.05	0.04	0.64	3.59	0.71	b
Alpena 1974	Brown Trout	0.50	1.10	0.04	0.13	0.33	2.90	0.10	0.01
	Chinook	0.97	2.31	0.05	0.22				
	Perch	0.03	b	<0.01	0.15	0.37	4.69	0.18	0.03
	Whitefish	0.35	0.34	0.05	0.03				
1975	Perch	0.04	0.13	b	0.26	0.29	8.12	0.77	0.04
Tawas City 1974	Whitefish	0.12	0.22	0.03	0.03				
1975	Perch	0.07	0.20	b	0.27	0.27	7.64	0.38	0.03
Harbor Beach	Perch	0.13	0.30	b	0.34	0.31	7.70	0.40	0.03
Lexington	Perch	0.05	0.13	b	0.33	0.24	7.12	0.32	0.03
ONTARIO									
Detection Limit		0.001	0.001	0.001	0.01	0.01	0.01	0.5	0.2
Goderich	Perch	0.017	0.089	0.002	0.22	0.41	6.50	<0.5	<0.2
	Rainbow Trout	0.485	1.943	0.045	0.18	0.68	4.92	<0.5	<0.2
	White Sucker	0.261	0.606	0.034	0.14	0.75	6.57	<0.5	<0.2
Douglas Point	Rainbow Trout	0.549	2.179	0.035	0.16	0.75	4.85	<0.5	<0.2
	White Sucker	0.112	0.356	0.009	0.23	0.64	6.32	<0.5	<0.2
	Northern Pike	0.148	0.515	0.004	0.40	0.39	5.84	<0.5	<0.2
Owen Sound	Perch	0.037	0.189	0.003	0.29	0.59	7.53	<0.5	<0.2
	Rainbow Trout	0.338	1.073	0.036	0.19	0.65	6.42	<0.5	<0.2
	White Sucker	0.325	0.693	0.031	0.11	0.61	6.65	<0.5	<0.2
Thornbury	Perch	0.017	0.093	0.002	0.22	0.45	6.90	<0.5	<0.2
	Rainbow Trout	0.376	0.910	0.030	0.20	0.57	6.43	<0.5	<0.2
	White Sucker	0.323	0.562	0.023	0.10	0.62	7.70	<0.5	<0.2
Nottawasaga	Perch	0.040	0.183	0.003	0.32	0.64	4.30	<0.5	<0.2
	Rainbow Trout	0.415	1.207	0.034	0.18	0.53	5.09	<0.5	<0.2
	Walleye	0.351	0.827	0.010	0.57	0.37	4.30	<0.5	<0.2
	White Sucker	0.723	1.153	0.051	0.16	0.74	6.27	<0.5	<0.2
Penetang-Midland	Perch	0.024	0.115	0.002	0.27	0.60	7.15	<0.5	<0.2
	Walleye	0.114	0.258	0.004	0.46	0.46	4.43	<0.5	<0.2
	Rock Bass	0.011	0.074	0.002	0.17	0.55	7.43	<0.5	<0.2
Spanish River	Perch	0.007	0.046	<0.001	0.27	0.60	6.23	<0.5	<0.2
	White Sucker	0.037	0.131	0.003	0.06	0.57	6.70	<0.5	<0.2
	Northern Pike	0.024	0.114	<0.001	0.25	0.46	5.20	<0.5	<0.2
Serpent River	Perch	0.027	0.149	0.002	0.31	0.54	7.26	<0.5	<0.2
	White Sucker	0.043	0.125	0.004	0.04	0.66	5.78	<0.5	<0.2
	Northern Pike	0.085	0.266	0.001	0.40	0.49	6.45	<0.5	<0.2
Lake George	Perch	0.003	0.068	0.001	0.23	0.55	5.73	<0.5	<0.2
	White Sucker	0.073	0.194	0.004	0.13	0.64	5.55	<0.5	<0.2
	Northern Pike	0.024	0.096	b	0.02	0.41	4.99	<0.5	<0.2

a. References for data (2, 8 and 25).

b. Not detected.

The highest mean mercury values were found in yellow perch from Hammond Bay (0.31 mg/kg), Harbor Beach (0.34 mg/kg), and Lexington (0.33 mg/kg). The maximum mercury value measured was 0.49 mg/kg in a yellow perch from Hammond Bay.

ONTARIO

Ontario collected fish during 1974 from nine nearshore locations in Lake Huron (Table 4.1-15, Figure 4.1-1). Species of fish collected included rainbow trout (*Salmo gairdneri*), white sucker (*Catostomus commersoni*), northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), walleye (*Stizostedion vitreum*), and rock bass (*Ambloplites rupestris*). At each location, three species of fish were collected with at least one predator species represented. A sample consisted of 50 mature fish of similar size for each species. Analyses were performed on a composite of five fish fillets giving 10 composite samples for a species at each location. Samples were analyzed for 23 heavy metals and organic trace contaminants (Table 4.1-14) and results calculated on a wet weight basis.

Lindane, aldrin, and heptachlor were not detected in any fish samples. Levels of dieldrin, endrin, heptachlor epoxide, total DDT, chlordane, and PCB's from southern Lake Huron and Nottawasaga locations were slightly higher than corresponding levels in fish from the North Channel and Lake George (2,8). The predator species (rainbow trout, walleye, or northern pike) contained the highest concentration of both PCB's and pesticides, except for northern pike from the Spanish River mouth. There is a direct relationship between weight of rainbow trout and PCB residues. This relationship was not found in any other species. The maximum location mean concentration of PCB's (2.179 mg/kg) occurred in rainbow trout from Douglas Point while the minimum location mean (0.046 mg/kg) was found in yellow perch from Spanish River mouth. Total DDT reached a maximum location mean of 0.723 mg/kg in white suckers from Nottawasaga Bay. The levels of dieldrin, endrin, and heptachlor epoxide in fish were at least an order of magnitude lower than the FDA guidelines and the proposed Agreement objectives.

Heavy metal concentrations in Lake Huron nearshore fish are generally low. Mercury was the only metal approaching or exceeding the U.S. or Canadian guidelines. Three composite walleye samples from Nottawasaga Bay had a mean mercury concentration of 0.57 mg/kg, which exceeded the guidelines (0.5 mg/kg). Mercury in northern pike from Douglas Point (0.40 mg/kg) and the Serpent River mouth (0.40 mg/kg) and in walleye from the Penetang-Midland area (0.46 mg/kg) approached the guideline. All arsenic and lead concentrations were less than 10% of the guideline levels for freshwater animal products.

Arsenic, mercury, and chromium were the only metals which varied between species. Rainbow trout contained four times the arsenic of other species. The levels of mercury were variable among all species with walleye having a mean of 0.48 mg/kg, northern pike 0.33 mg/kg, yellow perch 0.27 mg/kg, rainbow trout 0.18 mg/kg, rock bass 0.17 mg/kg, and white sucker 0.12 mg/kg. Chromium levels were greatest in northern pike and rainbow trout, ranging up to 2.0 mg/kg. All other species contained levels generally <1.0 mg/kg.

There was little variation in radioactivity levels between species or between locations. There is no established maximum acceptable level for radioactivity in fish flesh. The observed values are low with all samples having a gross α <1.0 pCi/g based on wet weight. Samples analyzed for gross β radioactivity had a range of mean location values from 1.73 to 3.59 pCi/g. The minimum level was found in rainbow trout at Douglas Point, the site of an Ontario Hydro nuclear generating station.

SUMMARY OF EXISTING AND DEVELOPING PROBLEMS

ENRICHMENT

Several criteria have been proposed for the classification of lakes by trophic state based on the abundance of biomass, phytoplankton production, nutrient concentrations and loads, surface-to-volume ratio, and sediment types. While no one criterion provides reliable characterization in every case, these guidelines when taken together are useful for detecting changes in the trophic status and do indeed reflect the suitability of lakes for a variety of uses.

Seasonal mean chlorophyll α values in all nearshore segments were in the oligotrophic range except segments B and I in spring 1974 where mean chlorophyll α levels indicated mesotrophic conditions (Figure 4.1-8). Segment B exhibits high levels of resuspended solids which contribute to observed levels of nutrients. Most of the nutrient loading to segment B is from tributaries where upstream sources are diffuse. The enrichment of segment I resulted from southward flow of highly eutrophic waters from Saginaw Bay. However, Agreement water quality objectives were not exceeded by any segment B or I mean values. Coastal physical processes further aggravate nearshore water quality since nearshore waters are contained rather than mixed with offshore waters during spring (15,16,46).

Results of a long-term phytoplankton study (6) indicate that moderately high algal populations characteristic of mesotrophic lakes occur in the Ontario nearshore waters of southeastern Lake Huron. In contrast, phytoplantkon data from nearshore areas of Georgian Bay clearly reflect their relatively unproductive nature (6). Diatoms, which are associated with oligotrophic conditions, were the dominant algal group along the Michigan shoreline except in Thunder Bay at Alpena during June. During this period, blue-green algae, typical of mesotrophic conditions, were dominant. There appeared to be an overall north-to-south increase in algal abundance in Lake Huron, but this trend was masked, in part, by location variability.

The embayments of Goderich, Collingwood, Penetanguishene, Midland, Serpent Harbour, Spanish River mouth, Cheboygan, Alpena, and Harbor Beach were all found to have developing nutrient enrichment to varying degrees. Local enrichment of Collingwood Harbour is directly influenced by municipal STP loadings, flushing rate, runoff, and available nutrients from resuspended sediments. In 1974, chlorophyll α concentrations in Collingwood Harbour ranged from 0.1 to 29 $\mu g/\ell$. In late summer 1974, algal bloom conditions were observed within the harbour, extending over an area of $\sim$ 1.8 km^2. Phosphorus removal for the Collingwood STP is presently operational (May 1975) and further water quality studies are presently underway to assess the effectiveness of remedial measures.

In the nutrient enrichment section, Chapter 6.1, a discussion of future enrichment trends in local embayments of Lake Huron is included which utilizes results from the waste loading simulation model presented in Chapter 3.12. Based on the application of 85% phosphorus removal from the STP effluent at Collingwood and predicted urban growth, an estimated level of 10 μg chlorophyll α/ℓ would exist in the harbour by the year 2020 if the present discharge location and the physical characteristics of the harbour do not change. This level would be in the eutrophic range. To protect against further enrichment, the STP discharge may have to be relocated. A discharge to Nottawasaga Bay would be advantageous in terms of greater dilution volume, but due consideration would have to be given at that time to cost, location, and potential impact on local water use.

Goderich Harbour and the adjacent nearshore area are directly influenced by inputs of phosphorus and nitrogen from the Maitland River. Project Report D-27 shows that low flow loadings have been constant since 1966 (3); however, peak spring loadings have increased four and five times since 1966 for nitrogen and phosphorus respectively. If seasonal tributary inputs of nitrogen and phosphorus continue to increase, there is a strong possibility that adverse effects on water use in Goderich Harbour and adjacent nearshore Lake Huron would occur.

Project Report D-5 indicates that 3-to-5 fold variations in annual a.s.u. (areal standard unit) averages for phytoplankton stocks at the Goderich and Grand Bend intake sampling locations have occurred (6). Year-to-year differences at these locations suggest that a slight overall trend towards decreasing phytoplankton densities may be occurring.

Veal and Michalski (20) noted recent nutrient enrichment in Penetang and Midland Bays. Nutrient removal programs for municipal discharges are now fully operational at Penetanguishene, the Ontario Hospital, and Midland and are planned for Port McNichol. A decrease in phosphorus loadings to the area has occurred which should have a gradual beneficial effect on water quality in the area.

Applying the same approach as for Collingwood Harbour and assuming an 85% level of phosphorus removal from controllable sources, it is predicted that chlorophyll α levels by the year 2020 in Midland Bay and

Penetang Bay would be 3.9 and 6.8 μg/ℓ, respectively. The predicted chlorophyll α level in both bays is above 2 μg/ℓ, the level considered mesotrophic (17-19). It is apparent that 85% phosphorus removal from all controllable sources would not be sufficient in 2020 for the control of nuisance algal growth in Midland Bay; therefore, the best practicable nutrient removal technology at that time may have to be investigated. Future development and discharges to Penetang Bay would have to be strictly controlled in view of the limited assimilation capacity and long phosphorus retention time (2.5 years) of the bay. Effluent requirements in the future should be set by taking into account the nutrient removal technology available and the possible relocation of discharges to Midland Bay.

The level of chlorophyll α at the Spanish River mouth ranged from 0.5 to 4.0 μg/ℓ and in Serpent Harbour from 0.3 to 5.4 μg/ℓ. Although upstream inputs are the major sources of nitrogen and phosphorus to these areas, the chlorophyll α concentrations are not sufficiently elevated to presently cause concern. Nitrogen sources, primarily ammonia, to the Serpent River are from upstream mine tailing areas. In the event of future mine re-openings, increased loadings of nitrogen to Serpent Harbour may occur. Maximum reuse of process waters is being practiced at active mine sites in the Elliot Lake area, and additional treatment of final discharges from tailings ponds is being investigated.

Nutrient inputs to Spanish River mouth originate from upstream urban and industrial development. There are ongoing waste treatment programs for industrial and urban waste discharges to the Spanish River and its major tributaries, Junction Creek and the Vermillion River.

Enrichment of a lake is also reflected in the benthic animal community. Sediments are altered as the result of the settling of algae and other organic materials. The nearshore benthos contained those species which indicate a trend toward mesotrophic conditions. Along the Michigan nearshore there is a north-to-south change in the composition and abundance of benthic animals. The southern locations, Tawas City and Lexington, were dominated by pollution-tolerant sludgeworms and midges. The present pollution of these areas results from the influence of Saginaw Bay.

The enrichment at Cheboygan results from the municipal waste treatment plant. Chlorophyll α concentrations averaged 2.6 μg/ℓ. Nutrient control facilities, which are to be operational by 1978, should eliminate the overproduction of phytoplankton.

The problems of nutrient enrichment at Alpena are compounded by the long retention time of the harbour water. Total phosphorus concentrations near the river mouth averaged 54 μg/ℓ. Phytoplankton have sufficient time to develop and result in an average chlorophyll α level of 5.0 μg/ℓ. Nutrient removal at the waste treatment facilities is now operational. Surveillance of this harbour should be continued to determine if the waste treatment is effective in decreasing the water quality problems.

The enrichment problems at Harbor Beach are most severe within the harbour sea walls where chlorophyll α averaged 7.6 μg/ℓ. Dilution is sufficient outside the harbour to avoid any water quality problems. Nutrient removal facilities are expected to be completed in 1980.

The remaining local study areas of Owen Sound, Tobermory, Southampton, and Port Elgin displayed no significant nutrient enrichment. Because of restricted exchange with Georgian Bay, Parry Sound Harbour and Parry Sound have limited nutrient assimilation capacities. Although present studies did not indicate any nutrient enrichment problems, future studies may indicate the need for further nutrient abatement at controllable sources entering Parry Sound.

BACTERIAL CONTAMINATION

The Town of Blind River, the Spanish River mouth, Penetanguishene, Owen Sound, and Goderich exhibited poor bacterial quality on more than one occasion or at more than one sampling location. In many cases, sampling was not intensive enough to allow a strict comparison with objectives; however, the data are indicative of existing or potential problems from sanitary waste inputs.

Bacterial levels in the northwestern portion of the North Channel were elevated because of loadings from the St. Marys River. The rest of the North Channel was of high bacteriological quality except in the vicinity of Blind River where elevated fecal coliform and *Pseudomonas aeruginosa* levels were found in June 1974. At the mouth of the Spanish River high levels of total and fecal coliforms were evident in the summer and fall of 1974. At both locations the contamination was attributed to the discharge of inadequately treated sewage.

The inner portion of Penetang Bay exhibited total coliform densities exceeding Agreement objectives (Appendix C) during the summer of 1974. These were attributed to urban drainage and the discharge of inadequately disinfected waste; however, heavy recreational use may also be a contributor.

Fecal coliform and fecal streptococci levels at the Sydenham River mouth in Owen Sound exceeded objectives in May 1974. In the Goderich area, a few stations outside the harbour had high total coliform counts during a September 1974 survey.

Elevated total coliform counts were observed at Cheboygan, Alpena, Tawas City, and Harbor Beach, where municipal wastewaters are discharged to tributaries flowing into Lake Huron. Maximum total coliform densities were recorded at river mouth stations. The mouth of the Cheboygan, Thunder Bay, and Tawas Rivers had total coliform counts >1,000/100 mℓ. Two samples at the mouth of the Thunder Bay River had total coliform counts of 18,000 and 14,000/100 mℓ.

Total coliform densities in 29% of the samples from Alpena exceeded Agreement objectives during both sampling periods. During spring sampling Cheboygan and Harbor Beach total coliform densities exceeded Agreement objectives and during fall sampling, objectives were exceeded at Tawas City and Lexington (Segment I).

Fourteen percent of the samples from Cheboygan and Alpena had fecal coliform counts greater than 200 organisms/100 mℓ during the spring. During the fall, 14% of the Tawas City samples had fecal coliform counts >200 organisms/100 mℓ. As with total coliforms, fecal coliform densities were highest at river mouth stations. Maximum fecal coliform densities were found at the mouth of the Cheboygan River (470 and 440 counts/100 mℓ).

Fecal streptococci densities exceeded 100 counts/100 mℓ at Tawas City during the spring. When detected, maximum fecal streptococci densities were found at or near river mouth stations.

METALS CONTAMINATION

During present studies, Ontario MOE and Michigan DNR sampled sediments for metal analysis. Most of the heavy metals in the surficial sediments of Lake Huron nearshore areas reflect natural background levels. At present, there exist no Ontario guidelines for heavy metals in sediment except for those which are applied to the disposal of dredging spoils in open water. The Ontario guidelines (Appendix C) apply only to those areas subject to dredging and spoils disposal.

Dredging in Lake Huron takes place at the locations given in Chapter 3.9. On the Canadian side, this dredging occurs at 3-10 year intervals. For the past three years, the major dredging operation has been in conjunction with the Bruce Nuclear Power Development at Douglas Point.

Several harbours and embayments exhibited elevated concentrations of heavy metals. Collingwood Harbour sediments had high concentrations of zinc, cadmium, and lead which can be related to local shipbuilding operations. Zinc concentrations were also high in sediments at Penetang, Midland, and Parry Sound Harbour. Mining activities and mineralization in the Spanish and Serpent River basins have resulted in high nickel concentrations in North Channel sediments and in Serpent Harbour. The impact of these concentrations on water use is unknown since criteria have not been established.

Zinc levels at Cheboygan exceeded the EPA dredge spoil guideline (Appendix C). Zinc in Harbor Beach sediments was also above the EPA dredge spoil guideline. Iron and chromium were also elevated. These metals resulted from past operations of the Hercules Company.

ORGANIC CONTAMINANTS

PHENOLIC SUBSTANCES

Phenolic loadings to Spanish River mouth are associated with pulp and paper mill activity upstream and may be contributing to reports of fish tainting. Eddy Forest Products, Espanola has been examining the feasibility of the installation of an oxygen-alkali delignification process which would reduce phenol levels in the waste stream; however, in light of present economic constraints the installation has been postponed.

DDT AND METABOLITES

DDT and its metabolites were detected in sediments from segments D and E, Tobermory, Owen Sound, Collingwood Harbour, Penetanguishene, Midland, Spanish River mouth, and Serpent Harbour. In most areas, DDT sources can be attributed to past agricultural use except for levels present in the Serpent and Spanish River mouth areas where DDT may be derived from its past usage for the control of black flies.

DIELDRIN

Dieldrin was only detected in sediments in segment D, Owen Sound Harbour, and Penetang-Midland. A possible source of dieldrin is agricultural use in these areas.

PCB's

Two sediment samples taken from Ausable River mouth and Bayfield River mouth had PCB levels of 36 and 94 μg/kg, respectively. In Georgian Bay sediments, detected PCB levels ranged from 15-900 μg/kg. Owen Sound and Collingwood Harbour had the highest PCB concentrations recorded in sediment samples. Although the sale of PCB's has been restricted to closed system uses, because of their persistence it is expected that levels in sediments may not change appreciably for some time in the future.

The impact of these contaminants on the biota was investigated through residues in fish and is discussed in the following section.

FISH RESIDUES

In all areas the predator species (rainbow trout, walleye, and northern pike) had higher levels of PCB's and pesticides than non-predator species. The pesticides lindane, aldrin, and heptachlor were not detected in any of the nearshore fish samples (8).

The proposed Agreement objective (Appendix C) recommends that for the protection of wildfowl and animals which eat fish, whole fish, on wet weight basis, should contain no more than 0.1 μg/g of PCB's. This proposed objective was exceeded in most fish taken in all areas. The Canadian Food and Drug Directorate guideline of 2 μg/g for PCB's in fish was exceeded in the mean value of 50 fish taken at Douglas Point. Individual rainbow trout with PCB levels exceeding this guideline were also found in Goderich, Owen Sound, Thornbury, and Nottawasaga Bay.

The maximum levels of the sum of the concentrations of DDT and its metabolites was <1.0 μg/g, the proposed Agreement objective for the protection of fish-consuming aquatic birds (Appendix C). Dieldrin, aldrin, and heptachlor epoxide levels were each an order of magnitude less than the proposed Agreement objectives and the U.S. FDA guidelines (Appendix C).

The U.S. FDA has set a guideline of 5.0 mg/kg for PCB's in edible fish tissue. This guideline was not exceeded by any individual fish tested from Michigan nearshore waters. One chinook salmon from Alpena contained 2.31 mg/kg PCB's. No salmon or trout were collected south of Alpena.

Mercury was the only heavy metal found to exceed the guideline of 0.5 μg/g as set by the Canadian Food and Drug Directorate for the protection of human consumers of fish. Three composite samples of walleye from Nottawasaga Bay had a mean value of 0.57 μg/g. Northern pike from the Douglas Point area (0.40 μg/g) and the Serpent River mouth (0.40 μg/g) and walleye from the Penetang-Midland area (0.46 μg/g) approached the guideline set for mercury (8). No source for this contamination has been identified.

None of the fish tested had arsenic and lead concentrations greater than 10% of the levels established in the regulations under the Canadian Food and Drug Act (Appendix C).

THERMAL INPUTS

The only major input of heated water to the Ontario side of Lake Huron is from the Douglas Point-Bruce Nuclear Power Development site, located north of Kincardine, Ontario (Figure 4.1-1). Presently, the lake is receiving thermal discharges from the Douglas Point Generating Station and Bruce Heavy Water Plant "A". Temperatures in excess of the Ontario guideline for ΔT = outfall T - intake T = $11.6C^{o}$, have been reported for the combined discharge of the Douglas Point Generating Station and Bruce Heavy Water Plant "A". A program involving the new intake and discharge channel for the Bruce Heavy Water Plant complex is expected to be in operation by 1977, which should result in compliance with the Ontario guideline.

Bruce Generating Station "A" began operation in 1976. Data regarding the pre-operational water quality baseline in the vicinity of the outfall has been compiled by MOE and will be used for comparison with data obtained after the plant achieves full operating status.

The Karn-Weadock power plants on Saginaw Bay are the major plants along the Michigan shoreline of Lake Huron. The total heat load for both plants is 41.6 x 10^3 MW, which results in a large thermal plume in Saginaw Bay. The thermal plume encompassed a maximum area of 8.06 km^2 and extended up to 3.2 km along the southeast shoreline of the inner bay. The only change in water quality was an increase in water temperature. Minor changes were noted in the periphytic algal and benthic animal communities.

TRANSPARENCY

Nearshore segments A and B and Goderich Harbour had very low Secchi depths (1.5 m) and high turbidity (2-16 FTU) indicating high levels of suspended solids. Since natural shoreline erosion occurs in segments A and B at a rate between -1.58 to +1.97 m/a with an average recession rate = 0.12 m/a (47,48), one could expect high suspended solids levels. Goderich Harbour is influenced by the Maitland River which discharges an estimated 26,000 kg/d of suspended solids to segment B.

Shore erosion along the west shore of Lake Huron (segments G and I) is minimal which results in high transparency. Secchi depths in segments G an I were 7.1 and 4.7 m, respectively.

RADIOACTIVITY INPUTS

Although the amounts of radioactivity reaching Lake Huron are small, biomagnification of radionuclides in the tissue of many aquatic organisms and accumulation in bottom sediments of the receiving waters can occur. Measurements of radioactivity in fish collected from Lake Huron suggest that no significant levels have accumulated in the muscle of the species examined in the study. The lowest values of radioactivity were measured in fish collected from the Douglas Point area, the site of the Douglas Point Nuclear Generating Station.

Tritium accounts for the largest (number of curies) radioactivity discharge from CANDU reactors. The Douglas Point Generating Station is presently at 220 MW (electric) and the projected nuclear electric generating capacity in Lake Huron is 9000 MW by the year 2000. Based on current experience at the nuclear generating stations of Ontario Hydro, it is expected that effluent from Ontario reactors situated on Lake Huron will contribute a dose of $\sim$0.2 mrem/a by the year 2000, which is well below the dose limits set by the Atomic Energy Control Board for individual members of the public (500 mrem/a). A proposed Agreement objective of 1 mrem/a is being considered by Governments.

In general, the overall levels of radioactivity entering Serpent Harbour have decreased since the late 1960's. The reduction of radioactivity levels in water can be attributed to a decrease in mining activity, re-use of process waters, elimination of direct discharges to the receiving waters, natural decreases in streamflows, and the use of barium chloride treatment. During two 1975 surveys, ^{226}Ra levels >3 pCi/ℓ, the Ontario permissible criterion for surface water supply

(Appendix C), were noted within Serpent Harbour. On May 30, 1975, an area within the harbour extending 5 km from Serpent River mouth had ^{226}Ra levels greater than the criterion. During the September 23, 1975 survey ^{226}Ra levels in excess of the criterion were noted for an area extending 2.7 km from the river mouth (3).

Consumer's Power at Midland, Michigan, is constructing a nuclear plant with an electric generating capacity of 1636 MW. The plant is scheduled for completion about 1980. The plant is not expected to contribute any significant amount of radioactivity to Lake Huron.

4.2 SAGINAW BAY

This subchapter deals with Saginaw Bay on Lake Huron. As a near-shore area heavily influenced by human activity, Saginaw Bay is an obvious area of concern. However, the bay is also of considerable interest from a purely scientific point of view. The space and time scales are such that the results of scientific investigations on the bay may often be extrapolated to the Upper Lakes in general. However, unlike the main lake areas, Saginaw Bay reacts quickly to environmental changes and therefore the results of perturbations can be observed on the order of months instead of years.

The subchapter is divided into five sections. First, a description of the Saginaw Bay is presented. Next, the physical, chemical, and biological limnology of the bay is discussed. A special section on modelling methodology is included since modelling is used to assess present and future water quality problems. Then, these problems are described and categorized as either existing or potential. Finally, pollution abatement programs are discussed. Possible results of present programs are described using models, and the need for future action is suggested.

DESCRIPTION OF STUDY AREA

Saginaw Bay (Figure 4.2-1) is located on the western side of Lake Huron, extending in a southwesterly direction from the lake into the lower peninsula of Michigan. Within the bay, there are several islands; the most prominent include the Charity Islands located in the centre of the bay, and several islands surrounded by the low lying marshes on the southern side of the bay.

GEOLOGY AND TOPOGRAPHY

The western shore of the outer bay is primarily sand with a few rocky outcrops near Point Lookout. The eastern shore north of Sand Point is sandy, grading rapidly into rocky shore east of Hat Point. The shore areas of the inner bay vary from predominantly marsh to low, sandy ridges.

Geologically, Saginaw Bay has been considered a shallow extension of Lake Huron (1). Following the final retreat of the Pleistocene Ice, the bay region was covered by glacial Lake Saginaw. As the lake receded, about three to five thousand years ago, it exposed lacustrine sediments which are marked by today's sand beaches. The bay extends across the boundaries of Mississippian and Pennsylvanian rocks. However, the

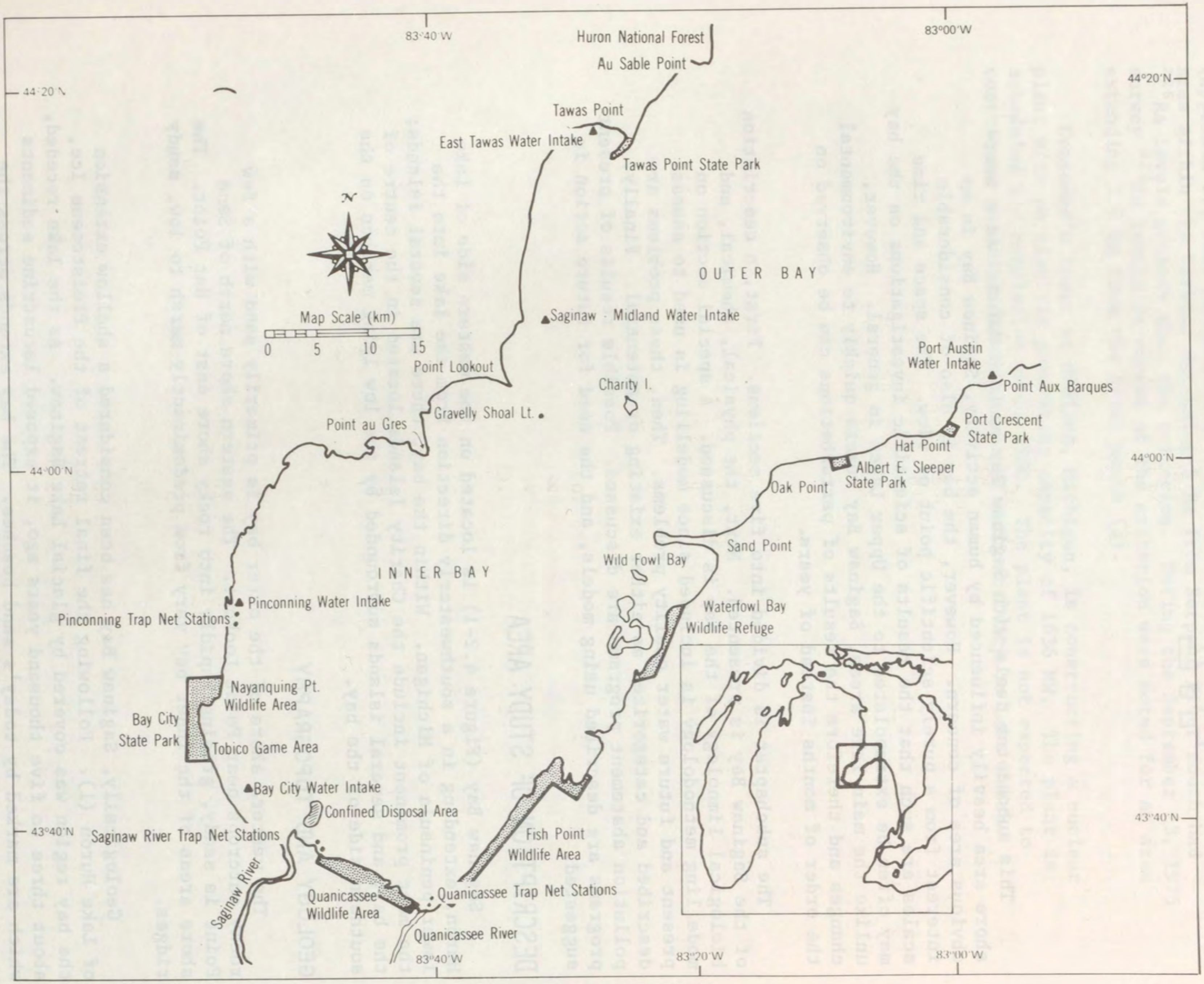


FIGURE 4.2-1 SAGINAW BAY GEOGRAPHY

Pleistocene glacial till defines most of the bay bottom. These deposits of quartz, sand, gravel and silt have been locally shifted and sorted by bay currents. Extensive sandy flats exist south of Wild Fowl Bay and west from the Saginaw River to Point Au Gres. An extensive reef area, Coryeon Reef, extends from the Charity Islands south to just north of the Quanicassee River mouth. Overall, the inner bay is dominated by extensive shallows.

The bay is 42 km wide at its mouth between Pointe aux Barques and Au Sable Point, with a minimum width of 21 km between Sand Point and Point Lookout. The bay is 82 km long, with a shoreline of 230 km and a surface area of 2960 km^2. A broad shoal from Charity Island to Sand Point divides the bay into the inner and outer bay. The inner bay has a mean depth of 4.6 m with a maximum depth of 14.0 m, whereas the outer bay has a mean depth of 14.6 m with a maximum depth of 40.5 m. As a result, the inner bay contains only 30% of the 30 x 10^9 m^3 of water in the bay.

WATER USES

Saginaw Bay serves the water needs of over 1.2 million people. Although small in comparison to Lake Huron proper, its value as a resource is higher in proportion because of its proximity to major population centres.

DOMESTIC WATER SUPPLY

Five municipal water intakes are located in Saginaw Bay (Figure 4.2-1), serving Saginaw-Midland, Pinconning, East Tawas, Bay City, and Port Austin. These water utilities serve a population of over 300,000 with an average total water consumption of about 235,000 m^3/d (Table 4.2-1).

INDUSTRIAL WATER SUPPLY

Michigan Sugar Company at Sebewaing utilizes the bay as a water supply directly. About 15,000 m^3/d are used for washing and process water.

RECREATION

The bay and its shoreline are used for boating, fishing, picnicking, swimming, and hunting. Park and wildlife refuge areas around the bay are shown in Figure 4.2-1. In addition, there are numerous local parks and privately owned seasonal homes which serve as recreational facilities (3).

Swimming takes place at the state parks and along the sandy portions of the bay shoreline, especially near Tawas City. Swimming at the Bay City State Park has been discouraged because of problems with algal blooms, bacteria, and turbid water.

Recreational boats on Saginaw Bay are served by seven harbour

TABLE 4.2-1

DOMESTIC WATER SUPPLY INTAKES - SAGINAW BAY, 1974(2)

INTAKE	POPULATION SERVED	WATER PUMPED (m^3/d)
Saginaw-Midland	224,000	190,000
Bay City	78,000	41,000
East Tawas	4,000	2,000
Pinconning	1,400	900
Port Austin	900	700
TOTAL	308,300	234,600

facilities as well as numerous local and private marinas and launching facilities. The available berths are not sufficient to fulfill the present demand. Programs underway will provide facilities for an additional 8,500 boats by 2020; however, this will leave over 20,000 boat demands unmet (4).

The bay provides a year-round sports fishery. Sport fish species include perch, bass, pike, catfish, walleye, and carp. Brown and rainbow trout planting started in 1968 and it is expected that these species will fulfill the fishing demand, which is expected to triple by 2020.

The Michigan Department of Natural Resources (DNR) has established six wildlife areas for public hunting and fishing.

WILDLIFE

Approximately 16,400 ha of marsh along the bay shoreline provide excellent wildlife habitats. The marshes provide both a nesting place and a migratory stopover area for a variety of puddle and diving ducks, geese, and swans. These are some of the finest waterfowl areas in the midwest.

COMMERCIAL NAVIGATION

Commercial navigation is of primary economic importance to the Saginaw Bay area. Products including coal, cement, petroleum, limestone, and foreign exports and imports totalling over 7 x 10^6 t were shipped through the bay to the Saginaw River docks in 1966 (5). This creates an income of over $7 million (1970 dollars) which is expected to increase to $132 million by 2020 (1970 dollars)(6). Shipping of this nature requires a navigation channel to be dredged through the inner bay and up the Saginaw River. Over 380,000 m^3 of spoil are removed annually, some of which is disposed of in a diked disposal area in the bay (Figure 4.2-1). Also, projects are underway which would extend the navigation season throughout the year.

COMMERCIAL FISHING

Saginaw Bay has been one of the most productive commercial fishing areas in the Great Lakes. The bay has the highest fish productivity in Lake Huron. This industry became established in the early 1800's and reached a peak in 1902 of 6,430,000 kg production (7). Over 90 species have been reported in the bay. Since the 1930's production and diversity of fish have changed drastically until 1966 when production decreased to 1,160,000 kg. These changes have been caused by the introduction of sea lampreys, alewives, and carp; by overfishing; and by water quality degradation. Carp now represent 30-50% of production. Whitefish, lake trout, and yellow perch remain as valuable resources. Yellow perch fishing was restricted in 1970. Northern pike and walleye have been completely closed to commercial fishing. The difficulty of harvesting most of the other species at a profit restricts commercial fishing (8).

WASTEWATER SOURCES

Saginaw Bay receives the waste discharges and runoff from a drainage basin serving over 1.2 million people (9, 10). Over 50% of the basin is farm land, 34% is forested, 3.5% is urbanized, and 1.2% is recreation land. The value of total farm products in 1964 was over $253 million. Products include sugar beets, beans, corn, wheat, dairy foods, and livestock. The basin also serves a varied industrial base including the food, chemical, automotive, lumber, and power generating industries.

The above activities result in a considerable input of municipal and industrial waste to Saginaw Bay (Figure 4.2-2, Table 4.2-2) via its tributaries, especially the Saginaw River, which drains most of the basin. There are few direct wastewater discharges to Saginaw Bay. The materials of primary concern for bay water quality include nutrients, organics, and dissolved solids.

Loadings of total phosphorus, total nitrogen, chloride, dissolved solids, and reactive silicate to Saginaw Bay via the Saginaw River are given in Table 3.3-4. The Saginaw River basin has been examined to identify the major sources of these materials. Pollutant loadings for the four major Saginaw River tributaries have been calculated. When the magnitudes of the tributary loadings were compared to tributary flow, it was found that the Tittabawasee River contributes a disproportionate amount of dissolved solids and chloride. The Flint River was found to contribute disproportionate amounts of total phosphorus and dissolved solids. The major municipal and industrial point sources in these two river basins have been identified (Table 3.3-5). Estimates have also been made of the fraction of the input to Saginaw Bay from non-point sources within the Saginaw River Basin (Table 3.3-5). The relatively high percentages of non-point sources illustrates clearly the limitations of pollution control programs aimed at reducing point source loads, as will be discussed in detail later in this subchapter. Additional discussion about inputs is given in Chapter 3.3.

LIMNOLOGY

Surveys have been conducted on Saginaw Bay since 1935 which permit some trend analysis for water quality. However, the significant spatial differences in bay water quality make visual representations of trends in the whole bay difficult. Also, application of water quality models requires spatial resolution of the physical system. In order to address these problems, the bay has been divided into five segments (Figure 4.2-3). The inner bay is subdivided into segments I, II, and III, while the outer bay is subdivided into segments IV and V.

PHYSICAL

This section includes temperature, dissolved oxygen, and conductivity which are useful indicators of water quality. Also included is a discussion of water movement and dispersion which, in general, is not a function of bay water quality but rather of meteorology and topography.

FIGURE 4.2-2 SIGNIFICANT SOURCES OF WASTEWATER IN SAGINAW RIVER WATERSHED (11)

TABLE 4.2-2

SIGNIFICANT DISCHARGES OF WASTEWATER TO THE SAGINAW BAY WATERSHED (11)

RIVER BASIN	MUNICIPAL	FLOWS (m^3/d)	INDUSTRIAL	FLOWS (m^3/d)
Flint River	Flint	128,700	GMC, Buick	28,100
	Flushing	4,200	GMC, Chevrolet	5,900
	Genessee Co. #2	15,100	GMC, Fisher Body	2,600
Tittabawasee River	Midland	24,600	Dow Chemical	585,200
Shiawassee River	Genessee Co. #3	5,700		
	Owasso	7,600		
Saginaw River	Bay City	45,400	Consumers Power	3,543,000
	Saginaw	123,800	Dow, Bay Refining	336,500
	Zilwaukee	14,800	GMC, Chevrolet, Metal Casting	141,700
			Michigan Sugar (Carrolton)	12,400
			Monitor Sugar	22,700
Cass River	Frankenmuth	4,600	Michigan Sugar (Coro)	2,300
Pine River			Michigan Chemical	35,600
			Total Leonard, Alma Refinery	2,300
Chippewa	Mt. Pleasant	9,500		
Saginaw Bay at Sebewaing			Michigan Sugar (Sebewaing)	11,500

Since water circulation can have a profound effect on water quality variables, some detailed explanation is warranted.

TEMPERATURE

Water temperatures in Saginaw Bay vary from 0°C in the winter to 20-25°C in the summer. Thermal overturns normally occur during May and October, where depth is sufficient for stratification (primarily in the outer bay). The presence of a thermal bar in April reduces mixing and limits dilution of pollutants within the bay. In general, higher temperatures result in lower dissolved oxygen concentrations. Since optimum growth conditions for different species of aquatic organisms are dependent on temperature, temperature changes can cause species shifts. The only major thermal discharge to the bay is from the Karn and the Weadock electric generating plants of Consumers Power Company located at the mouth of the Saginaw River. A maximum of 806 ha of the bay is heated 1.2 C° or more above ambient.

DISSOLVED OXYGEN

The dissolved oxygen concentration in almost all cases met the Michigan State standard. In 1974, 11 out of 705 shipboard dissolved oxygen measurements were below 6.0 mg/ℓ. In 1975, one value (3.0 mg/ℓ) was below 6.0 mg/ℓ. The minimum of 2.7 mg/ℓ was observed during late summer 1974 in the inner bay. An average of 9.2 mg/ℓ was observed for this region during the late summer. Overall, the spatial variability of mean dissolved oxygen levels was slight (Table 4.2-3) (12).

A water quality buoy, equipped with a dissolved oxygen sensor and recorder measured dissolved oxygen at a station in the middle of the inner bay every 4 hours during the summer of 1974. During the periods July 8-11 and July 13-15 dissolved oxygen was consistently below 6.0 mg/ℓ. These were the only days on which dissolved oxygen was observed below this standard at this site. The minimum recorded was 3.1 mg/ℓ (13).

Unless the water body is supersaturated, the normal maximum concentration of dissolved oxygen is between 8 and 14 mg/ℓ, depending on temperature. It is important to maintain dissolved oxygen as high as possible to provide conditions favorable for the growth and reproduction of a normal population of fish and other aquatic organisms. Organic, oxygen-demanding material discharged from wastewater treatment plants is usually the major cause of dissolved oxygen deficits. Dead algal matter can contribute to the deficit in certain situations as well as algal respiration at night.

CONDUCTIVITY

Conductivity measurements made in 1965 averaged 324 μS/cm in the inner bay and 210 μS/cm in the outer bay (14). As of 1974, the inner bay had been reduced to 256 μS/cm while the outer bay remained essentially unchanged (12). Conductivity measurements provide a rapid estimate of dissolved solids content. The major sources of dissolved solids loading

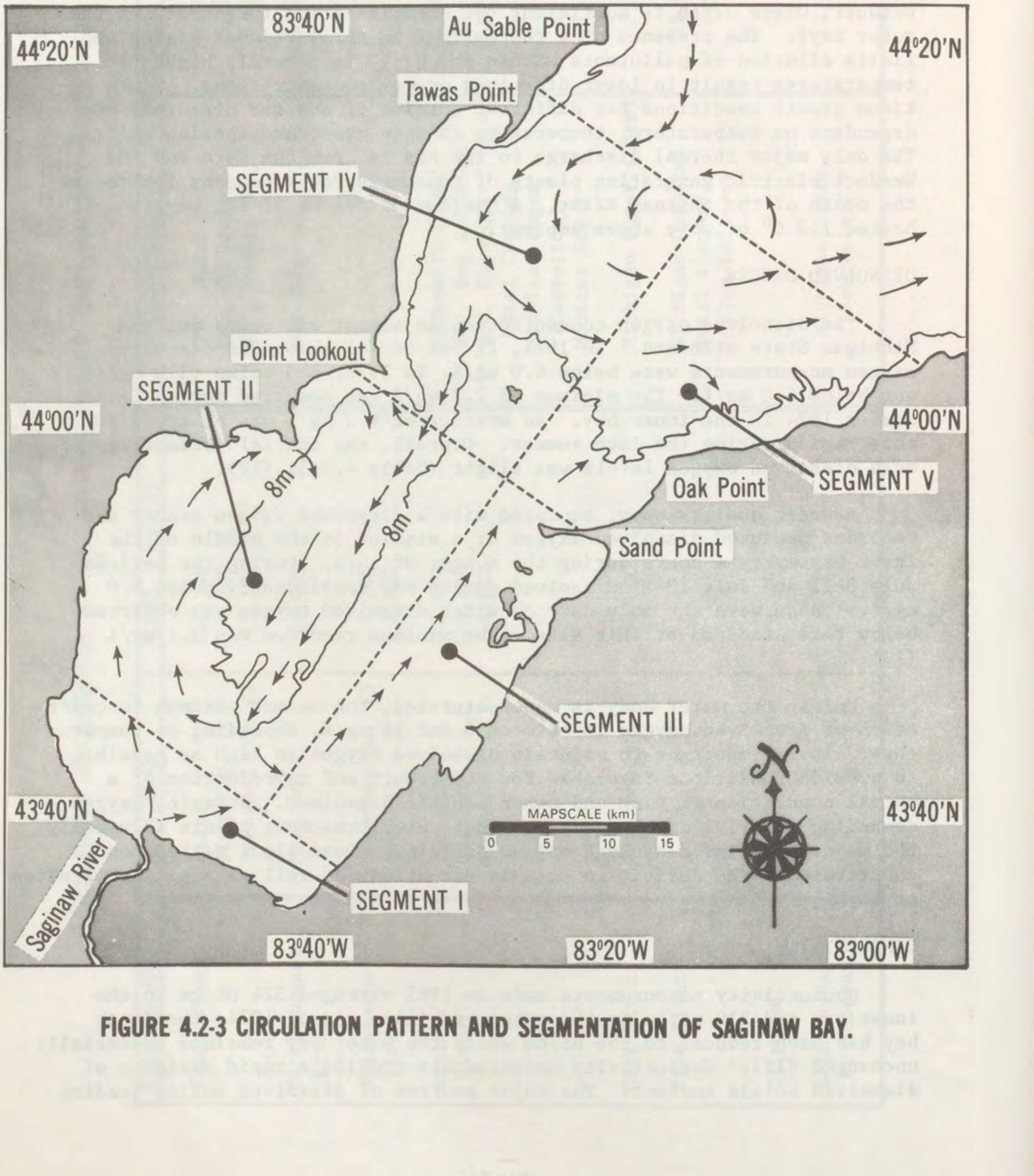


FIGURE 4.2-3 CIRCULATION PATTERN AND SEGMENTATION OF SAGINAW BAY.

to the Saginaw River are the Dow Chemical Company at Midland and the Michigan Chemical Company at St. Louis (Table 3.3-5). Significant reductions have occurred since 1965.

WATER MOVEMENTS AND DISPERSIONS

The circulation patterns in Saginaw Bay have been investigated by a number of different methods (15-19). From the qualitative and quantitative results of these studies a reasonable description of transport and dispersion in the bay can be given.

Flow or net movement of water from Lake Huron to the inner bay is through the deep channel on the northern side of the bay. From the channel, the water moves past the mouth of the Saginaw River and out to Lake Huron along the southern shore of the bay (Figure 4.2-3). The residence time of water in the inner bay is approximately four months, while the bay as a whole has a residence time of two months (20). This is because large amounts of water enter the bay from Lake Huron, but "short circuit" before flushing the inner bay. The southwest corner of the inner bay is nearly stagnant. This is evidenced by the high chloride and conductivity concentrations observed in this area. The circulation pattern in the inner bay is dependent mainly on wind speed and direction, while the pattern in the outer bay depends on the overall circulation of Lake Huron and bay geometry, as well as wind. The circulation pattern in the bay responds to wind speed and direction changes within 8 to 9 hours (16).

The circulation pattern (Figure 4.2-3) for prevailing southwesterly wind conditions indicates the occurrence of two eddies or gyres, one in the northeast corner of the inner bay and the other in the central part of the outer bay near its mouth. Although the net contribution to water movement due to these eddies is zero, they have a mixing effect and thus promote mass exchange. This phenomenon is known as dispersion.

The magnitude of water movement and dispersion fluctuates throughout the year due to various physical factors. During the period from December to March, the inner bay is usually covered with ice. Very little water movement occurs and pollutants tend to accumulate beneath the ice. As mentioned earlier, a thermal bar forms a horizontal barrier to mass exchange between the bay and lake in the early spring. This effect causes a 50% reduction in net water movement and a 75% reduction in dispersion between the inner and outer bay (19). As temperatures increase and the thermal bar dissipates, water movement and dispersion increase. In June, the bay is almost completely flushed out due to storms and high flows from the Saginaw River. During late summer and fall the bay settles down to more or less average conditions. The annual average exchange from the inner to the outer bay is approximately 800 m^3/s. From the entire bay to Lake Huron, the annual average exchange is approximately 5000 m^3/s (20).

CHEMICAL

Included in this section are chemical parameters that are indicative of Saginaw Bay water quality. Many of the parameters discussed are

TABLE 4.2-3

WATER QUALITY CHARACTERISTICS OF SAGINAW BAY - 1974 (12)

	SEGMENT I	SEGMENT II	SEGMENT III	SEGMENT IV	SEGMENT V	TOTAL BAY
Dissolved Oxygen ($mg\ O_2/\ell$)						
Mean ± Std. Dev.	10.1±1.6	10.1±2.0	10.1±1.7	11.6±1.8	11.0±1.6	10.6±1.9
Range	4.7-16.0	2.7-14.0	7.6-14.8	8.8-15.5	8.3-15.0	2.7-16.0
# of samples	156	205	50	175	119	705
Chloride (mg/ℓ)						
Mean ± Std. Dev.	22.9±12.9	13.4±5.6	20.0±7.7	7.0±4.0	9.0±4.4	13.2±9.5
Range	5.4-85.4	2.7-67.0	6.1-40.3	2.9-40.0	3.3-26.2	2.7-85.4
# of samples	201	260	68	254	208	991
Chlorophyll *a* (mg/ℓ)						
Mean ± Std. Dev.	29.01±14.88	16.26±10.37	24.85±13.40	3.52±2.34	7.69±8.81	15.70±14.30
Range	1.07-74.40	2.33-45.70	4.41-58.50	0.40-11.50	0.32-57.40	0.32-74.40
# of samples	152	178	54	138	128	650
Total Phosphorus (mg/ℓ)						
Mean ± Std. Dev.	0.058 ±0.039	0.026±0.013	0.037±0.015	0.009±0.010	0.013±0.016	0.025±0.027
Range	0.002-0.290	0.003-0.069	0.011-0.081	0.002-0.089	0.002-0.048	0.002-0.290
# of samples	109	180	47	157	142	635
Dissolved Reactive Silicate ($mg\ SiO_2/\ell$)						
Mean	0.88±0.70	1.05±0.65	0.72±0.39	1.08±0.33	0.98±0.42	0.99±0.55
Range	0.07-3.94	0.05-3.69	0.05-1.87	0.07-2.03	0.04-3.17	0.05-3.94
# of samples	200	275	68	256	209	1011

TABLE 4.2-4

Water Quality Changes in Saginaw Bay[a]

PARAMETER	SAMPLE LOCATION			YEAR	REFERENCES
	SAGINAW RIVER MOUTH	INNER BAY	OUTER BAY		
Chloride (mg/ℓ)	50-300	25-40	10	1935-1936	21
	280	60	11	1956	22
	170	47	8	1965	14
	48	18	8	1974	12
	35	13	8	1975	12
Chlorophyll *a* (μg/ℓ)	-	18	3	1965	14
	48	26	8	1974	12
	37	21	8	1975	12
Total Phosphorus (μg/ℓ)	-	41	18	1956	22
	170	-	-	1965	14
	111	38	12	1974	12
	154	32	13	1975	12

a. Values shown are means unless a range is given.

useful as qualitative measures of water quality; however, some of the parameters are major problems and are in violation of specific criteria. Emphasis is placed on the latter parameters. Major problems include nutrients and toxic substances. Observed concentrations are compared with the jurisdictional standards and objectives, which are tabulated in Appendix C.

ALGAL NUTRIENTS

Dissolved phosphorus, nitrogen, and reactive silicate are the algal nutrients of importance in Saginaw Bay. While deficiencies in each of these nutrients can limit algal growth, dissolved phosphorus is the only major, controllable nutrient that is absolutely required by all of the various types of algae. This is especially true for blue-green algae which are the most obnoxious from a water quality point of view. For this reason, emphasis is placed on phosphorus in this discussion. Since the only historical data on phosphorus are for total phosphorus concentrations, this parameter will be used to discuss trends.

TOTAL PHOSPHORUS

For the period 1956 to 1974, there has been no significant change in total phosphorus concentration in Saginaw Bay (Table 4.2-4). There are, however, significant spatial differences in total phosphorus concentrations based on 1974 data (Table 4.2-3). These concentrations do not meet the Agreement objective (Appendix C).

The sources of phosphorus in the basin include municipal and industrial waste discharges, runoff from agricultural land, and resuspension of phosphorus-containing solids from dredging activities. The effect of dredging is actually a redistribution of materials from the original sources.

CHLOROPHYLL *a*

Chlorophyll *a* is a relatively simple measure of algal biomass in a body of water. Based on chlorophyll *a* concentration data from 1965 and 1974, an apparent increase in this parameter was observed (Table 4.2-4). Spatial differences in Saginaw Bay for chlorophyll *a* are pronounced (Table 4.2-3). There are no specific water quality objectives for chlorophyll *a* concentration, although chlorophyll *a* values in the bay are often 100 times the values in Lake Huron proper.

ORGANICS

The limited data on trace organic concentrations in Saginaw Bay water will not allow trend detection (Table 4.2-5). However, PCB's and di(2-ethylhexyl)phthalate exceed the proposed Agreement objectives, while dieldrin is present in detectable quantities. The presence of these compounds is significant due to their direct toxicity to aquatic life and to the possibility of their accumulation in the food chain. The contamination of Saginaw Bay with organic compounds results from the discharge of these compounds to the Saginaw River and its tributaries.

TABLE 4.2-5

ORGANICS IN SAGINAW BAY - 1974 (24)

PARAMETER	CONCENTRATIONS IN ng/ℓ			PROPOSED AGREEMENT
	SAGINAW RIVER	INNER BAY	OUTER BAY	OBJECTIVES
Arochlor 1242	70	10	Not Found	-
Arochlor 1254	10	3	Not Found	-
Arochlor 1260	<10	<10	<10	-
Total PCB	80-90	13-23	0-10	1[a]
Dieldrin	0.8	0.5	0.6	1[b]
pp'DDT	<1	<1	<1	3[c]
DDE	<1	<1	<1	3[c]
DDD	<1	<1	<1	3[c]
Di(2-ethylhexyl)-phthalate	4 samples in bay ranged from <1000 to 1400; mean = 1300			600

a. This level may not be adequate to provide protection to certain predators, and could presently not be enforced because of insufficiently sensitive quantification limits.

b. Objective is for aldrin plus dieldrin.

c. Objective is for DDT plus metabolites.

The Saginaw River has the highest PCB concentrations of any river tested in Michigan. The major and several of the minor point sources were identified and corrective action initiated at the source. Water and fish samples collected and analyzed subsequent to the corrective steps being taken still exhibit relatively high concentrations of PCB's and other organic contaminants. These data indicate there still remains a significant input to the Saginaw Bay system from diffuse (non-point) and, therefore, difficult to control sources.

HEAVY METALS

As in the case of organics, there are insufficient data for trend detection for heavy metals (Table 4.2-6). Most of the available criteria for heavy metals appear to be met; however, the data are incomplete. Heavy metals present problems similar to organics with respect to toxicity and bioaccumulations. Sources of heavy metals are mainly electroplating operations which discharge to the Saginaw River or its tributaries.

An anomaly occurred for copper in Saginaw Bay during 1974 (12). Samples on 3 separate dates from a station near Sand Point were found to contain between 36 and 90 μg/ℓ of copper which is an order of magnitude larger than the bay average (Table 4.2-6).

CHLORIDE

Chloride is generally considered to be an indicator of pollution. Data collected since 1935 on the concentration of chloride in the Saginaw River and the inner and outer bays indicate a dramatic improvement in water quality. The mean concentration of chloride in the inner bay has decreased from an average of 60 mg/ℓ in 1956 to an average of 18 mg/ℓ in 1974 (Table 4.2-4). The concentrations now observed are well below the Michigan State Standard (50 mg/ℓ). The U.S. Water Quality Criteria is met at the desirable level (25 mg/ℓ) except near the mouth of the Saginaw River.

Significant spatial gradients in chloride concentrations are observed in Saginaw Bay (Table 4.2-3). This situation permits the use of chloride as a tracer of water movement in the bay (18). As has been mentioned in the conductivity discussion, the dissolved solids discharges to the Saginaw River have been significantly reduced. These reductions include a 50% decrease in the chloride load.

DISSOLVED REACTIVE SILICATE

This parameter is included because it is a nutrient for diatom growth and, in contrast to the other parameters discussed here, a major source is Lake Huron. That Lake Huron acts as a source of reactive silicate is demonstrated by a comparison of mean concentrations for Segments I and IV (Table 4.2-3). The direction of the concentration gradient is the opposite of other parameters which have the Saginaw River as their only source. Silicate depletion probably is an important factor in the early summer species shift from diatoms to blue-green algae (31).

TABLE 4.2-6

HEAVY METALS IN SAGINAW BAY[b] - 1974 (24)

HEAVY METALS	CONCENTRATIONS IN µg/ℓ						U.S. DRINKING WATER STANDARD	U.S. WATER QUALITY CRITERIA	AGREEMENT OBJECTIVE
	SPRING 1974			FALL 1974					
	Min.	Max.	Mean	Min.	Max.	Mean			
Cu	1.	5.	2.	3.	6.	3.4	–	1000	5[a]
Cd	–	–	2	–	–	2	10	10	0.2[a]
Zn	10	55	23	4	15	8	5000	5000	30[a]
Fe	32	110	65	29	170	93	300	300	300
Mn	3	9	6	3	14	8	50	50	–
Cr	–	–	1	1	1	1	50	50	50[a]
Pb	5	10	7	5	7	6	50	50	20[a]
Hg	–	–	–	–	–	0.2	2	–	0.2[a]

a. Proposed.

b. See also Appendix C for complete listing of criteria, standards, objectives, and guidelines.

HYDROGEN ION (pH)

The annual average pH for Saginaw Bay in 1974 was 8.45 (12). This represents an increase of between 0.3 and 0.5 units since 1956 (22). Individual samples ranged from 6.88 to 9.58 with 47% of the samples in excess of the Agreement objective of 8.5; however, the proposed Agreement objective is 9.0 (Appendix C). These relatively high pH values are probably caused by algal uptake of CO_2 rather than any source of high pH effluents.

ALKALINITY

Alkalinity is an indirect measure of the buffer capacity of water. The annual average alkalinity for Saginaw Bay in 1974 was 92 mg/ℓ as $CaCO_3$ (12). This respresents a decrease from 1956 when the bay average was over 100 mg/ℓ (22). In 1937, the bay average was in the low 90's (21).

SEDIMENTS

Saginaw Bay sediments have been studied several times since 1970 (25-29). The bay bottom is not uniformly covered with sediments (Figure 4.2-4). The spatial variation of the samples analyzed as well as differences in experimental technique preclude trend detection. Sediment chemistry data are presented as ranges and means (Table 4.2-7) and compared to EPA dredge spoil disposal guidelines. Sediments are considered unpolluted, moderately polluted, or heavily polluted depending on whether concentrations are less than, within, or greater than the guideline range, respectively, for each parameter. On this basis, Saginaw Bay sediments are moderately polluted with respect to zinc, lead, total Kjeldahl nitrogen, and chemical oxygen demand and unpolluted with respect to the rest of the parameters studied.

The size of some of the ranges presented for metal and nutrient concentrations in the sediments is indicative of the strong influence of the Saginaw River. Extremely high values in the river decrease markedly in the inner bay and gradually decrease further toward the mouth of the bay. Guidelines for the previously mentioned parameters were exceeded only in samples taken in or near the Saginaw River. Sediment values for pesticides and PCB's were all below the analytical detection limit except for dibutyl phthalates which varied in concentration from 290 μg/kg in the river mouth to <200 μg/kg in the outer bay, again reflecting the general path of pollutants from the Saginaw River (29).

Sediment contamination by toxic substances has a direct effect on benthos and bottom feeding organisms. However, as the overlying water column becomes depleted in nutrient or toxic materials, the sediments can often replenish some of the deficit through the mechanisms of diffusion and resuspension. It is estimated that 50% of the phosphorus that settles in the bay during the year is resuspended at a later time (30).

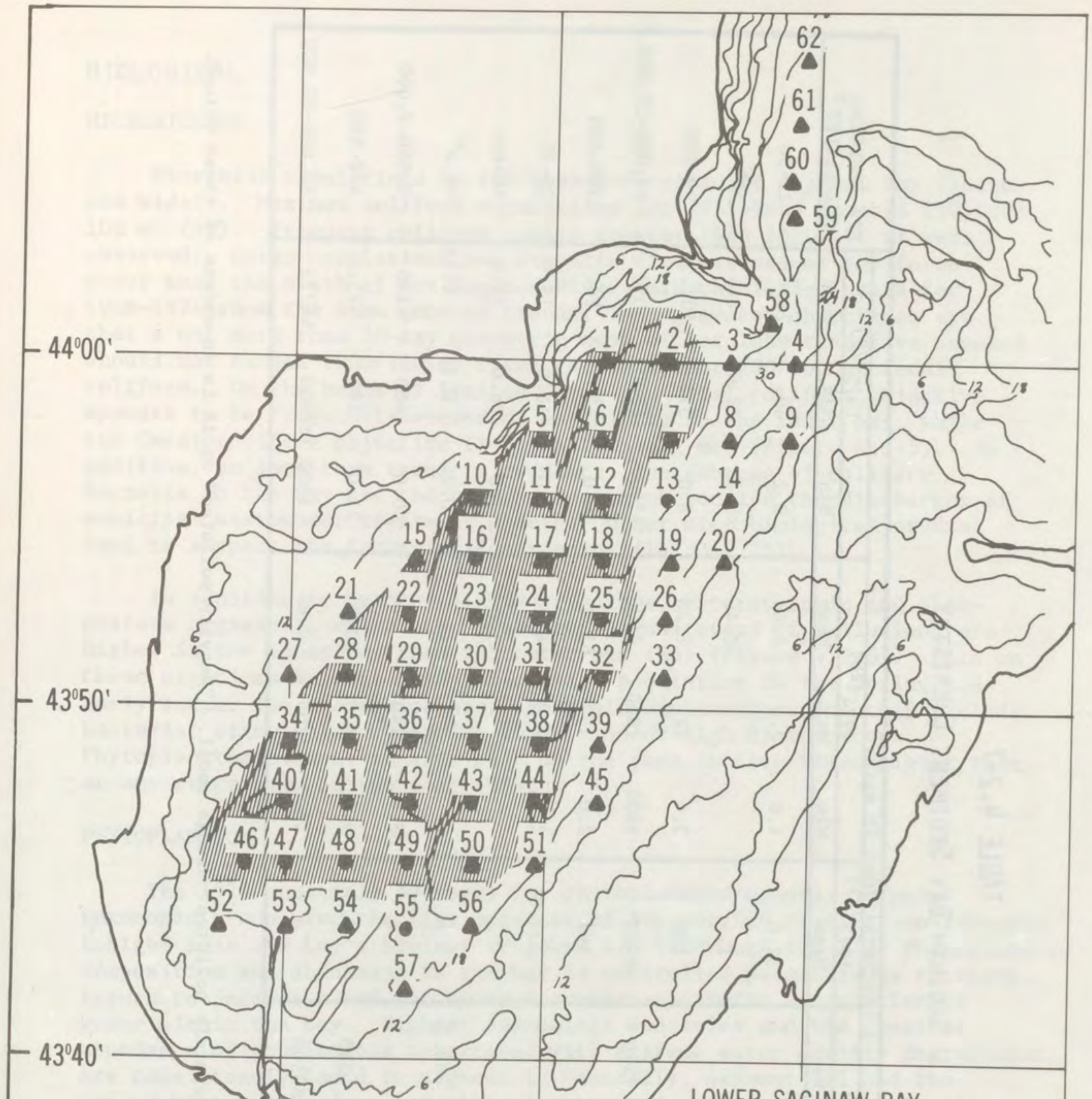


FIGURE 4.2-4. SAGINAW BAY SEDIMENTS (30). SURFICIAL MUD DEPOSITS (Bordering areas are mainly sand)

TABLE 4.2-7

SAGINAW BAY SEDIMENT CHEMISTRY

PARAMETER (mg/kg)	CONCENTRATIONS IN mg/kg 1970[26] Min.	1970[26] Max.	1970[26] Mean	1973[27] Mean	1974[28] Min.	1974[28] Max.	1974[28] Mean	1975[29] Min.	1975[29] Max.	1975[29] Mean	EPA DREDGING GUIDELINES[b]
Cu		a		32.0	1.0	2.8	1.66	0.2	60.	23.	25-50
Cd		a		1.4			<0.4	<0.4	2.0	1.4	>6[c]
Zn		a		106	3.4	12	8.26	6.0	310	101.5	90-200
Fe	5400	9400	7140	6462	1600	7800	4600	1600	18000	9050	17,000-25,000
Mn		a		197	2.0	100	63.3	19.0	600	244	300-500
Cr		a		37.9	2.2	7.8	4.26	2.0	40.0	19.0	25-75
Pb		a		a			<1.0	<1.0	96.0	45.0	40-60
Hg			<0.2	a			<0.1	<0.02	0.16	0.12	>1.0[c]
TKN		a		a	38.0	240	110	80.0	2600	1150	1,000-2,000
Total P	280	540	340	2.0	9.0	38.0	20.3	21.0	180	75.5	420-650
COD	33000	110000	63500	a	1500	5200	2766	1300	110000	44775	40,000-80,000

a. Not analyzed.
b. Values given are for "moderately polluted" dredge spoil. "Heavily polluted" spoil is in excess of these values. See Appendix C.
c. Heavily polluted.

BIOLOGICAL

MICROBIOLOGY

Microbial populations in the nearshore areas of Saginaw Bay fluctuate widely. Maximum coliform populations for 1965-1966 reached 250,000/100 mℓ (33). Frequent coliform counts greater than 1000/100 mℓ were observed. Large populations and dramatic fluctuations of coliforms occur near the mouth of the Saginaw River. Microbiological data for 1968-1974 show the same general trends. The Agreement objectives are that a not more than 30-day geometric mean of not less than five samples should not exceed 1000/100 mℓ total coliform, nor 200/100 mℓ fecal coliform. On the basis of limited data, the total coliform objective appears to be frequently exceeded, especially in the inner bay, while the fecal coliform objective is probably being met (Figure 4.2-5). In addition, no long-term trend is evident. The sources of coliform bacteria in the bay are the tributaries which receive the discharges of municipal wastewater treatment plants. Other microbiological studies tend to support the foregoing description (14, 34, 35).

In addition to health-related organisms, heterotrophic and phosphatase organisms, which can be sensitive indicators of pollution, are higher in the inner bay than the outer bay (36) (Figure 4.2-6). Data on these organisms suggest a peak microbial population in the spring and early summer for the entire bay. Possible explanations for this include bacterial stimulation by spring runoff and/or high diatom crops. Phytoplankton biomass in this part of the year is five times higher than at any other time of the year (37).

PHYTOPLANKTON

The 1974 quarterly averages for phytoplankton counts, by major taxonomic group, for the five segments of Saginaw Bay provide considerable insight into the bay's biology (Figures 4.2-7 through 4.2-11). Phytoplankton composition and abundance in the bay is controlled primarily by nutrient inputs to Segment I and the average counter-clockwise circulation of water within the bay. Highest assemblage densities and the greatest abundance of populations associated with extreme water quality degradation are consistently found in segment I. Generally, segment III had the second highest abundance of phytoplankton and was dominated by species characteristic of highly disturbed habitats. Segments IV and V had much lower average assemblage densities than segments I-III, with most stations having a greater admixture of species abundant in the open waters of Lake Huron. Phytoplankton abundance was greater in segment V than in segment IV.

The most striking characteristic of phytoplankton assemblages in Saginaw Bay is the extreme spatial and temporal variation of populations. The greatest variability is found in segment I, where the overall assemblage is dominated by local and transient blooms of particular populations in response to variations in nutrient loadings and weather conditions. Also, part of the variability may result from physiological

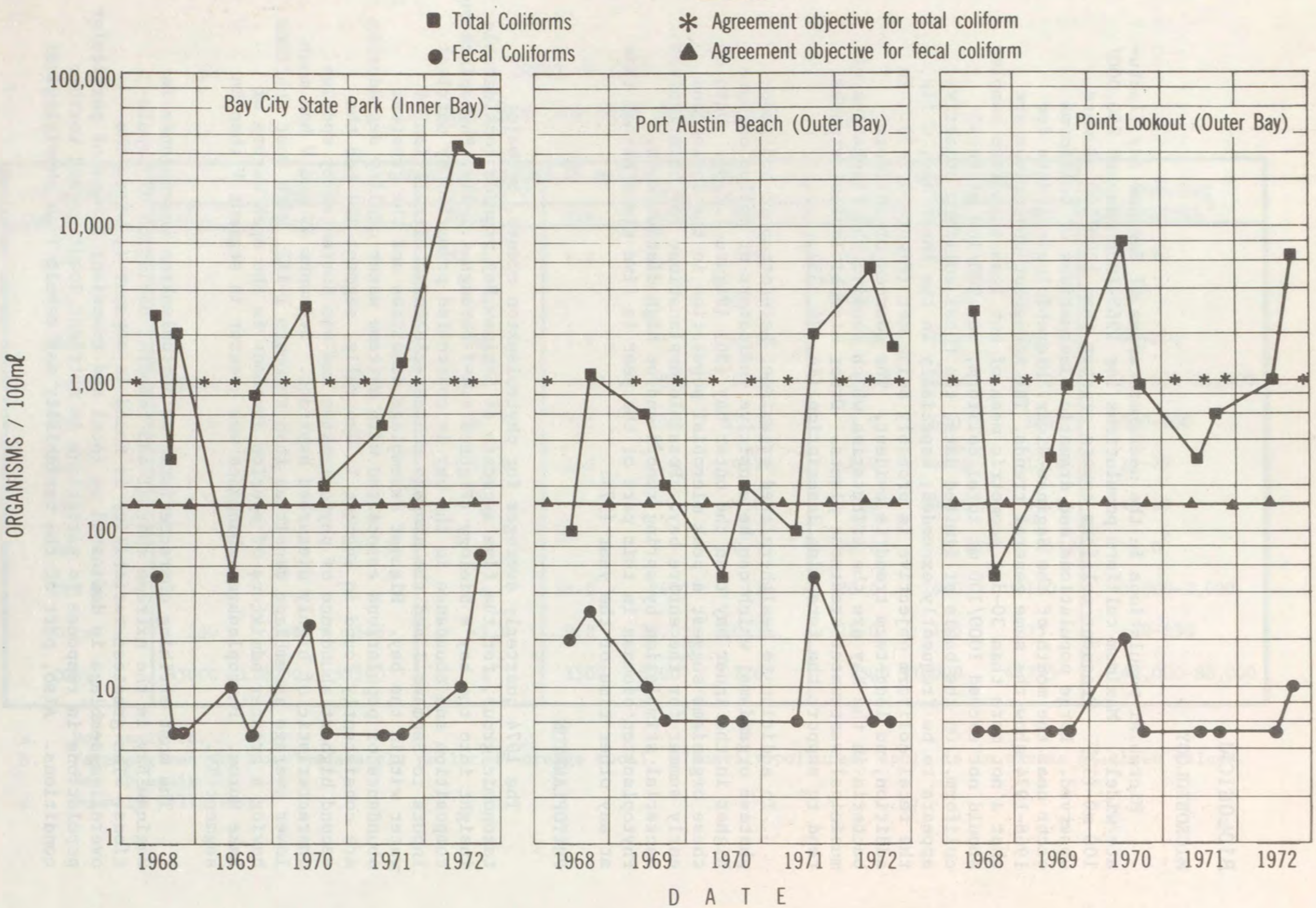


FIGURE 4.2-5 BACTERIAL COUNTS IN SAGINAW BAY SHOWING FIVE-YEAR TRENDS. FROM REFERENCE (74).

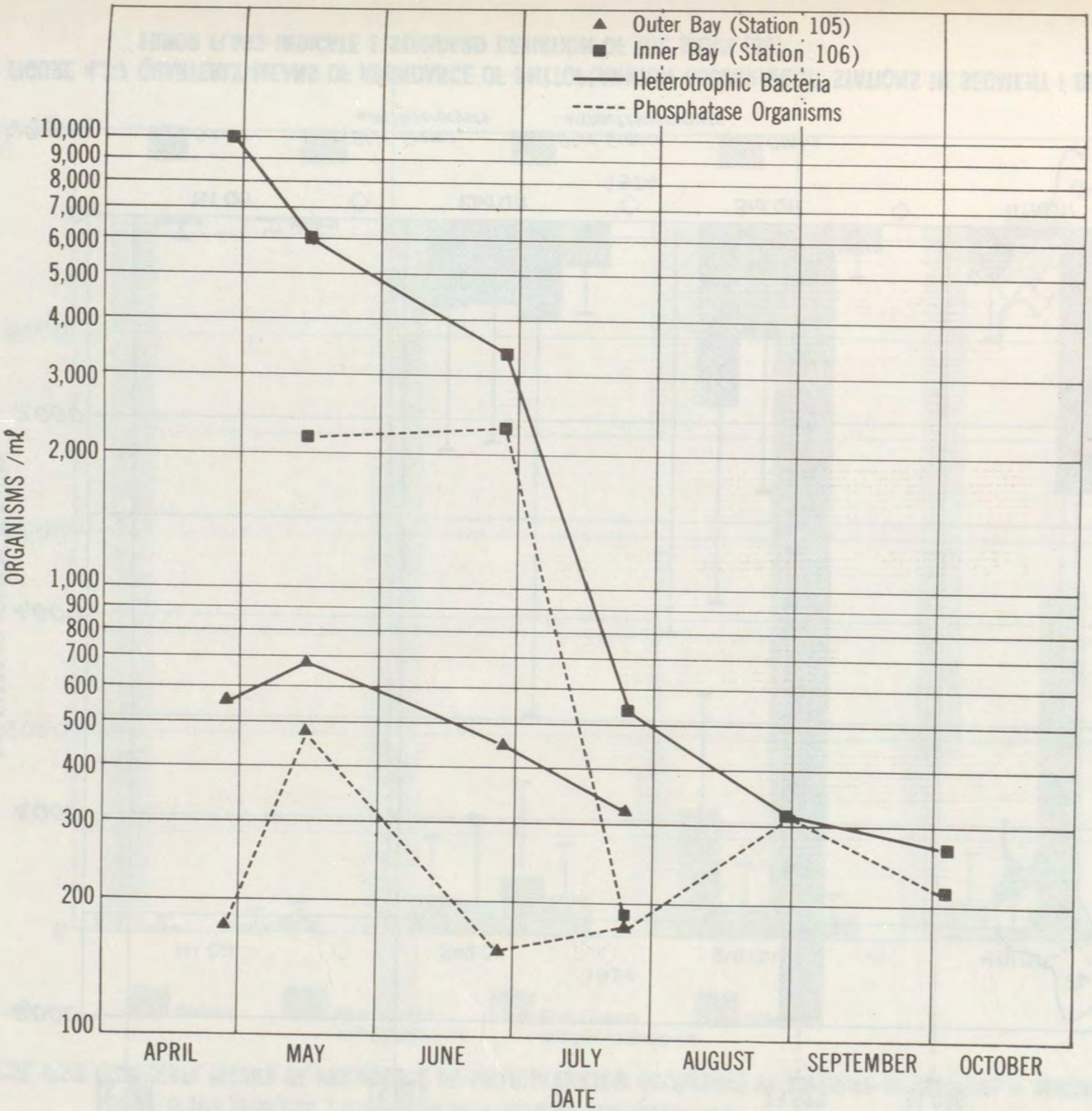


FIGURE 4.2-6 HETEROTROPHIC AND PHOSPHATASE ORGANISMS FOR TWO STATIONS IN SAGINAW BAY IN 1974 (35)

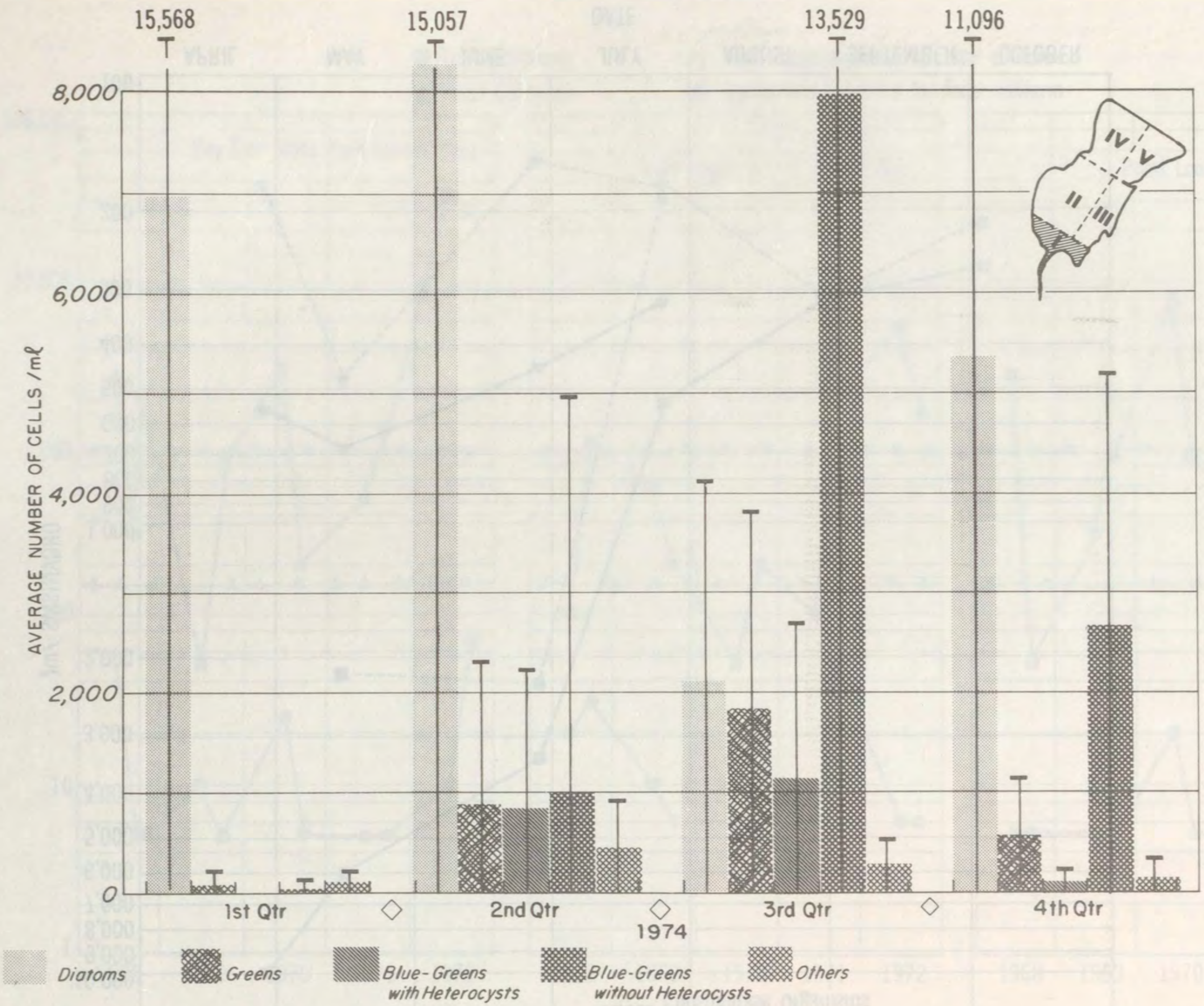


FIGURE 4.2-7 QUARTERLY MEANS OF ABUNDANCE OF PHYTOPLANKTON OCCURRING AT STATIONS IN SEGMENT I DURING 1974. ERROR FLAGS INDICATE 1 STANDARD DEVIATION OF THE MEAN (38)

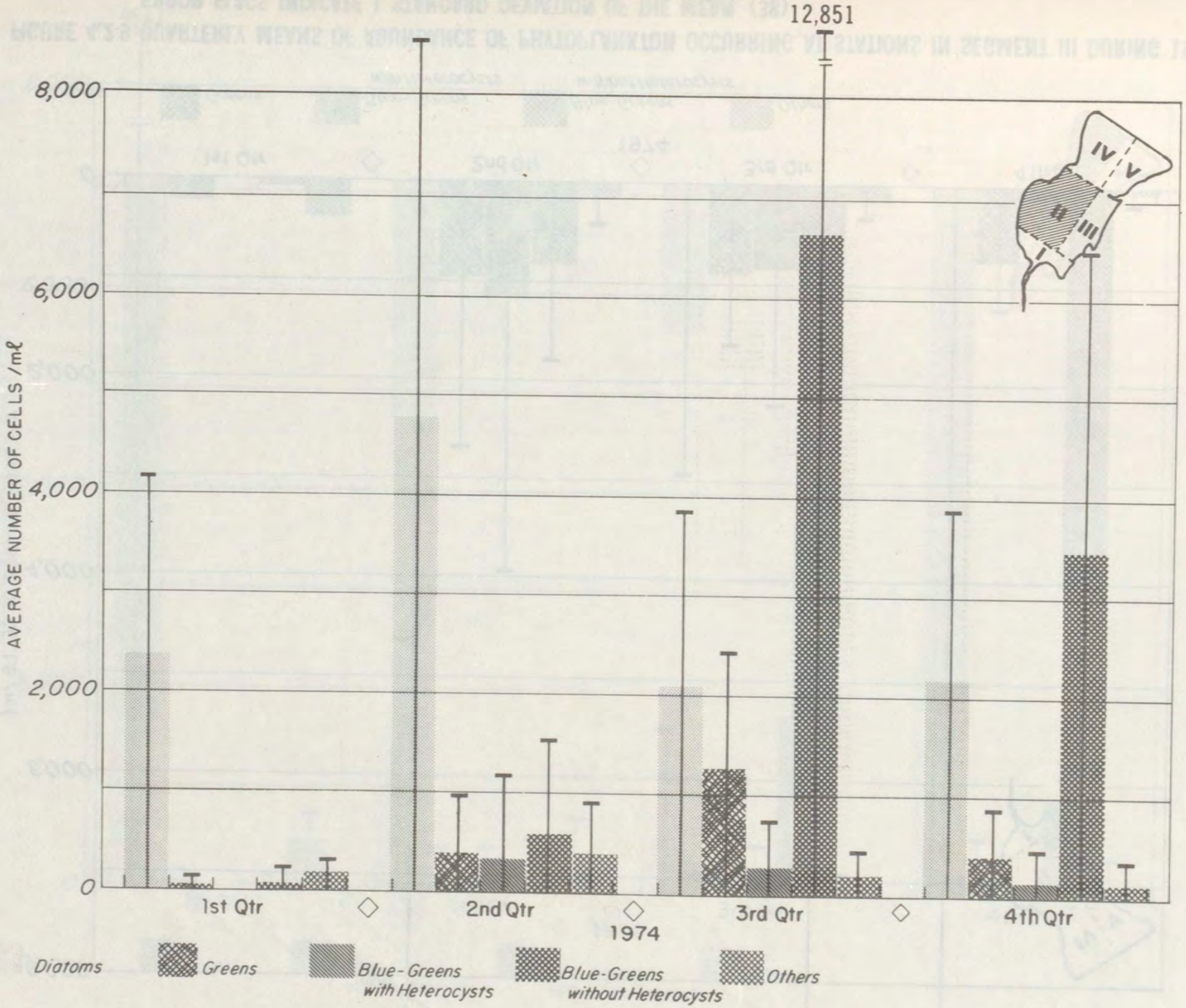


FIGURE 4.2-8 QUARTERLY MEANS OF ABUNDANCE OF PHYTOPLANKTON OCCURRING AT STATIONS IN SEGMENT II DURING 1974. ERROR FLAGS INDICATE 1 STANDARD DEVIATION OF THE MEAN. (38)

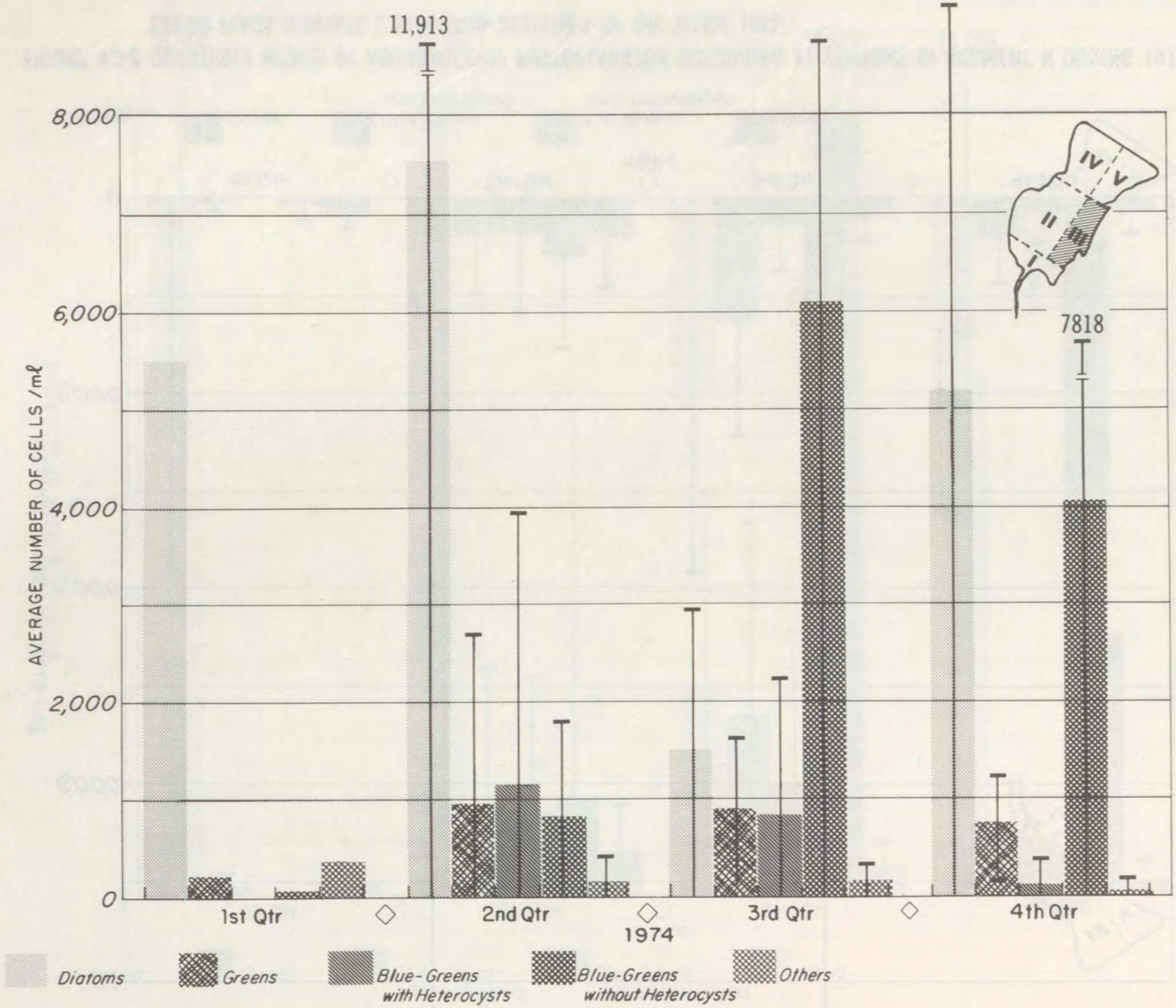


FIGURE 4.2-9 QUARTERLY MEANS OF ABUNDANCE OF PHYTOPLANKTON OCCURRING AT STATIONS IN SEGMENT III DURING 1974. ERROR FLAGS INDICATE 1 STANDARD DEVIATION OF THE MEAN. (38)

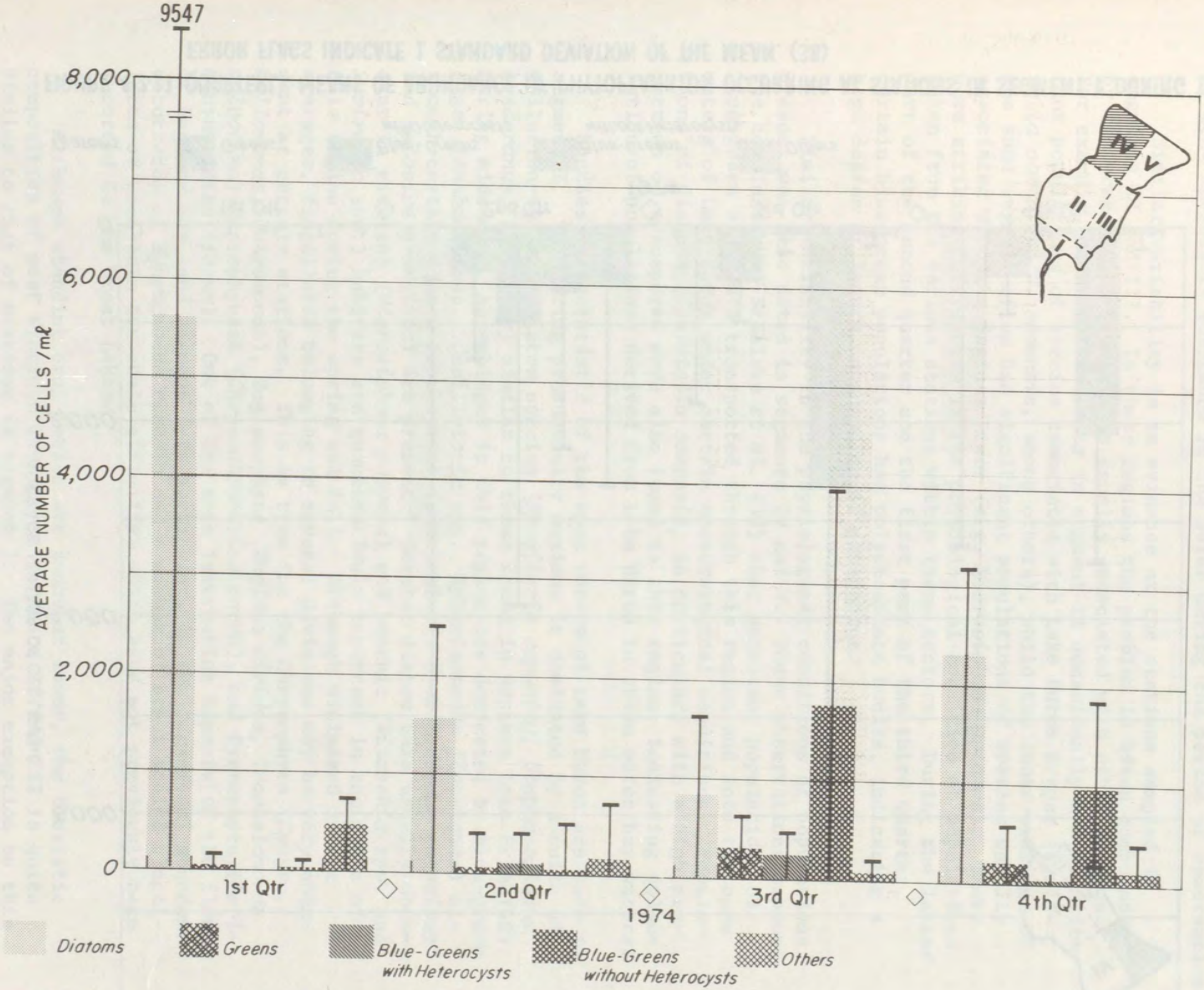


FIGURE 4.2-10 QUARTERLY MEANS OF ABUNDANCE OF PHYTOPLANKTON OCCURRING AT STATIONS IN SEGMENT IV DURING 1974. ERROR FLAGS INDICATE 1 STANDARD DEVIATION OF THE MEAN. (38)

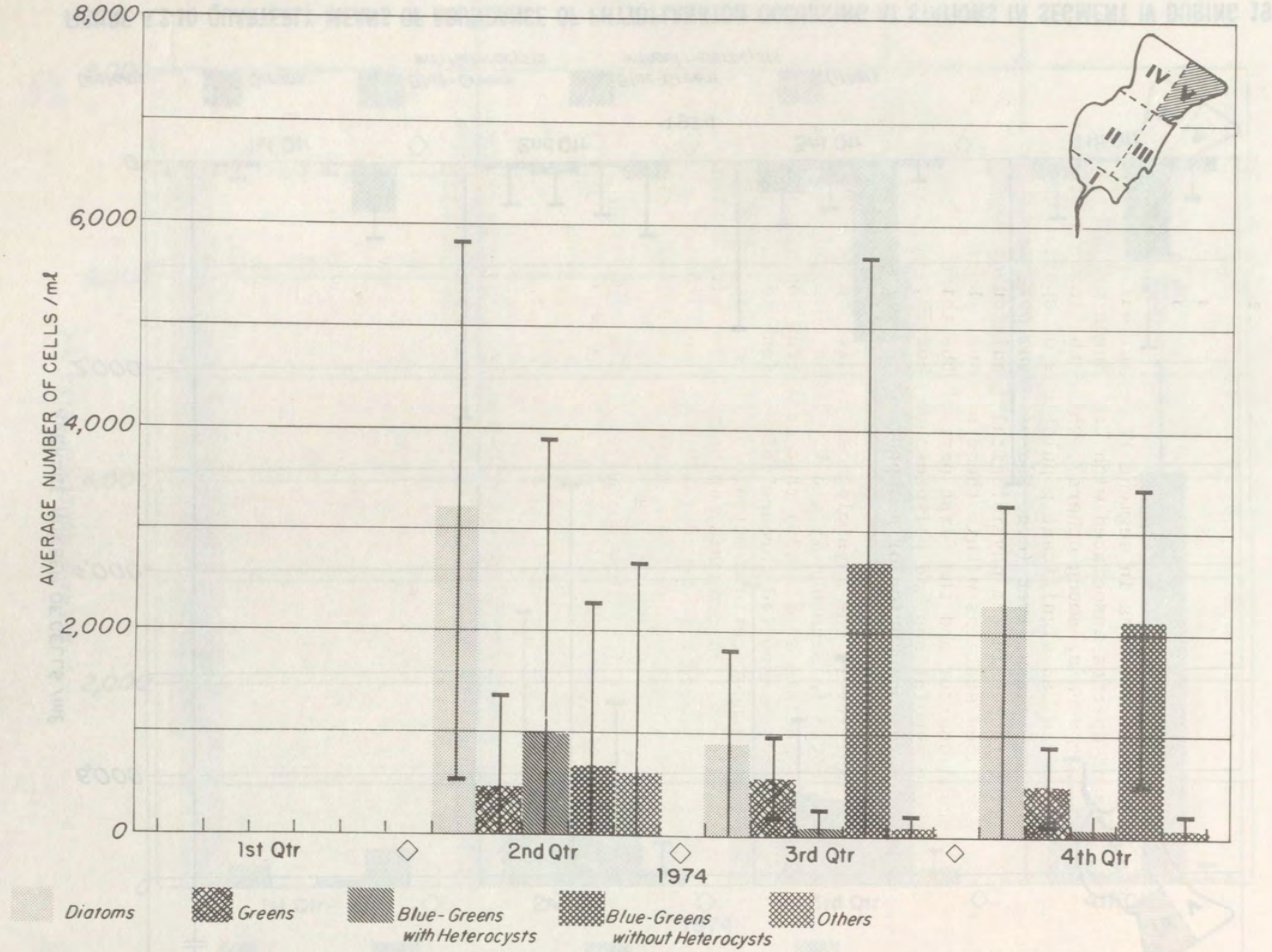


FIGURE 4.2-11 QUARTERLY MEANS OF ABUNDANCE OF PHYTOPLANKTON OCCURRING AT STATIONS IN SEGMENT V DURING 1974. ERROR FLAGS INDICATE 1 STANDARD DEVIATION OF THE MEAN. (38)

inhibition of phytoplankton populations as is strongly suggested by the apparent condition of cells taken in some samples and by time series primary productivity studies (38). Strong, time-variable depressions in photosynthetic rates were observed and could be explained by the presence of some inhibitory substance in the water during the period of observation.

Similar variability is in evidence at the stations sampled in segments II and III. In these regions the problem is often compounded by the presence of populations usually associated with other regions. For example, outermost stations in segment II occasionally had significant populations of species associated with Lake Huron proper (*Cyclotella comta* and *C. comensis*, among others), while the inner stations of the same segment often had significant populations of species usually associated with the Saginaw River (e.g. *Microsiphona potomos*). There were striking differences in the physiological condition of populations taken from the various stations within these sectors. During the latter part of the second quarter and the first part of the third quarter, certain blue-green populations had polyphosphate bodies, indicating a high degree of luxury consumption of phosphorus.

Similar variability in the physiological conditions of populations present was also noted in segments IV and V. These observations support the conclusion of Schelske *et al.* (39) that senescent populations of blue-green algae are transported through this region and into the open waters of Lake Huron under certain meteorological conditions. Populations of diatoms (*Cyclotella comensis*, in particular) with a high proportion of auxospores were also found in this region, indicating stimulation of populations derived from Lake Huron in these outer bay waters.

Species characteristic of the open waters of Lake Huron are rare in segment I. The spring productivity maximum is dominated by a suite of pollution-tolerant diatom species (*Fragilaria capucina*, *Stephanodiscus binderanus*, *S. tenuis*) similar to those found in western Lake Erie (40). During midsummer, assemblages in this region are dominated by blue-green algae (*Anabaena* spp., *Oscillatoria* spp., *Aphanizomenon flos-aquae*) although certain diatom populations (particularly *Coscinodiscus subsalsus* and *Melosira granulata*) are present. Several diatom taxa usually abundant in riverine (*Microsiphona potomos*) and benthic (*Nitzschia* spp. and *Surirella* spp.) habitats are quantitatively important in the flora of this region during the spring and fall. Although minimized in the averages, flagellates belonging to several divisions may be very abundant at certain stations. This is true for the Chrysophyta (*Synura*, *Mallomonas*, *Ochromonas*), Euglenophyta (*Euglena viridis*, *Trachelomonas volvocina*) Haptophyceae (*Chrysochromulina parva*), and Pyrrophyta (*Peridinium aciculiferum*). One of the more interesting aspects of the flora of Saginaw Bay, and segment I in particular, is the occasional abundant occurrence of *Hynemomonas roseola* and a number of other scaled flagellates of uncertain taxonomic affinities which have not previously been reported in the Great Lakes.

Although standing crop levels are somewhat lower, the floristic composition of most stations sampled in segments II and III is quite similar to that of stations in segment I. The major exception to this is the occasional incursion of species common in the offshore waters of Lake Huron, as has been mentioned previously.

The outer bay segments (IV and V) are floristically intermediate between the inner bay and open Lake Huron; further, segment V receives greater influence from Saginaw River inputs to the bay than segment IV.

Although the phytoplankton standing crops range from those commonly found in eutrophic lakes, in segment I, to those usually found in waters classified as mesotrophic, as in segment IV, the composition of phytoplankton assemblages in Saginaw Bay is unique. The most striking quality from the standpoint of composition is the predominance of halophilic species in the assemblage of the inner bay. The phytoplankton flora of Saginaw Bay thus appear to reflect the effects of loadings of materials other than nutrients, such as chloride.

BENTHOS

Saginaw Bay benthos have been extensively studied revealing natural ecological subdivisions: a *Chironomus-Limnodrilus* habitat, a *Gammarus* habitat, and a *Pontoporeia* habitat (41-45) (Figure 4.2-12). The first was occupied by the mayfly *Hexagenia*, as well, but its abundance has decreased sharply. *Chironomus-Limnodrilus* habitat consists of soft mud bottoms in the deeper areas (>6 m) surrounding the shipping channel and the shallow depressions in the south-southeastern part of the inner bay. Edges of the bay, shallows around islands, and the Coryeon Reef support the diverse assemblages of oligochaetes, insects, molluscs, and crustaceans characterized by the amphipod *Gammarus*. The deepwater amphipod *Pontoporeia* dominates the offshore areas of the outer bay, where benthos are composed of fewer species but larger numbers in the same taxa represented in the inner bay.

Large changes in zoobenthos densities occured over the period 1955-1971 (Table 4.2-8) (46). Oligochaetes and chironomids approximately doubled their densities, but amphipods decreased by half. Sphaeriid clams decreased abruptly from 1955 populations of over $100/m^2$ to less than a few individuals per square metre, then re-established populations to over $100/m^2$ by 1965. A catastrophic event, such as oxygen depletion, probably occured in 1955 or 1956 from which sphaeriids recovered, but not *Hexagenia*. Ephemeroptera populations were practically nonexistent in the bay after 1956, and the mayflies remaining belonged to genera other than *Hexagenia*.

Changes in Saginaw Bay benthos follow almost exactly the patterns observed in western Lake Erie (49) and in Green Bay (50). Moreover, the distribution of oligochaete species in Saginaw Bay in 1956 provides clear evidence of eutrophication already occuring at that time. The occurrence of eutrophic-indicator assemblages of benthos in the Sebewaing area may reflect additional organic waste discharges in this location as well as the influence of the Saginaw River plume (51).

Hexagenia and amphipod decreases were probably detrimental to the

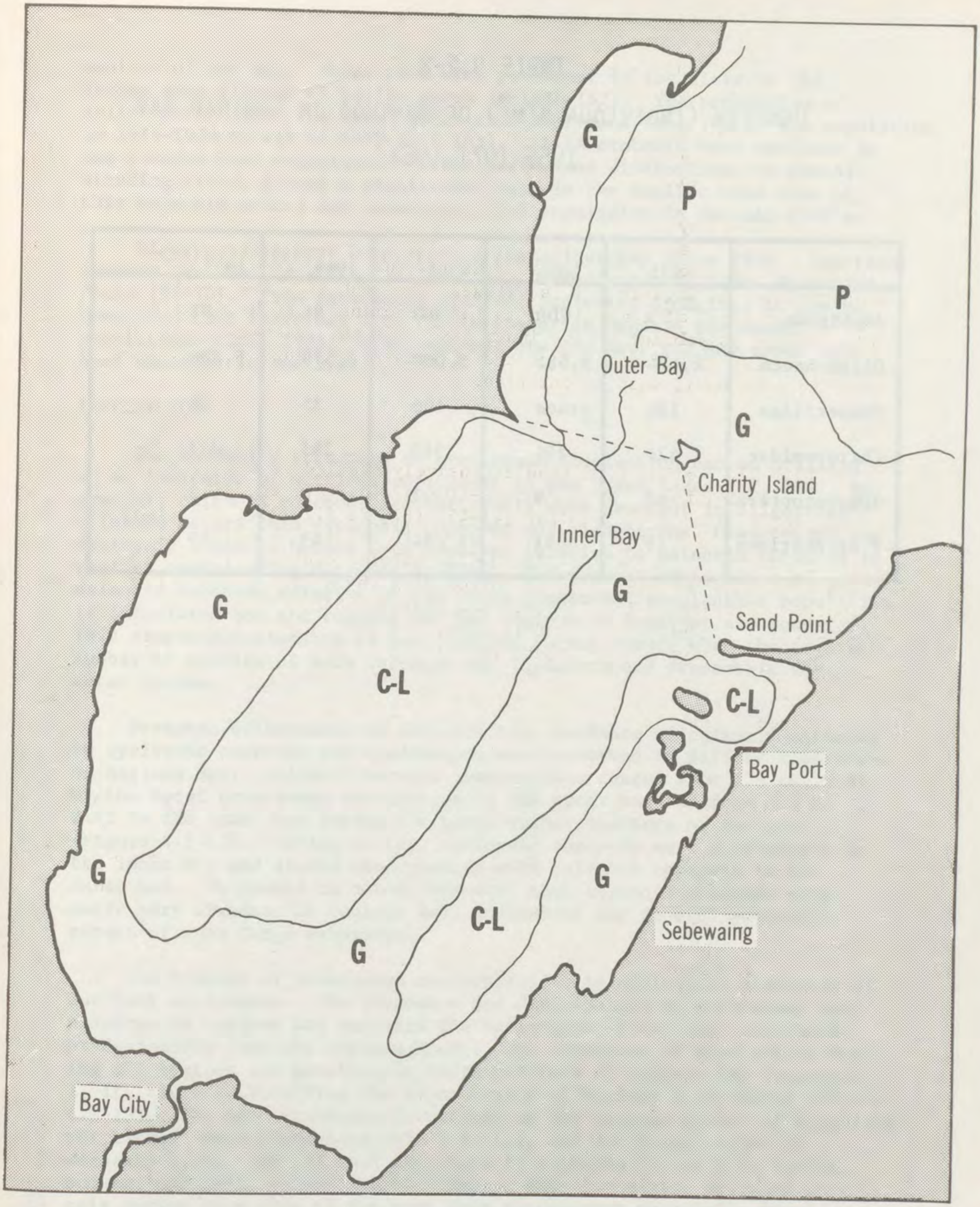


FIGURE 4.2-12

BENTHIC HABITATS OF SAGINAW BAY. C-L Chironomus-Limnodrilus, G – Gammarus, P – Pontoporeia. (41-45)

TABLE 4.2-8

DENSITY (INDIVIDUALS/M^2) OF BENTHOS IN SAGINAW BAY 1955-1971 (46)

	1955 (43)	1956 (47)	1965 (47)	1965 (48)	1971 (46)
Amphipoda	123	200	330	96	87
Oligochaeta	2,174	3,532	3,060	6,579	5,888
Sphaeriidae	122	trace	100	35	24
Chironomidae	424	294	360	795	873
Ephemeroptera	63	9	1	0	2
# of Stations	19	51	24	43	29

ecology of the bay. These taxa were prominent in the diets of the larger size classes of yellow perch in 1956 (52). The proportion of yellow perch above the legal catch size decreased from 74% of the population in 1929-1930 to 11% in 1955-1956 (53). It is probable that declines in the favored food organisms of large perch, and fluctuations in benthic standing crops, played a significant role in the smaller mean size of this valuable sports and commercial fish population in the mid-1950's.

River mussels have been studied in Saginaw Bay since 1908. Important species include *Lampsilis, siliquoidea, Onodonta grandis,* and *Fusconaia flava* (54-56). From subsequent studies, including dredging, it can be concluded that there has been little change in Saginaw Bay mussel populations since 1908. River mussels are not now, and may never have been abundant in the area.

ZOOPLANKTON

The community structure of crustacean zooplankton can be utilized as an indicator of nutrient enrichment in the Upper Lakes (57, 58). In general, calanoid copepods are relatively more abundant in oligotrophic offshore waters than cyclopoid copepods and cladocerans. Cladocerans and cyclopoid copepods become more abundant relative to calanoid copepods in regions experiencing nutrient loading. The percent composition of calanoid copepods relative to the total crustacean zooplankton population is calculated and the results for the regions of interest are compared. This simple relationship is best applied during summer when the greatest number of species of both Copepods and Cladocera are present in the water column.

Dramatic differences in the relative abundance of calanoid copepods to cyclopoid copepods and cladocerans were observed in different portions of Saginaw Bay. Calanoid percent compositions ranged from 1.6 to 15.3% of the total crustacean zooplankton in the outer bay and from 0.6 to 2.4% in the inner bay during the three warmer quarters of the year (Figure 4.2-13). During winter, cyclopoid copepods were predominant in the inner bay and shared co-dominance with calanoid copepods in the outer bay. It should be noted, however, that calanoid copepods were never very abundant in Saginaw Bay, indicating the general eutrophic nature of this large embayment.

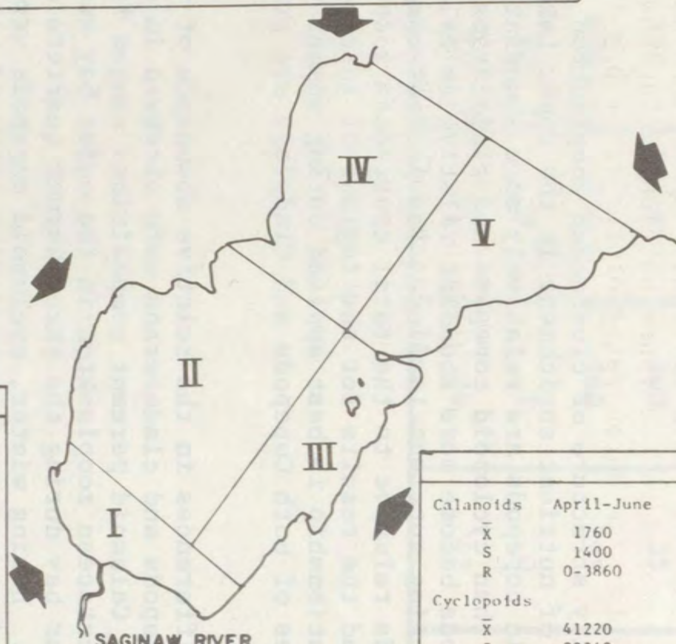
The biomass of crustacean zooplankton is an additional indicator of nutrient enrichment. The abundance and distribution of crustacean zooplankton in Saginaw Bay reflects the influences of nutrient enrichment predominantly from the Saginaw River. The abundance of zooplankton during all seasons was greatest in those portions of Saginaw Bay (segments I, II, and III) receiving the major inputs of Saginaw River water (Figure 4.2-13). The mean abundance is defined as the average number of organisms per litre. Mean abundances were 2.6, 2.4, and 3.5 times higher in segments I, II, and III than they were in segments IV and V in spring, summer, and fall, respectively. Limited data for winter revealed that only during this time of the year when cladocerans especially were inhibited by cold temperatures was the abundance of crustacean zooplankton

SEGMENT IV

Calanoids	April-June	July-Sept	Oct-Dec	Jan-March
$\bar{X}$	3680	5890	4280	540
S	5230	5310	2940	0
R	50-20240	210-24870	0-10470	540
Cyclopoids				
$\bar{X}$	5720	8010	8720	20
S	9200	6140	4410	0
R	230-35630	290-24960	0-19730	20
Cladocerans				
$\bar{X}$	34650	53890	7540	360
S	72920	110790	12680	0
R	0-255510	2300-622990	560-63780	360
N	35	45	23	1

SEGMENT II

Calanoids	April-June	July-Sept	Oct-Dec	Jan-March
$\bar{X}$	1880	2200	1490	570
S	1540	2480	730	0
R	140-5780	0-9710	20-3070	570
Cyclopoids				
$\bar{X}$	16780	12600	12830	2240
S	16260	10360	6740	0
R	1480-80430	850-50720	7290-32420	2240
Cladocerans				
$\bar{X}$	131390	117530	49080	10
S	214710	158220	25810	0
R	360-695700	3920-897410	15100-91050	10
N	37	49	20	1



SEGMENT V

Calanoids	April-June	July-Sept	Oct-Dec	Jan-March
$\bar{X}$	1840	4670	4810	
S	1290	4710	2410	
R	0-5440	0-17410	620-8760	
Cyclopoids				
$\bar{X}$	7480	6800	8320	
S	10730	6470	3480	
R	0-42720	0-30300	2120-15920	
Cladocerans				
$\bar{X}$	103010	50120	18190	
S	227910	94110	20010	
R	0-872990	260-514720	1430-70120	
N	33	48	21	0

SEGMENT I

Calanoids	April-June	July-Sept	Oct-Dec	Jan-March
$\bar{X}$	1550	1510	1710	1550
S	1390	1810	1210	160
R	0-4430	0-8000	390-3950	1430-1660
Cyclopoids				
$\bar{X}$	30700	15430	20880	2100
S	30810	8240	10940	2260
R	680-104290	3140-37000	7780-52460	50-3690
Cladocerans				
$\bar{X}$	152630	124900	63400	260
S	237050	98430	23000	60
R	2860-786850	15430-434440	27040-108630	210-300
N	32	32	15	2

SEGMENT III

Calanoids	April-June	July-Sept	Oct-Dec	Jan-March
$\bar{X}$	1760	1480	1110	2710
S	1400	1470	350	0
R	0-3860	0-4420	730-1490	2710
Cyclopoids				
$\bar{X}$	41220	18210	25590	2800
S	29340	11060	6710	0
R	6290-78860	6160-43720	19190-36100	2800
Cladocerans				
$\bar{X}$	230540	162720	93740	180
S	293580	115220	22000	0
R	5140-754850	36150-439290	67400-128520	180
N	9	15	5	1

FIGURE 4.2-13

MEAN ABUNDANCE OF MAJOR GROUPS OF CRUSTACEAN ZOOPLANKTON IN FIVE SEGMENTS OF SAGINAW BAY DURING 1974 (59).

nearly the same in all portions of the bay.

Cladocerans generally disappear from the water column near the time of fall overturn in the oligotrophic waters of the Upper Lakes and spend the colder months as resting eggs (epipphia) in the sediments. However, in eutrophic waters, such as Green Bay, Cladocera remain in adult condition year round (58). In Saginaw Bay, cladocerans are the predominant zooplankters throughout the warmer months and are still present, although in lesser numbers, during winter.

Cyclops vernalis is a good indicator of eutrophy in the Great Lakes. In Lake Erie, this species was found only in the extreme western end of Lake Erie at the mouths of the Detroit and Maumee Rivers in 1930 (60), but had spread throughout the lake by 1967 (61). In Lake Michigan, this species is extremely rare in the main portion of the lake but is prominent in the fauna of Green Bay (58). *Cyclops vernalis* is the common cyclopoid copepod in the inner portion of Saginaw Bay but is rare in the predominantly Lake Huron water of the outer bay (Figure 4.2-14).

FISH

As alluded to earlier, the commercial fishing industry is in a depressed state. It is therefore difficult to estimate occurence and abundance of species from commerical catch data. Desirable fish may not be caught due to economic conditions. A trap net survey of three similar areas in Saginaw Bay was conducted by the Michigan DNR in 1972 (62). The results are useful in providing a qualitative description of the present fish population. Samples were taken near Quanicassee, the mouth of the Saginaw River, and the mouth of the Pinconning River (Figure 4.2-1). The three locations yielded a total of 26 species. Desirable species (crappie, pumpkinseed, yellow perch, and northern pike) dominated the Quanicassee and Pinconning locations; 78% by number of fish collected at the Saginaw River location were undesirable (gizzard shad, carp, and bullheads). The results from the Quanicassee and Pinconning locations are probably more indicative of the Saginaw Bay fish population. High water temperatures and increased enrichment in the vicinity of the Saginaw River favor undesirable rough fish at this location. The effects of degradation on the bay's fish population, including alterations in species abundance and uptake of toxic substances, will be discussed in a later section of this subchapter.

MODELLING METHODOLOGY

The limnological data presented in the preceding sections is useful in characterizing the state of Saginaw Bay. Analyses of trends in these data can give an indication of water quality in the near future. However, management issues such as long-term projections of bay water quality and requirements for reversal of undesirable trends cannot be addressed by these data alone. While limnological data may be used to infer which water quality parameters are important, mathematical models of the physical, chemical, and biological processes that affect water quality are uniquely qualified to address the management questions of loading reductions and timing of such reductions. When these mathematical

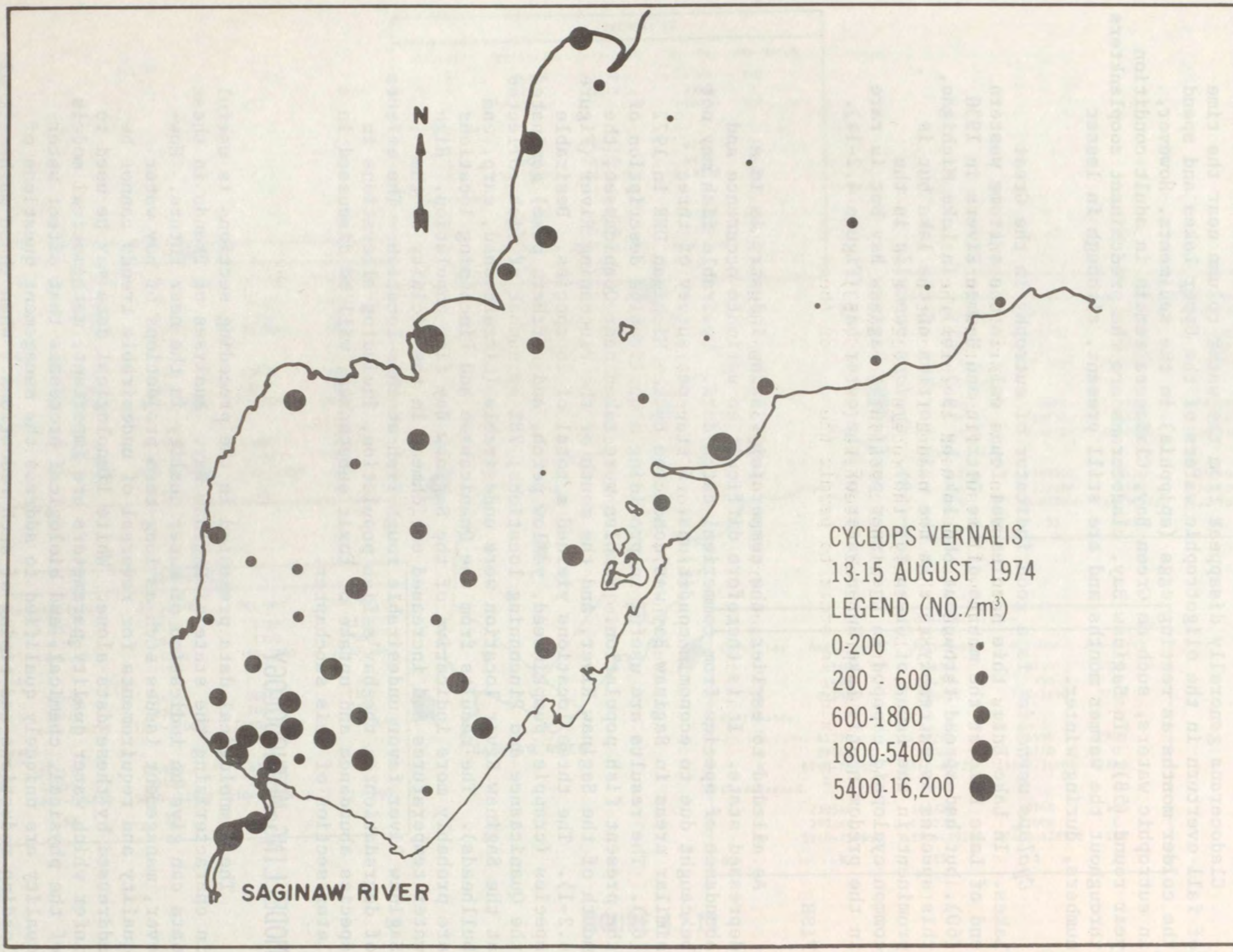


FIGURE 4.2-14 DISTRIBUTION AND ABUNDANCE OF CYCLOP VERNALIS IN SAGINAW BAY DURING AUGUST, 1974 (59)

models are used in conjunction with available data, actions necessary to achieve and maintain a desirable water quality can be specified.

In this section, the mathematical models used to address management issues for the present report are briefly described. The assumptions necessary for implementation of the models are listed. It should be noted that many of the models discussed are still in the development stage and that more sophisticated versions may become available in the future.

CHLORIDE MODEL

Chloride models have been used in this report to calculate expected chloride concentrations that will result from future increases in chloride loading. These models have also been used to infer the circulation patterns within Saginaw Bay that are needed for input to the biomass model to be discussed. Basically, the models involve time-variable mass balances of chloride with and without spatial resolution. Details of these models have been presented elsewhere (18, 19, 63). The following assumptions were made in order to permit the use of these models as a predictive tool:

(1) The chloride concentration of Lake Huron can be taken to be constant at 5.5 mg/ℓ.

(2) The circulation patterns for future years will be similar to that calculated in 1974.

(3) The pattern or timing of chloride loading will be similar to that measured in 1974.

CHLOROPHYLL *a* MODELS

These models use chlorophyll *a* as an indicator of phytoplankton biomass in lakes. The chlorophyll *a* model used in this chapter describes the coupled Saginaw Bay-Lake Huron system and is also used in Chapter 5. Details of this model have been presented elsewhere (64-66). Essentially, the model represents a mass balance around each ecological or nutrient compartment and around physical space. In this case, ecological compartments include phytoplankton and zooplankton, nutrient compartments include the different forms of phosphorus and nitrogen, and physical space includes a single segment encompassing most of Saginaw Bay as discussed further in Chapter 5.

BIOMASS MODEL

This model uses phytoplankton cell volume measurements as direct indicators of phytoplankton biomass. This allows simulation of different functional groups of phytoplankton, an important advantage in view of the varied water quality characteristics associated with different phytoplankton groups such as diatoms and blue-greens. The model used for projections in this report is spatially simplified with the inner portion of Saginaw Bay represented as one well-mixed segment. This model partitions total phytoplankton biomass into 5 different functional groups and uses a more detailed formulation of nutrient uptake and cell growth kinetics than the chlorophyll *a* model. Details of the model are discussed elsewhere (67-69). This is the first attempt to use a biomass model as a management tool.

APPLICATION OF PHYTOPLANKTON MODELS TO SAGINAW BAY

In order to apply these phytoplankton models to an actual physical system, such as Saginaw Bay, a calibration to existing data must be obtained. This involves inputting such information as circulation, loadings, boundary conditions, and initial conditions to the model and adjusting model output to agree with field observations. An important qualification that the present models are subject to is that the role of sediments in the nutrient dynamics of the bay is still unquantified.

Upon completion of the calibration step, the models can be used to simulate phytoplankton response to increases or decreases in nutrient loads. Certain assumptions were made about future conditions in order to generate these simulations for Saginaw Bay:

(1) The flow within Saginaw Bay and from the Saginaw River remains similar to that observed in 1974.

(2) Waste load reductions are immediate in time.

(3) The future proportions of reactive phosphate and non-reactive phosphate in the total phosphorus load remain the same as measured in 1974.

The biomass model differs from the chlorophyll model in that it is not part of a coupled Saginaw Bay-Lake Huron system. This presents a special problem in the determination of future boundary conditions since these conditions will change as nutrient loads change. Additional spatial resolution is needed to resolve this ambiguity.

EXISTING AND POTENTIAL PROBLEMS

Water quality problems in Saginaw Bay must be considered in relation to future increases in urban and industrial growth. Such problems are therefore divided into two groups: existing and potential. Although there is some overlap, existing problems can be documented with experimental data while potential problems are indicated by trends in data and by modeling projections. In cases where documentation is sparse, further study is needed.

EXISTING PROBLEMS

As the limnology section indicates, water quality parameters of concern in Saginaw Bay are nutrients, organics, heavy metals, dissolved oxygen, and coliform bacteria. Water quality problems in the bay result from the effect these parameters have on beneficial uses. In this section, the effects of these parameters on water supply, sport and commercial fisheries, and recreation are described, thus identifying problem areas.

WATER SUPPLY

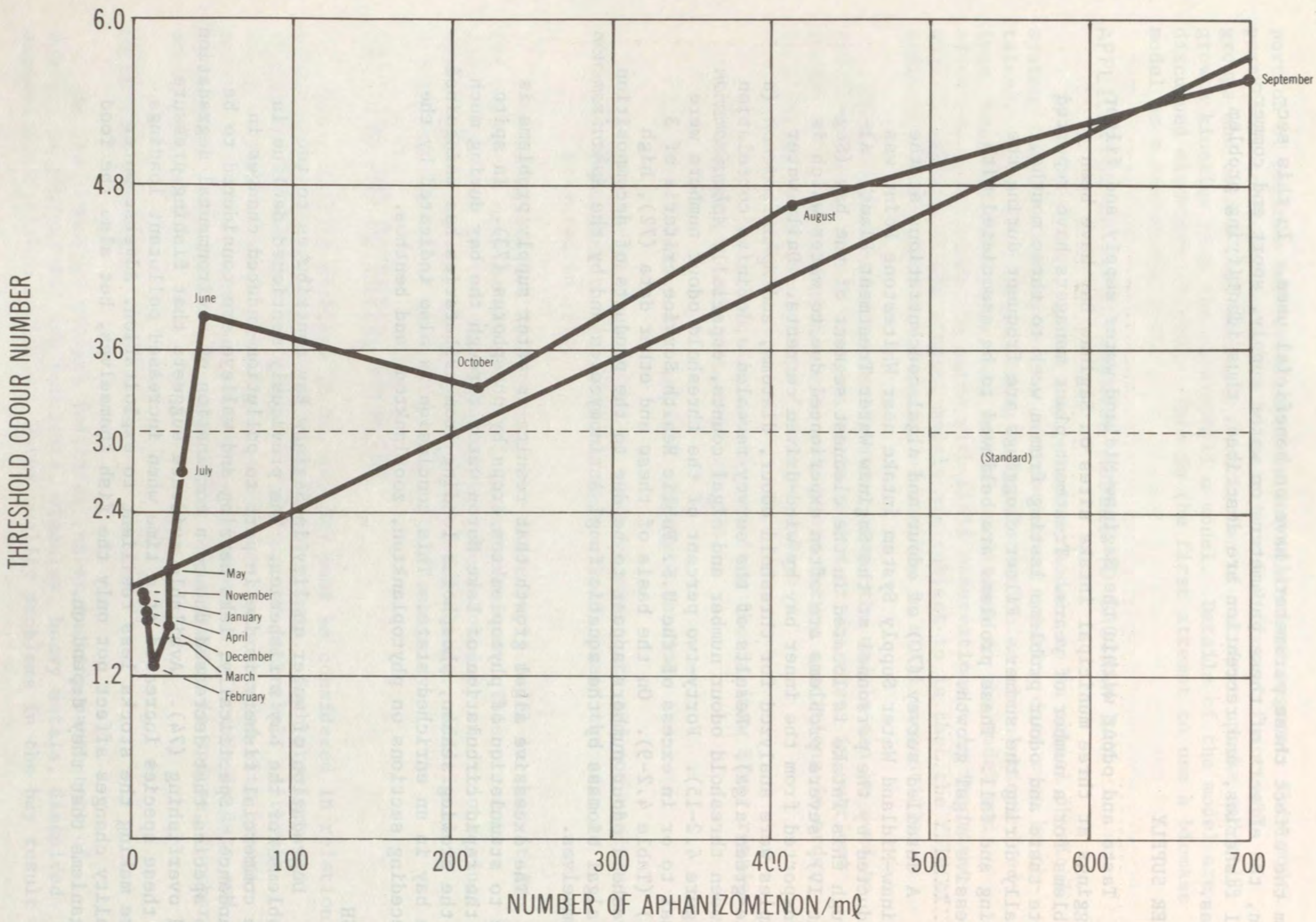
Taste and odour within the Saginaw-Midland water supply and filter cloggings at three municipal intake sites on Saginaw Bay have been problems for a number of years. Treatment plant managers have reported acute taste and odour problems lasting from a week to three months, usually during the summer. Filter cloggings are frequent during the spring and fall. These problems are believed to be associated with excessive algal growth.

A detailed survey (70) of odour and algal concentrations at the Saginaw-Midland Water Supply System intake near Whitestone Point was conducted by the personnel at the Saginaw Water Treatment Plant. Although this intake is located in the cleanest segment of the bay (Segment IV), severe problems are often experienced due to water which is transported from the inner bay by wind-driven currents. Daily water samples were analyzed for threshold odour, diatoms, and *Aphanizomenon* (a blue-green alga). Results of the survey revealed a definite correlation between threshold odour number and algal counts, especially *Aphanizomenon* (Figure 4.2-15). Forty-two percent of the threshold odour numbers were equal to or in excess of the U.S. Public Health Service criteria of 3 (71) (Table 4.2-9). On the basis of these and other data (72), high threshold odour numbers appear to be due to the products of decomposition of algal biomass by the aquatic fungi Actinomycetes and by the *Aphanizomenon* themselves.

The excessive algal growth that results in water supply problems is due to stimulation of phytoplankton crops by phosphorus (73). In spite of the rapid circulation of Lake Huron water through the bay during much of the growing season, phosphorus loading from tributaries has maintained the bay in an enriched state. This conclusion is also indicated by the preceding sections on phytoplankton, zooplankton, and benthos.

FISH

Degradation of water quality in Saginaw Bay contributes to two problems for the bay's fisheries. The previously mentioned decline in the commercial fishery is due in part to pollution-induced changes in abundance. Specifically, lake herring and walleye are considered to be two species that decreased due to a combination of environmental degradation and overfishing (74). Available evidence suggests that fishing pressure on these species increased at a time when increased pollutant loadings were making the stocks less resilient to exploitation. Adverse water quality changes affect not only the fish themselves, but also the food organisms that they depend on.



ODOUR = (5.597 x 10^{-3}) Aphanizomenon Number + 1.832   Coefficient of Correlation = 0.8913

FIGURE 4.2-15 ODOUR VS. APHANIZOMENON NUMBER (70). (November 1973 - October 1974)

TABLE 4.2-9

THRESHOLD ODOUR AT WHITESTONE POINT WATER INTAKE

SAGINAW BAY (70)

THRESHOLD ODOUR NUMBER	# OF SAMPLES ≥ THRESHOLD ODOUR[a]	% ≥ THRESHOLD ODOUR	# AT VALUE	% OF TOTAL
1	247	100	69	28
2	178	72	74	30
3[b]	104	42	55	22
4	49	20	26	11
5	23	9	1	0.4
6	22	9	16	6
7	6	2	2	0.8
8	4	2	3	1
9	1	0.4	0	0
10	1	0.4	1	0.4

a. 247 daily samples collected from November 1973 to October 1974.

b. 1962 USPHS Drinking Water Criteria (71).

Another problem for the bay's fishery is metals and organics contamination. In 1972, four species of fish (perch, carp, sucker, and whitefish) were collected and analyzed for PCB's, dieldrin, total DDT, and mercury (75). Except for carp, all averaged below 1 mg/kg for each parameter (whole fish). Carp, with a higher percentage of fat, averaged 4 mg/kg for PCB's, 1 mg/kg for total DDT, 0.13 mg/kg for mercury, and 0.05 mg/kg for dieldrin. Catfish were collected in 1973 and showed higher values for the same four parameters; average values were 8.2, 0.08, 3.8, and 0.18 mg/kg for PCB's, dieldrin, total DDT, and mercury, respectively (76). Most of the PCB and some of the total DDT values exceeded the FDA guideline of 5 mg/kg as well as the proposed Agreement objectives of 0.1 and 1.0 mg/kg, respectively (see Appendix C).

Four species (perch, carp, sucker, and smelt) in 1974 and perch from two locations in 1975 were collected and analyzed for a wider variety of metals and organic compounds (77). Carp again had high concentrations of PCB's, total DDT, zinc, and mercury, although only a few of the PCB levels exceeded the FDA guideline. Most other organic compounds were near or below the detection limits; however, perch from Quanicassee and Tawas City both had detectable levels of Aroclor 1254, averaging 0.13 and 0.20 mg/kg, respectively. Lead and cadmium were also near or below the detection limit.

A qualitative examination of several fish indicated the presence of numerous organic compounds, some of which are not routinely studied (78). Dichloro- to nonachlorobiphenyls; o,p and p,p' isomers of DDE, DDD, DDT; trichloro- to hexachlorobenzenes; *cis* and *trans* isomers of chlordane and nonachlor; hexa-, hepta-, and octachlorostyrenes; and penta-, hexa-, and heptahydroxy-PCB's were detected. Quantitative data were not available.

The data available on metals and organics contamination in fish are too sketchy to allow any conclusions to be drawn. Except for the carp and catfish, the concentrations are, in general, low in comparison to present guidelines.

RECREATION

Bacterial contamination in Saginaw Bay has been shown to be somewhat of a problem. This situation affects the recreational uses of swimming and boating. Although some of the effects are difficult to quantify, high total and/or fecal coliform determinations have contributed to discouraging swimmers at Bay City State Park, near the mouth of the Saginaw River. In many respects, the aesthetic perception of Saginaw Bay by potential recreational users is also affected by the same conditions that impair water supply uses: excessive nutrient stimulation of algae.

POTENTIAL PROBLEMS

Population and industrial activity in the Saginaw Bay basin are projected to increase significantly by the year 2020 (Chapter 1). The amount of municipal and industrial wastes requiring treatment will, therefore, also increase. Unless the rate of installation of treatment facilities keeps pace with these increases, loadings of most pollutants to the bay will eventually exceed present levels. In addition, non-point sources remain largely uncontrolled and loading quantities from these sources are also functions of urban and industrial growth.

Continued impairment of the beneficial uses of Saginaw Bay as a water supply, a fishery, and a recreational area is a strong possibility if pollutant loadings increase in the future. However, further problems may develop as a result of additional waste inputs. Wetland areas are located along approximately 50% of the bay's shoreline. These marshes are the major food source of waterfowl (79, 80) and are used directly by other forms of wildlife as food (81). Wetland areas also purge contaminants from the nearshore waters to some extent. Increased pollutant loadings may threaten the ecological stability of these areas.

As has been previously described, Saginaw Bay receives substantial flushing from Lake Huron during most of the year. While this situation has largely beneficial effects on Saginaw Bay, the opposite is true for the rest of the lake, especially the southwest shore. A discussion of existing effects is presented in Chapter 5, but increased pollutant loadings may worsen the situation. The problem will become particularly acute if substantial amounts of phosphorus become available in the open lake for algal stimulation. This may occur as a result of the flushing to the lake of algae that have taken up phosphorus in excess of their metabolic requirements.

Projected loadings of nutrients, suspended solids, and chloride such as those described in Chapter 3.12 can be used to suggest possible future water quality in Saginaw Bay.

NUTRIENTS

Future nutrient loads were used as input for the phytoplankton biomass model in order to simulate the response of the inner bay, assuming no change in present nutrient control measures. The total 1974 load (Table 4.2-10) was divided into point and non-point sources as was described previously. The point sources were considered to be potentially controllable. Only the controllable portion of the nutrient load was increased to simulate population and industrial growth. The uncontrollable portion was kept constant at the 1974 value.

The results of these simulations are purely speculative in nature and are intended only to illustrate general trends. This is because it is not possible to define a reasonable ultimate limit for boundary conditions between the inner and outer bays (37). All simulations were run using only the existing 1974 boundary conditions.

Five different combinations of projected phosphorus, nitrogen, and reactive silicate loads were used. The following principal results were obtained:

TABLE 4.2-10

1974 NUTRIENT LOADING TO SAGINAW BAY

NUTRIENT	1974 LOADING IN KILOGRAMS[a]		
	TOTAL LOAD	CONTROLLABLE	UNCONTROLLABLE
Total Phosphorus	1,270,000	720,000	550,000
Total Nitrogen	14,100,000	8,000,000	6,100,000
Reactive Silicate (as SiO_2)	57,300,000	-	-

a. These loads differ somewhat from those used in Volume I and in Chapter 3.3. A different calculation method was used in each case and the time period is different. See Reference (84) for a comparison of different calculation methods.

(1) Future increases in blue-green crops depended only on the increase in phosphorus load and were independent of the increase in nitrogen load. This is because nitrogen-fixing blue-greens became dominant when only phosphorus loading was increased.

(2) Diatom crops increased only when reactive silicate loading was increased and were practically independent of increases in either phosphorus or nitrogen. This is because reactive silicate concentrations in 1974 in Saginaw Bay reached limiting values in the spring.

SUSPENDED SOLIDS

Suspended solids loads to Saginaw Bay are projected to increase during the next 50 years (Chapter 3.12). One of the major deterrents to the development of water-oriented recreational uses in Saginaw Bay is the discoloration of water by suspended solids. An increase in suspended solids would further decrease light penetration in the water column, thereby adding to the aesthetic deterioration of the bay. As these suspended solids settle and accumulate as sediment, they can adversely affect the benthic community in the bay. Also, dredging operations would have to be accelerated to keep navigation channels open. This, in turn, would intensify the problem of dredged spoil disposal.

CHLORIDE

Within the past decade, chloride loading to Saginaw Bay has been reduced by 50%. However, municipal and industrial inputs of chloride are estimated, in the absence of further treatment, to increase (Chapter 3.12). Results of the chloride model, which was described previously, indicate that a 50% increase in loading would result in violations of the Michigan State standard of 5.0 mg/ℓ (Figure 4.2-16). Fortunately, the two primary dischargers of chloride now regulate their chloride release under permit for the Michigan Water Resources Commission.

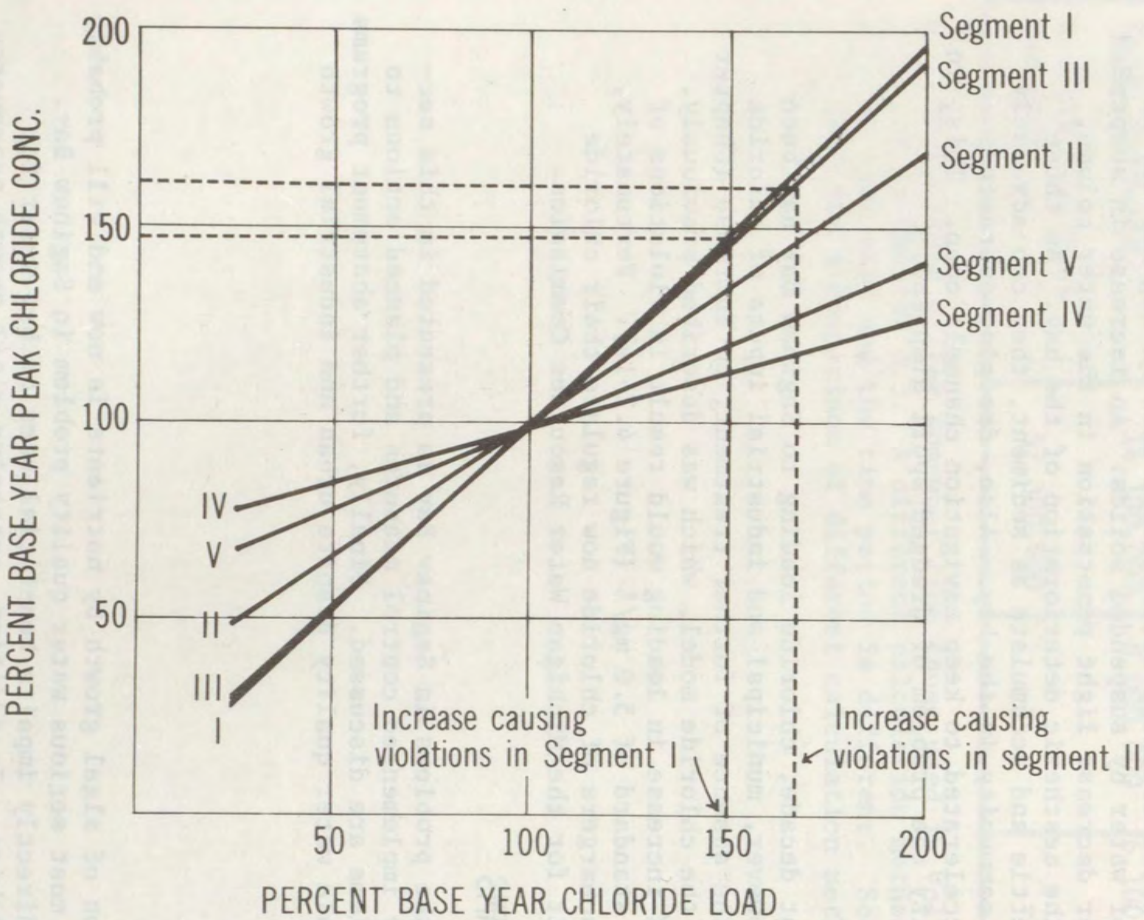
ABATEMENT PROGRAMS

A summary of the problems in Saginaw Bay is presented in this section. The recently implemented control measures and planned actions to address these problems are discussed. Finally, further abatement programs to maintain desirable water quality despite urban and industrial growth are recommended.

PROBLEM SUMMARY

ENRICHMENT

The stimulation of algal growth by nutrients is now and will probably continue to be the most serious water quality problem in Saginaw Bay. Such algal growth directly impairs beneficial uses of bay water for water supply and fishing. In addition, excessive algal growth aggravates the problems of dissolved oxygen depletion, water discoloration, and



Measured 1974 peak Chloride

Seg.	Conc. (mg/ℓ)
I	34.
II	21.0
III	31.
IV	9.0
V	11.

FIGURE 4.2-16 SENSITIVITY OF SEGMENT PEAK CHLORIDE CONCENTRATIONS TO CHANGES IN CHLORIDE LOAD (82). Based upon several cruises per year, the peak chloride concentration is the maximum cruise-average value expected.

bacterial growth.

TOXIC SUBSTANCES

Pollution of the bay by heavy metals and organics could inhibit growth at all levels of the food chain. Accumulation of these substances in fish may further depress the commercial fishing industry.

COLIFORM BACTERIA

Bacterial contamination in the inner bay especially at parks and public beaches, may continue to be of some concern.

DISSOLVED OXYGEN

Depletion of oxygen in the inner bay especially near the mouth of the Saginaw River has an adverse effect on benthic organisms. More serious depletion could effect the entire food chain in the bay.

SUSPENDED SOLIDS

Suspended solids from natural sources and from human activities necessitate considerable dredging in the bay. Discoloration of bay water by these solids reduces aesthetic value.

CHLORIDE

Chloride is not, at present, a problem. However, if due to industrial expansion and urban growth, loading does increase to the levels of 10 years ago, the problem will return.

Many of the problem areas listed above can be defined only subjectively because of lack of information on them and weak or non-existent criteria. Further studies must be undertaken on Saginaw Bay to identify the important toxic substances and the compartments of the ecosystem in which they are most important. An even greater effort than was expended on studying enrichment may be necessary in view of the added complication of bioaccumulation through the food chain. In addition, analytical procedures must be improved and standardized for both heavy metals and organics.

Information on bacterial contamination is lacking in two respects. For this report, insufficient data were collected to establish a violation as required by the Agreement objective. In addition, the effectiveness of total coliform as an indicator of the presence of pathogens in a system such as Saginaw Bay needs to be evaluated.

Criteria for bay water quality need to be strengthened. In order to evaluate the effects of enrichment on the sport and commercial fisheries, effects due to overfishing and predators have to be separated. Dissolved oxygen depletion in a transient, non-stratified embayment such as Saginaw Bay is often not considered a problem if standards are met.

However, if the criterion is not specific to the physical system, a problem may still exist. In Saginaw Bay, diurnal fluctuations due to the tremendous amount of biological activity are of considerable importance.

Much of the suspended solids that cause discoloration of bay water and excessive sedimentation are from "natural" sources. However, land use in tributary basins may actually be responsible for much of the natural solids loading. Guidelines must be established for control of these sources.

RECENT AND PLANNED ABATEMENT

Planned programs to address the above problems as well as recent improvements whose effects will soon be experienced are discussed in this section. Again, emphasis is placed on phosphorus removal.

The primary and traditional objective of waste management in the Saginaw Basin has been to meet water quality requirements in the tributaries. This has resulted over the years in the construction of waste treatment facilities designed for removal of BOD and suspended solids, and for elimination of pathogenic bacteria and viruses. Some phosphorus removal occurs as a secondary benefit. Only recently has more attention been focused on controlling the enrichment of the Great Lakes and specifically algal biomass by requiring removal of phosphorus.

PHOSPHORUS CONTROL

In 1974, about 1,000 kg/d of phosphorus originated from the Flint Municipal Sewage Treatment Plant and about 1,100 kg/d came from all other municipal treatment plants (Table 3.3-5). Phosphorus loading originating from industrial sources in 1974 was found to be insignificant when compared with other sources (83). The total phosphorus load to the Saginaw River is composed of these point sources plus diffuse or non-point sources. However, some of this phosphorus load settles out before reaching the bay. This phosphorus as well as associated sediment is presently dredged from the river and disposed of on land by the Corps of Engineers. It is estimated that 382,000 kg/a (1050 kg/d) of phosphorus are removed in this manner (23). If this practice were to be discontinued, this additional phosphorus would be eventually washed into the bay.

The primary effort to control phosphorus discharge has been to reduce the phosphorus content of laundry detergents and implement phosphorus treatment at municipal treatment plants. The present Michigan limit for phosphorus in laundry detergent is 8.7% and, as of January 1, 1977, all municipal sewage treatment plants in the Lake Huron basin were required to remove 80% of their incoming phosphorus load. To date, only minor progress has been made toward achieving this latter goal; however, major treatment projects are underway. The City of Saginaw is completing a 125,000 m^3/d activated sludge and phosphorus removal addition to their existing primary plant and is also constructing two combined sewer overflow retention basins for control of overflows. The City of Flint is constructing a 190,000 m^3/d advanced treatment plant with phosphorus removal and Genesee County is constructing a comparable 76,000 m^3/d facility. Both were to have been completed in 1976. Bay City has a secondary plant in operation including phosphorus removal. The city has an active sewer separation program and is constructing a combined stormwater overflow facility.

For the purpose of load reduction simulations, the total phosphorus load was again split into controllable and uncontrollable portions as was done previously (Table 4.2-10). The load reductions expected from the above control measures were applied to the controllable portion of the load, while the uncontrollable portion remained constant at 1974 values. As a result, the expected reduction in controllable phosphorus is 83% or, in terms of total phosphorus load, 47%.

SIMULATIONS OF PHYTOPLANKTON RESPONSE TO PHOSPHORUS CONTROL

Simulations of the response of Saginaw Bay phytoplankton to phosphorus load reductions were conducted using the chlorophyll *a* and biomass models described previously. These projections of future conditions are preliminary and only indicate the trends that are to be expected from a phosphorus reduction program. They are not a projection of absolute future conditions.

The chlorophyll *a* model projects that an 83% removal of phosphorus from controllable or municipal and industrial sources (47% reduction of total phosphorus) will result in a 33% reduction in average phytoplankton chlorophyll (66). The same phosphorus reduction will result in a 34% and a 38% reduction in the spring and fall phytoplankton chlorophyll peaks, respectively.

Simulation of phytoplankton groups, although more speculative, provides insight into the growth of phytoplankton forms. Two parameters of comparison were used for the reduction simulations: peak biomass in mg dry weight/ℓ and gross biomass production over the year, also in mg dry weight/ℓ. Results are reported separately for diatoms and blue-green algae because of the important differences in their water quality characteristics. In all cases, baseline conditions refer to the output of the biomass model calibrated to the 1974 data (37). In contrast to the simulations for future load increases, it is possible to define reasonable upper and lower limits for future boundary conditions in the case of load reductions. Best case reduction simulations refer to those generated for the most optimistic assumption about the boundary conditions, while the worst case refers to the most pessimistic assumption about the boundary conditions. The average case is an arithmetic mean of the "best" and "worst" values and is not intended to represent the most likely response of the bay. More information is available in the project report (37). The results for blue-green algae are the sum of the biomass concentrations for the two individual groups of blue-greens in the model: nitrogen fixers and non-nitrogen fixers. Most of the phytoplankton biomass in Saginaw Bay is represented by diatoms and blue-greens. A range of reductions is presented (Table 4.2-11). Sixty percent reduction corresponds to the present IJC goal for Lake Huron.

TABLE 4.2-11

RESULTS OF PHOSPHORUS REDUCTION SIMULATIONS (37)

Treatment	Percent Reductions in Peak Biomass					
	Diatoms			Blue-Greens		
	Worst Case	Best Case	Average	Worst Case	Best Case	Average
IJC Goal 60% Reduction in Controllable Phosphorus (34% Total Phosphorus)	0.0	16.0	8.0	16.0	59.0	37.5
Future IJC Goal 83% Reduction in Controllable Phosphorus (47% Total Phosphorus)	1.0	18.5	9.8	22.5	68.0	45.2
Hypothetical Goal 100% Percent Reduction in Controllable Phosphorus (57% Total Phosphorus)	2.5	22.0	12.2	30.0	75.0	52.5

Treatment	Percent Reductions in Gross Biomass Production					
	Diatoms			Blue-Greens		
	Worst Case	Best Case	Average	Worst Case	Best Case	Average
IJC Goal 60% Reduction in Controllable Phosphorus (34% Total Phosphorus)	5.5	9.0	7.25	19.0	66.0	42.5
Future IJC Goal 83% Reduction in Controllable Phosphorus (47% Total Phosphorus)	8.0	14.0	11.0	28.0	74.0	51.0
Hypothetical Goal 100% Reduction in Controllable Phosphorus (57% Total Phosphorus)	10.0	18.0	14.0	34.0	80.0	57.0

The 83% reduction figure is the future IJC goal, but is also the expected reduction when all planned treatment plants are on line. The hypothetical case of 100% reduction of controllable phosphorus is presented to illustrate the most that can be accomplished without reduction of non-point sources.

The principal results that emerge from the simulations are the following:

(1) Blue-green algae responded much more quickly than diatoms to reduced phosphorus loadings under all conditions (Figures 4.2-17 and 4.2-18).

(2) Responses of blue-greens on the basis of gross biomass production were slightly, but consistently, greater than the responses of blue-greens on the basis of peak biomass.

(3) A 57% reduction in total phosphorus loading (100% reduction in municipal and industrial phosphorus loading) resulted in a 52.5% average reduction in peak blue-green biomass and a 57% average reduction in blue-green gross biomass production (Table 4.2-11). This implies that the size of the blue-green crop is approximately proportional to the external loading of controllable phosphorus over its present range.

(4) The same phosphorus reduction as in (3) results in a 12.2% average reduction in diatom peak biomass and a 14% average reduction in diatom gross biomass production. This implies that diatoms do not respond in proportion to the external loading of controllable phosphorus over its present range.

Since blue-green algae are a serious water quality problem in Saginaw Bay, phosphorus control measures appear to be the appropriate course of action for restoration of many of the bay's beneficial uses. In summary, the implementation of the present phosphorus requirements would result in 83% removal. This in turn would result in a 33% reduction in average chlorophyll and 51 and 11% reductions in blue-green and diatom gross productions, respectively. These reductions are estimated to reduce the occurrences of taste and odour problems at the Whitestone water intake from 22% of the time to approximately 1% of the time. The actual occurrence of such improvements in the water supply is dependent not only on the assumptions made for the biomass model, but also on the quantitative relationship between threshold odour number and phytoplankton biomass, which, at present, is represented as merely a linear correlation. Further study is needed in this area.

TOXIC SUBSTANCES

As a result of the NPDES permit program, control measures have been or will soon be implemented for many metals and organics that are known to be toxic to human and animal life. Effluent limitations have been established for wastewater discharges in general and for discharges

FIGURE 4.2-17 PEAK BIOMASS VS. PHOSPHORUS REDUCTION FOR INNER BAY (37).

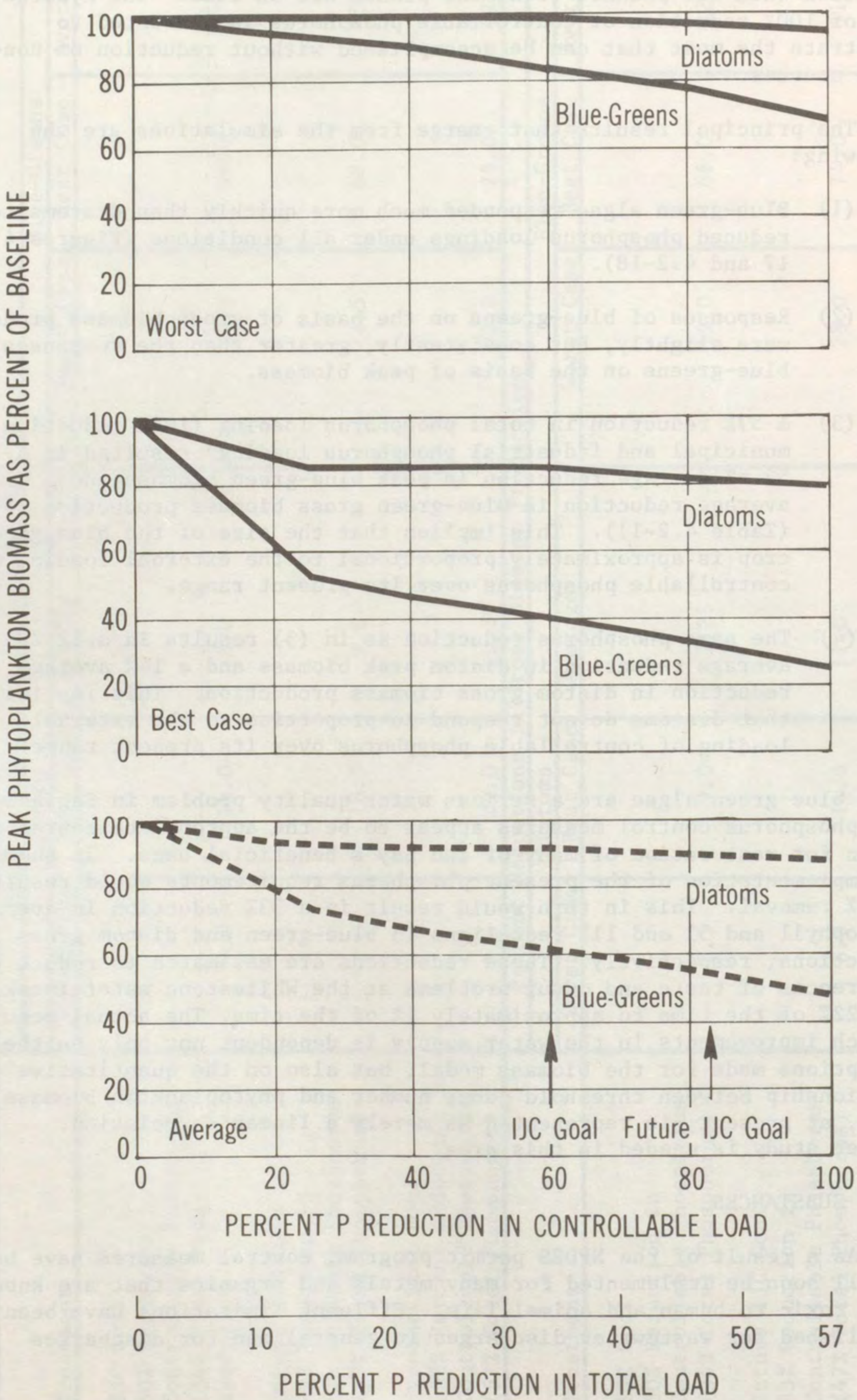
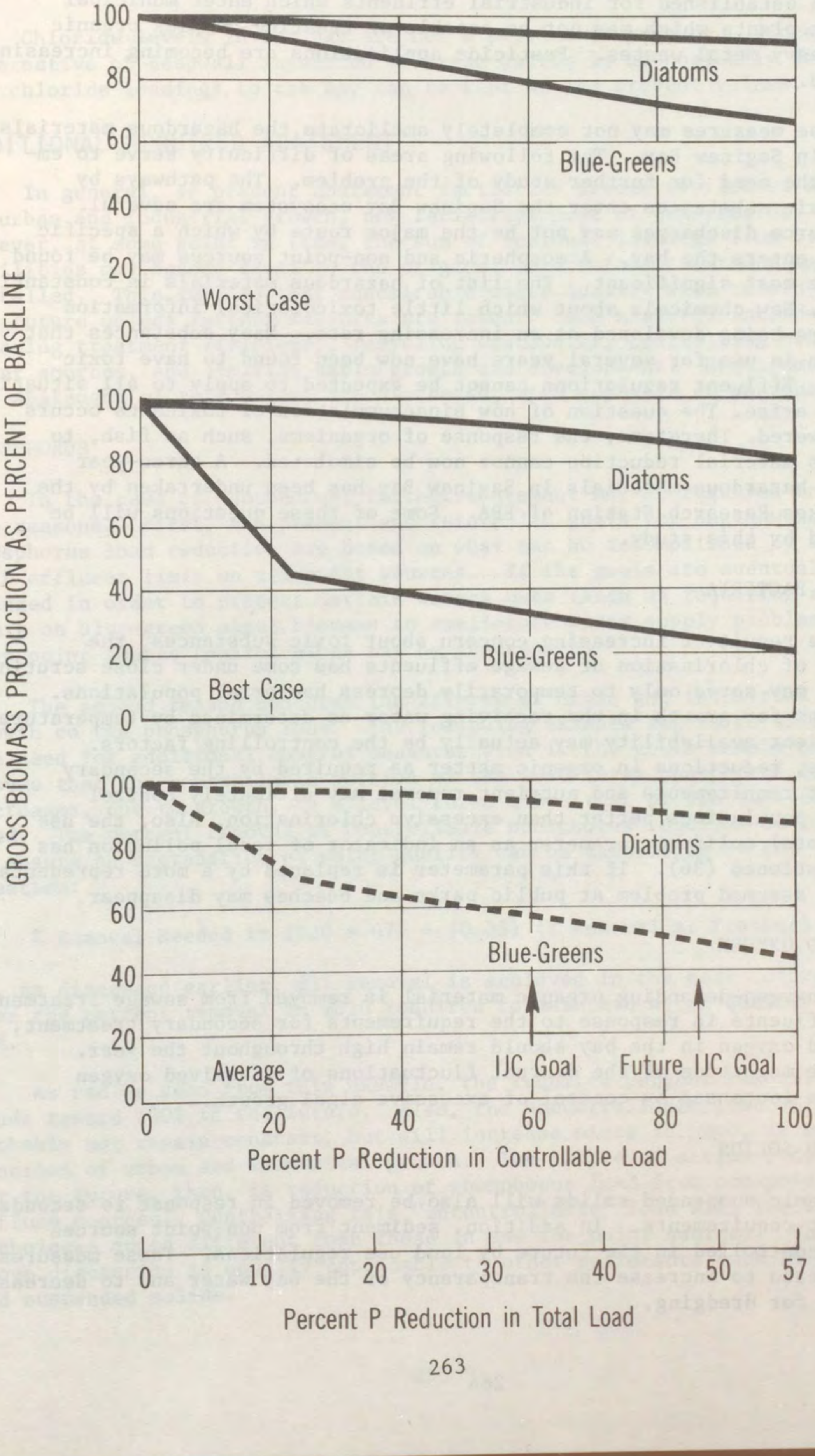


FIGURE 4.2-18 GROSS BIOMASS PRODUCTION VS. PHOSPHORUS REDUCTION FOR INNER BAY (37).



specific to certain industrial categories (32). Pretreatment standards have been established for industrial effluents which enter municipal treatment plants which may not be capable of treating complex organic and/or heavy metal wastes. Pesticide applications are becoming increasingly regulated.

These measures may not completely ameliorate the hazardous materials problem in Saginaw Bay. The following areas of difficulty serve to emphasize the need for further study of the problem. The pathways by which toxic substances enter the Saginaw Bay ecosystem are several. Point source discharges may not be the major route by which a specific material enters the bay. Atmospheric and non-point sources may be found to be the most significant. The list of hazardous materials is constantly changing. New chemicals about which little toxicological information exists are being developed at an increasing rate. Many substances that have been in use for several years have now been found to have toxic effects. Effluent regulations cannot be expected to apply to all situations that may arise. The question of how bioaccumulation of toxicants occurs is unanswered. Therefore, the response of organisms, such as fish, to hazardous material reduction cannot now be simulated. A three-year study of hazardous materials in Saginaw Bay has been undertaken by the Large Lakes Research Station of EPA. Some of these questions will be addressed by this study.

COLIFORM BACTERIA

As a result of increasing concern about toxic substances, the practice of chlorination of sewage effluents has come under close scrutiny. Chlorine may serve only to temporarily depress bacterial populations. Conditions for growth in the receiving water as determined by temperature and nutrient availability may actually be the controlling factors. Therefore, reductions in organic matter as required by the secondary treatment requirements and nutrient removal may ultimately control pathogen populations better than excessive chlorination. Also, the use of the total coliform parameter as an indicator of fecal pollution has been questioned (36). If this parameter is replaced by a more representative one, the assumed problem at public parks and beaches may disappear.

DISSOLVED OXYGEN

As oxygen-demanding organic material is removed from sewage treatment plant effluents in response to the requirements for secondary treatment, dissolved oxygen in the bay should remain high throughout the year. Also, the magnitude of the diurnal fluctuations of dissolved oxygen should be decreased by control of excessive algal growth.

SUSPENDED SOLIDS

Organic suspended solids will also be removed in response to secondary treatment requirements. In addition, sediment from non-point sources will be controlled in the future by land use regulations. These measures are expected to increase the transparency of the bay water and to decrease the need for dredging.

CHLORIDE

Chloride levels in the bay are not a problem at present. Since the alternative of deepwell injection of brine wastes is economically feasible, the chloride loadings to the bay can be kept at the present values.

ADDITIONAL REQUIRED ABATEMENT

In general, as present abatement facilities become overloaded due to urban and industrial growth, new facilities must be constructed. However, at some point in time, the sum of residual loadings from treatment facilities may become equal to the original load before treatment was installed. This implies that undesirable water quality will return in the future unless further measures are taken. Such measures include increasing treatment efficiency, recycling wastewater, controlling non-point sources, and limiting basin growth and development. Requirements for abatement of this nature are discussed, with emphasis on phosphorus.

PHOSPHORUS

In the case of phosphorus, further abatement may be required for two reasons. First, the present and future IJC goals for Saginaw Bay phosphorus load reduction are based on what can be accomplished by a 1 mg/ℓ effluent limit on all point sources. If the goals are eventually changed in order to protect certain waters uses (such as requiring a limit on blue-green algal biomass to ameliorate water supply problems), then point source control alone may be inadequate.

The second reason concerns the effects of urban and industrial growth on the phosphorus load. The following example serves to illustrate the need for additional control measures even if the goals remain unchanged. Assume that the controllable portion of the 2020 total phosphorus load increases, due to growth, to a level three times that of the 1974 controllable load. The percent removal of controllable phosphorus required in 2020 to ensure no degradation of water quality can be calculated by the equation:

$$\% \text{ Removal Needed in 2020} = 67\% + (0.33)\ (\% \text{ Removal at Present})$$

If, as discussed earlier, 83% removal is achieved in the near future, then the percent removal in 2020 required to maintain water quality is 94%.

As can be seen from this example, the required percent removal tends toward 100% in the future. Also, the uncontrollable load will probably not remain constant, but will increase since it, too, is a function of urban and industrial growth. The course of action indicated for the future, then, is reduction of phosphorus load from non-point or diffuse sources. Controlling this "uncontrollable" load will require techniques quite different than those in use for point sources. The above discussion is equally applicable to other pollutants such as BOD and suspended solids.

HAZARDOUS MATERIALS

As previously discussed, a study is being undertaken to identify significant sources of metals and organics entering Saginaw Bay. Since some sources may not be controllable and since conventional treatment technology may not be appropriate for load reductions, abatement measures for toxic substances may involve elimination or replacement of the material in question. This is especially true for many of the chlorinated hydrocarbons presently in use.

COMPLETE RESTORATION OF WATER QUALITY

Due to lack of historical information a "pastoral" description of Saginaw Bay has not been given. Requirements for complete restoration of the bay to this "pastoral" condition have not, therefore, been estimated. It can be speculated that the Saginaw Bay area was extremely desirable to settlers in the 19th century and that this was due, in part, to the high productivity of the bay. Diatoms were probably much more dominant and water clarity was probably considerably greater than it is today. If quantitative information of this nature is necessary to define future water quality goals, then studies should be made of sediment cores which contain historical records. Another possibility is a comparative study of a different bay in the Great Lakes with similar physical characteristics.

SUMMARY

Saginaw Bay on Lake Huron serves 1.2 million people either directly or indirectly through its use as a source for water supply, recreation, commercial fishing, and commercial navigation. It also receives wastewater generated by municipalities and industries including the Dow Chemical Company, the Michigan Chemical Company, and the Flint Municipal Sewage Treatment Plant, the three most important dischargers. Although the bay is flushed every 60 days by Lake Huron, the chemistry and the biology of the bay (especially the inner bay near the mouth of the Saginaw River) are showing increasing evidence of eutrophication and other problems normally attributed to human activity. Biological indicators such as phytoplankton, zooplankton, and benthos all exhibit a shift towards more pollution-tolerant organisms. Trends in phosphorus and other pollutant concentrations are upward with the exception of chloride. Toxic organics are beginning to be problems in the bay. Existing and potential problems are summarized in the Abatement Programs section of this subchapter.

Mathematical modelling has been used to assess present problems in the bay and to evaluate possible future solutions to these problems. The models were used as management tools to address the problems of enrichment and chloride build-up in the bay. Pollutant load reductions and/or increases were postulated and the response of biological or chemical indicators was simulated. Pollution abatement measures on line or under construction appear to be adequate to meet water quality standards or criteria and restore many beneficial uses of Saginaw Bay in the near future. However, longer term maintenance of these conditions will require additional treatment and, at some point in time, control of non-point sources.

Further work is needed in many areas, especially in water quality criteria development and in the assessment of the hazardous materials problem. Water quality criteria that are tailored specifically to nearshore, multiple use areas such as Saginaw Bay are lacking. The problems of toxic substances in the Saginaw Bay system have just recently been recognized. Studies to address the problems have been undertaken and will include the modelling methodology mentioned above.

HAZARDOUS MATERIALS

[illegible] significant [illegible] some sources [illegible] technology [illegible] for [illegible] material in question [illegible] hydrocarbons present [illegible]

COMPLETE RESTORA[illegible] WATER QUALITY

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SUMMARY

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4.3 ST. MARYS RIVER

DESCRIPTION OF STUDY AREA

The St. Marys River is the connecting waterway between Lake Superior and Lake Huron. The upper portion of the river extends from Whitefish Bay to the St. Marys rapids. A series of works (locks, power diversion channels, regulating gates) have been constructed as aids to control the outflow of Lake Superior for navigation and for power development. The lower river has an irregular shoreline and contains three large islands, Sugar and Neebish Islands on the U.S. side and St. Joseph Island on the Canadian side (Figure 4.3-1). Sugar Island diverts the river below the locks into two channels Lake Nicolet and Lake George. Neebish Island subdivides the river from Lake Nicolet into the west and middle channels while St. Joseph Island subdivides the flow from Lake George into the middle and east channels.

GEOLOGY AND TOPOGRAPHY

The rock formations of the land bordering to the St. Marys River consist of schists, granite, and diabases of Precambrian age and are mantled and in places deeply buried beneath the overlaying glacial drift.

The land on the Canadian side is a drift-covered strip from one to eight kilometres in width. The land surface rises toward the north in a succession of terraces and reaches a maximum altitude of about 120 m above the mean water surface elevations of both Lake Superior and Lake Huron. On the United States side, the topography is characterized by gradually rising terrain which develops into a flat area with an altitude of about 90 m above the lakes.

WATER USES

DOMESTIC WATER USE

The upper St. Marys River is the source of supply for the U.S. and Canadian cities of Sault Ste. Marie. The total average pumpage from the river is 0.5 m^3/s. No public water supply is taken from the lower St. Marys River. A portion of the Canadian city is supplied with well water.

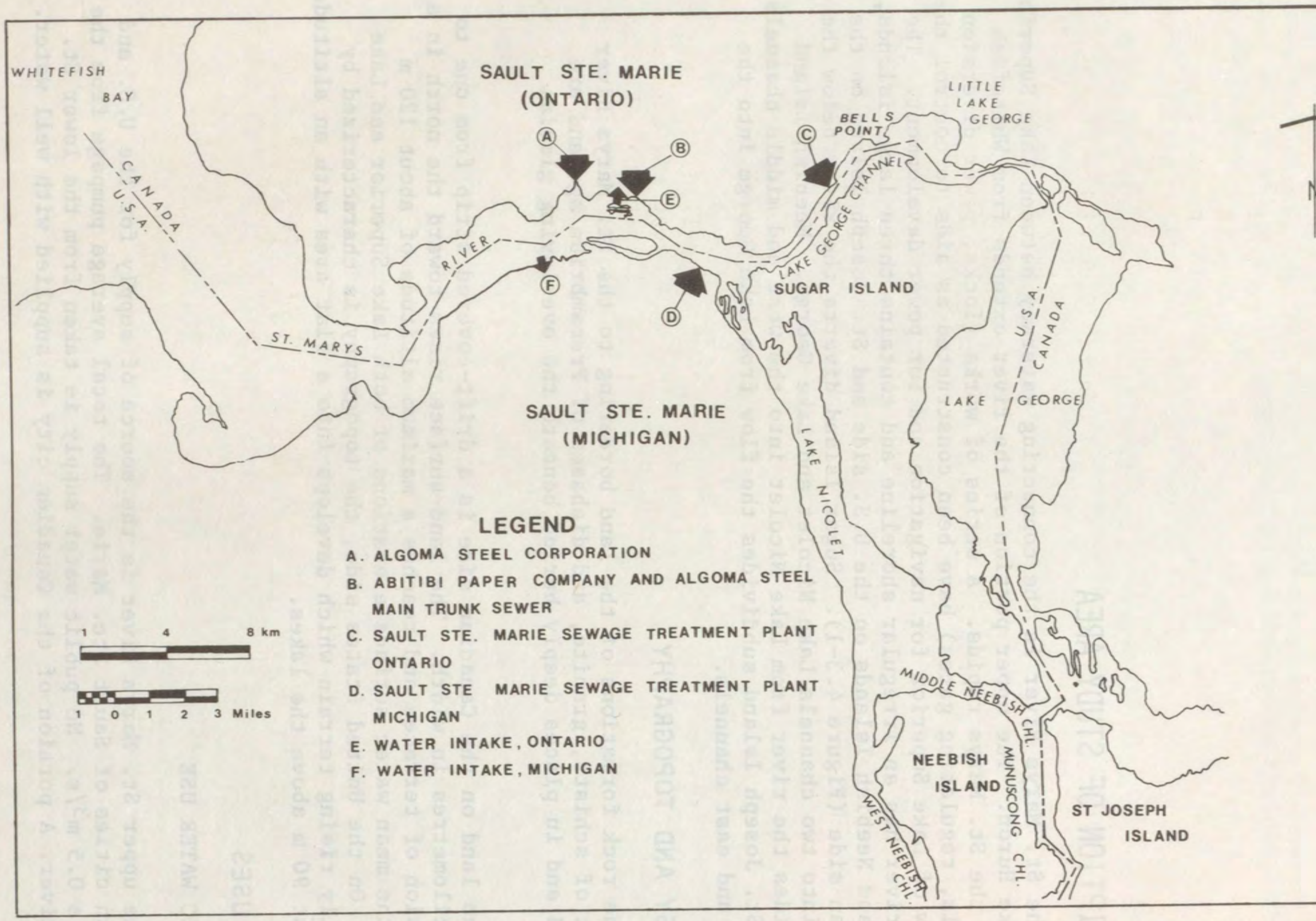

FIGURE 4.3-1 MUNICIPAL INTAKES, OUTFALLS AND INDUSTRIAL WASTE DISCHARGES

POWER AND IRRIGATION

The Great Lakes Power Corporation plant located between the Canadian lock and the mainland uses approximately 500 m^3/s while the United States Government's hydroelectric plant located between the U.S. locks and the rapids requires about 350 m^3/s. The Edison Sault hydroelectric power plant is served by a 1 km-long canal which diverts water from a point just above the U.S. locks and delivers it to the plant at a rate of 835 m^3/s. Although the above uses do not add pollution to the river, they alter the pattern of currents in the system.

Sault Ste. Marie, Ontario, Golf and Country Club withdraws about 0.01 m^3/s during the summer for irrigation purposes.

NAVIGATION

Vessel traffic through the locks is very heavy. The average number of vessels passing through the locks in the past 20 years decreased from 26,122 vessels in 1953 to 12,712 in 1970 (1). In recent years the cargo carried is 10^8 t/a. The vessels carry mainly crude oil, steel, coal, petroleum products, taconite, and iron ore between Lake Superior and the industrial centres on the lower lakes.

RECREATION

The bays and lakes in the lower river provide excellent recreational possibilities. Use is intensive in the two parks nearest the cities of Sault Ste. Marie. There is private bathing along all parts of the river other than the immediate vicinity of the cities. The Algoma Health Unit restricts swimming in the river from the locks to Bells Point at Little Lake George. Boating and fishing are popular forms of recreation throughout the entire area.

WASTE DISPOSAL

Locations of municipal and industrial discharges from both the Canadian and U.S. shores into the river are shown in Figure 4.3-1. Municipal waste waters from both cities are treated in primary plants with chlorination facilities. The chlorinated effluent from the Sault Ste. Marie, Ontario sewage treatment plant (STP) is discharged to the Lake George Channel at a rate of 0.6 m^3/s while that of the U.S. discharged to the river at a rate of 0.17 m^3/s.

Industrial waste discharges from Sault Ste. Marie, Ontario total 7.2 m^3/s; Algoma Steel Corp. Limited and Algoma Steel Tube Division discharge 6.4 m^3/s and Abitibi Paper Company discharges 0.8 m^3/s. There are no industrial discharges from Sault Ste. Marie, Michigan to the river.

LIMNOLOGY

Existing agency surveillance programs were used in monitoring water quality in the river (Figure 4.3-2). Water quality parameters analyzed were: phenol, cyanide, ammonia, nutrients, chlorophyll α, heavy metals, and bacteriological parameters. Bottom surficial sediments were analyzed for nutrients, heavy metals, and trace organics. The results of these studies are presented below; details are given in Reference (4).

PHYSICAL

TEMPERATURE, pH, DISSOLVED OXYGEN, ALKALINITY, AND CONDUCTIVITY

Levels of temperature, alkalinity, pH, and dissolved oxygen in the St. Marys River did not exhibit significant changes over the period of record (1967-74). Seasonal variation in temperature exhibited a pattern similar to that observed in Lake Superior and the North Channel. The average surface temperature is 5°C in spring and 19°C in summer throughout the river. Average levels of alkalinity, pH, and dissolved oxygen saturation were 40 mg $CaCO_3/\ell$, 7.9, and 92% respectively, throughout the river and were similar to those observed for waters of Lake Superior. Conductivity levels downstream from municipal and industrial outfalls revealed slight increases over background levels of 97 µS/cm. However, temporal trends for conductivity levels at these locations did not indicate significant changes.

WATER MOVEMENT AND WASTE DISPERSION

Iso-concentration contours for phenols provided an insight into the factors influencing the mixing process in the river (Figure 4.3-3).

The contours are deflected towards the Canadian shore due to irregularity of the shoreline coupled with the lateral force exerted by the discharge from the Edison Sault hydroelectric power canal, which amounted to 40% of the total river flow during 1974. As a result, pollutants follow the channel to the north of Sugar Island via the Lake George Channel. The above phenomenon was also observed during the previous years.

The flow around Sugar Island, which varies with the amount of ice cover, is proportioned in the ratio of 69 ± 3% in the Lake Nicolet Channel and 31 ± 3% in the Lake George Channel. The curving flow at the beginning of the Lake George Channel creates a zone of high velocities towards the U.S. shore; secondary currents may be induced due to the variation in the centrifugal force (2). These secondary currents help increase the transverse mixing process (3). Thus, contaminants hug the Canadian shore at the beginning of the Lake George Channel and then disperse laterally and impinge on the U.S. shore farther downstream, reflecting the occurrence of the transboundary movement in the channel.

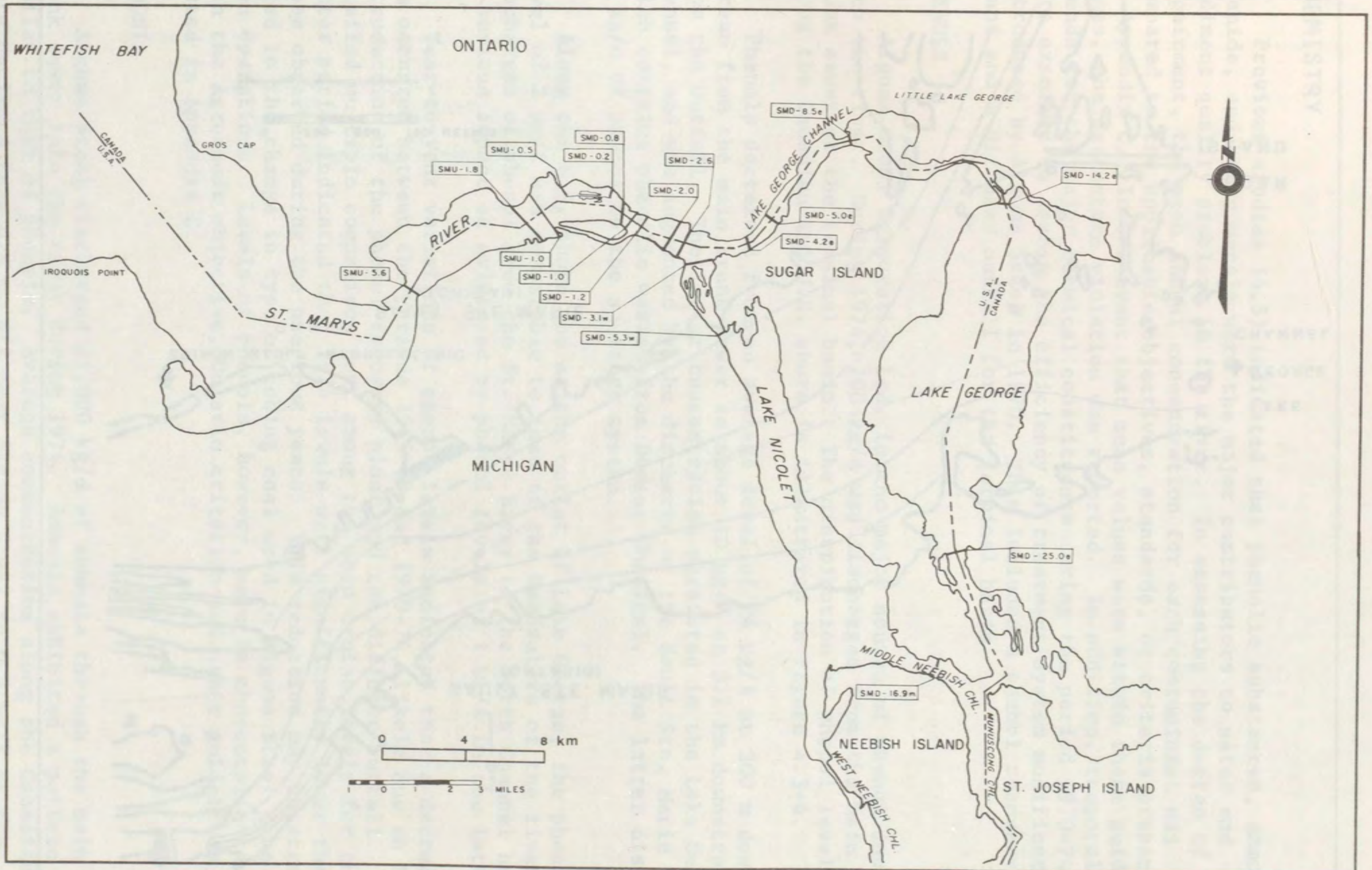

FIGURE 4.3-2 ST. MARYS RIVER-WATER QUALITY MONITORING RANGES

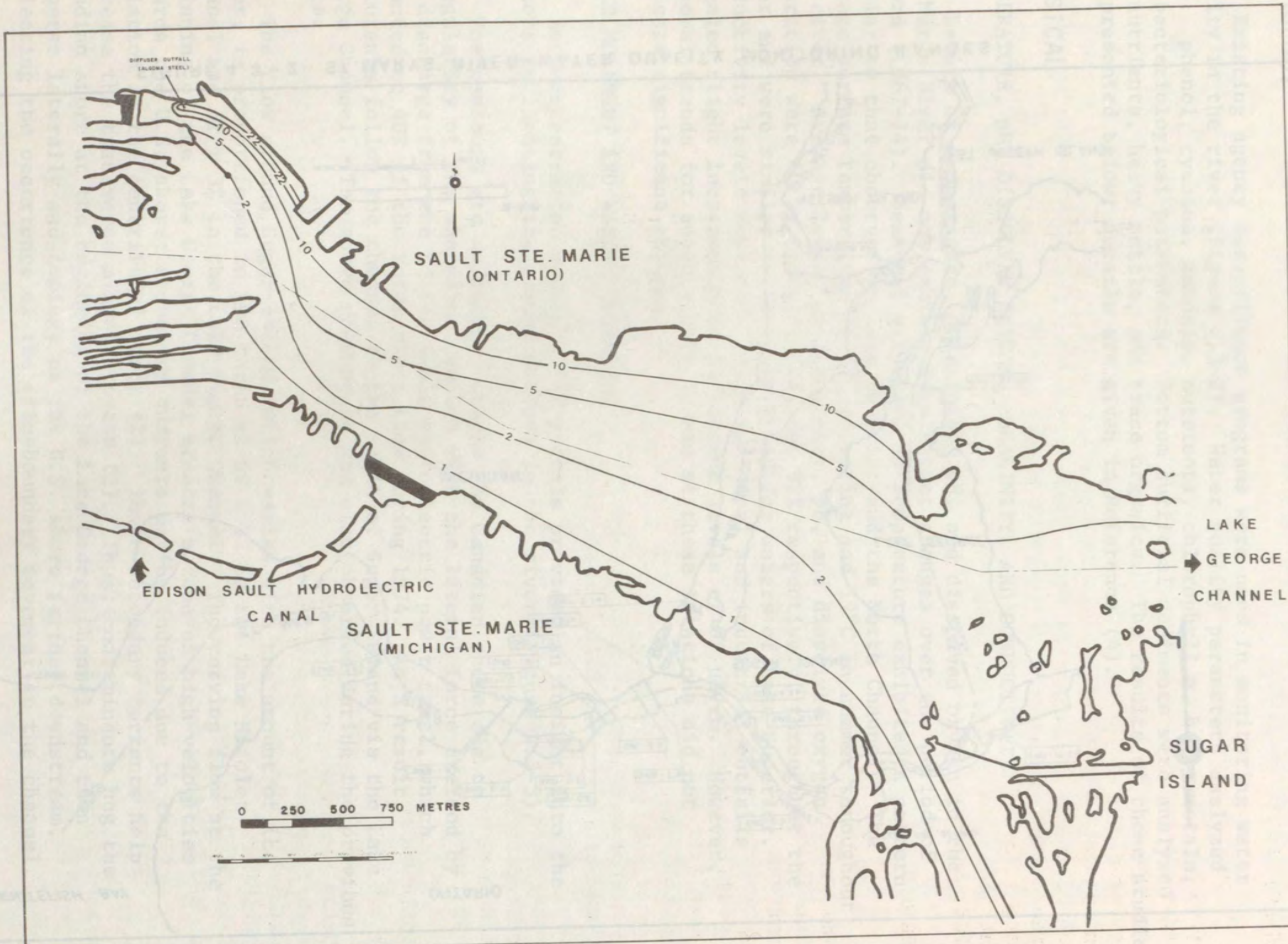

FIGURE 4.3-3 : PHENOL ISO-CONCENTRATION (μg/ℓ) CONTOURS DURING 1974.

CHEMISTRY

Previous studies (4,5) indicated that phenolic substances, ammonia, cyanide, and heavy metals were the major contributors to water and sediment quality problems in the river. In assessing the degree of impairment, the mean annual concentration for each contaminant was compared to the applicable objectives, standards, or criteria presented in Appendix C. In the event that mean values were within these guidelines, the percentage violation was reported. In addition, temporal trends for the major chemical constituents during the period 1970-74 were examined to assess the efficiency of treatment system modification introduced by Algoma Steel in 1970. This included a phenol recovery plant and a diffuser outfall for the terminal basin.

PHENOLS

Algoma Steel Corporation Ltd. is the major source of phenol inputs into the river. During 1974, 200 kg/d was discharged from the main trunk sewer of the terminal basin. The distribution of phenol levels along the Canadian and U.S. shore is illustrated in Figure 4.3-4.

Phenols decreased from an average level of 24 μg/ℓ at 300 m downstream from the main trunk sewer to about 10 μg/ℓ at 3.2 km downstream from the outfall. The latter concentration persisted in the Lake George Channel, and was augmented by the discharge of the Sault Ste. Marie STP which contains phenolic wastes from Domtar Chemical. The latter discharges 23 kg/d of phenol to the sanitary system.

Along the U.S. shore and at the outlet of Lake George, the phenol level of 2 μg/ℓ was comparable to that at the headwaters of the river. Discharges of phenol from the St. Marys River to the North Channel have no serious impact as evidenced by phenol levels of 1 μg/ℓ in the latter.

Year-to-year variations of phenol levels indicated that a decrease has occurred between the periods 1963-69 and 1970-74, likely due to the introduction of the phenol recovery plant and the diffuser outfall. A detailed multiple comparison test among the mean cruise levels for the latter period indicated that 1974 levels were significantly lower than those observed during the previous years. This reduction may be attributed to the change in type of coking coal used in Algoma Steel coke oven operations. Levels of phenols, however, were in non-compliance with the Agreement objective, Ontario criterion and other guidelines listed in Appendix C.

AMMONIA

Algoma Steel discharged 11,000 kg/d of ammonia through the main trunk sewer into the river during 1974. Ammonia exhibited a pattern similar to that of phenols. Average concentration along the Canadian shore declined from 0.4 mg N/ℓ near Algoma Steel to 0.2 mg/ℓ at the beginning of the Lake George Channel (Figure 4.3-5). Levels in the

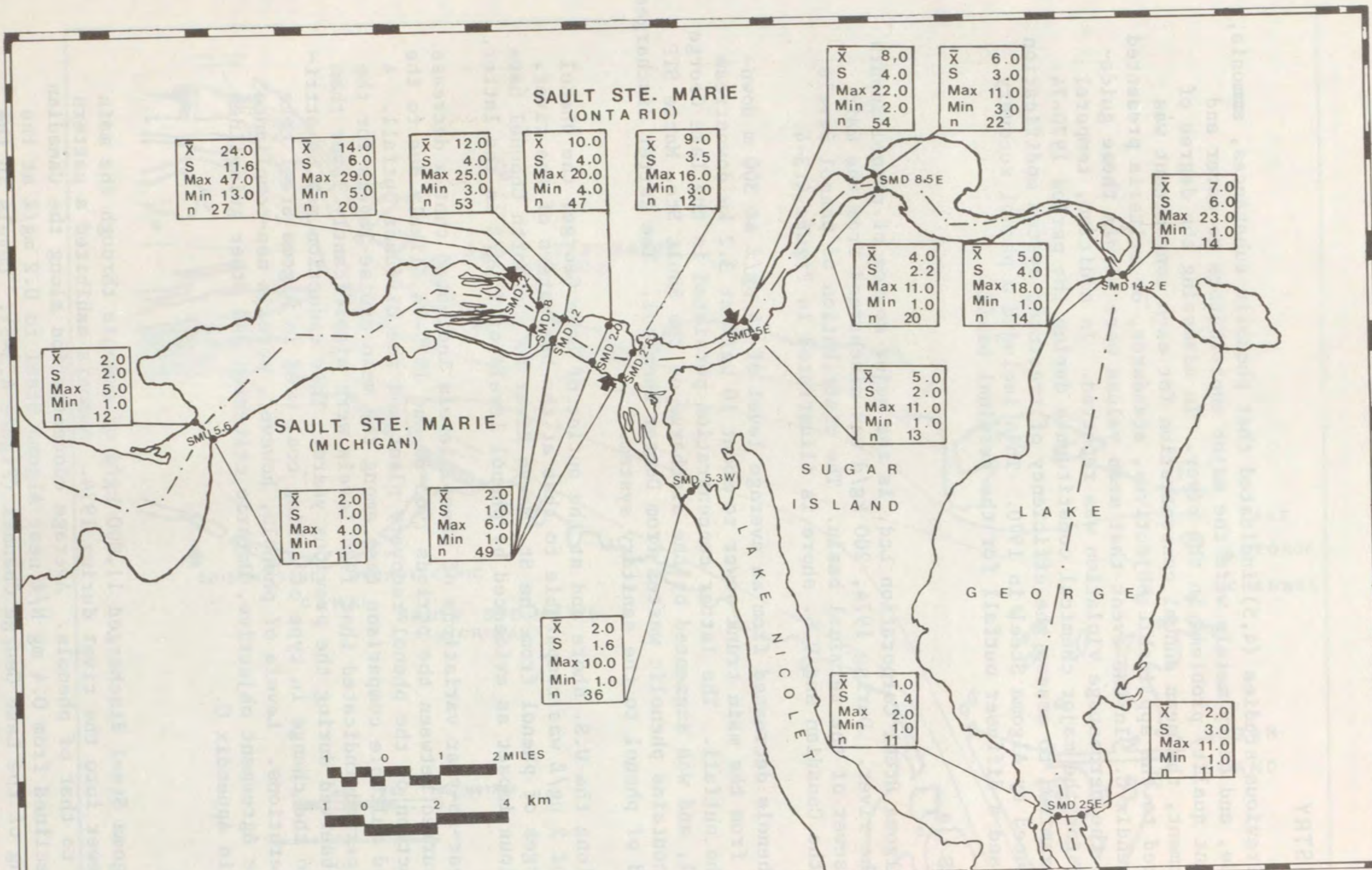

FIGURE 4.3-4 : 1974 STATISTICAL SUMMARY OF PHENOLS DISTRIBUTION µg/ℓ

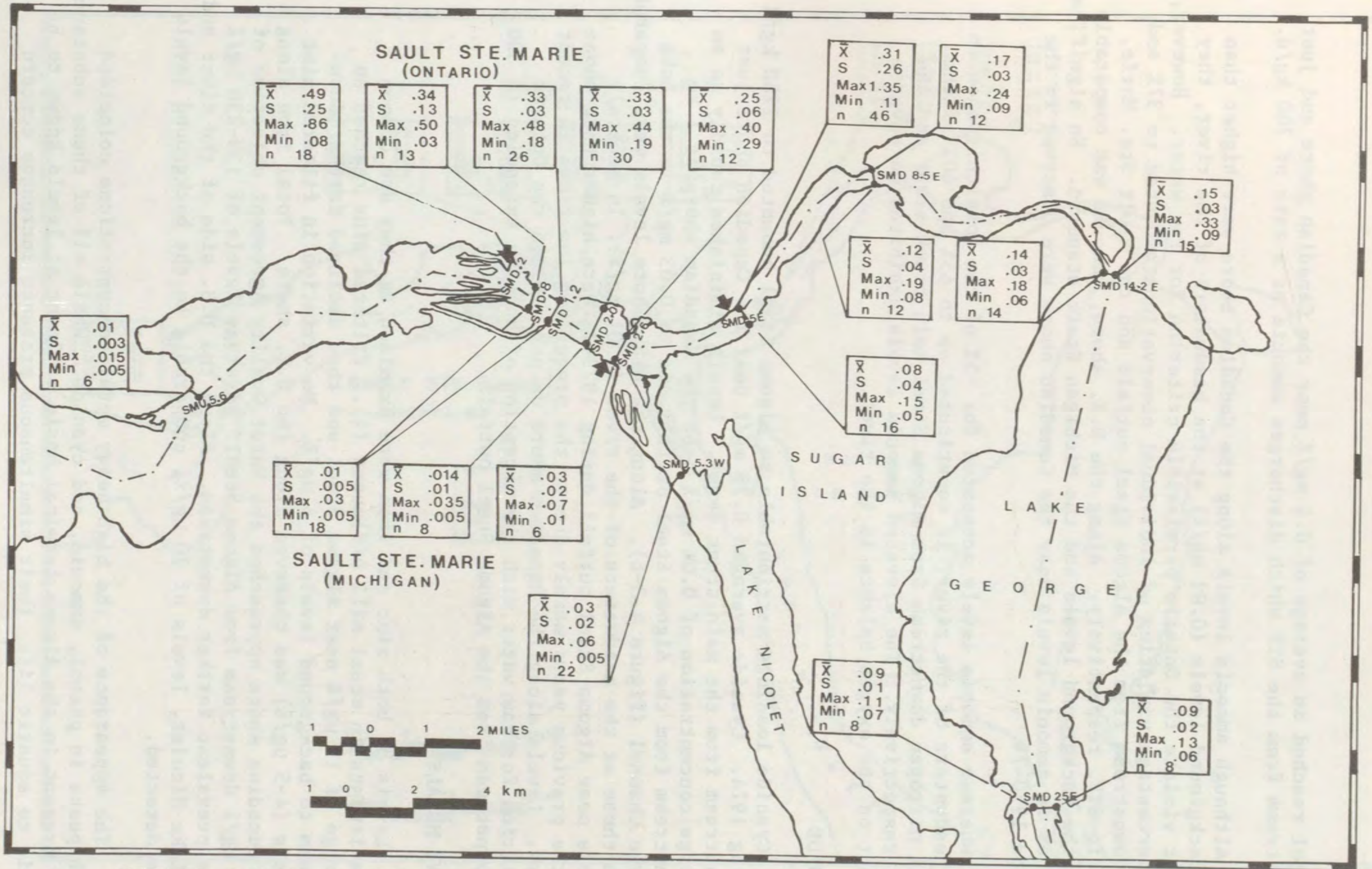

FIGURE 4.3-5 : 1974 STATISTICAL SUMMARY OF AMMONIA DISTRIBUTION mg N/ℓ

channel reached an average of 0.4 mg/ℓ near the Canadian shore and just downstream from the STP which discharges ammonia at a rate of 700 kg/d.

Although ammonia levels along the Canadian shore were higher than the background levels (0.01 mg/ℓ) at the headwaters of the river, they do not violate the Ontario permissible criterion for raw water. However, the percentage violation of individual observations amounted to 37% and 17% downstream from the Algoma Steel outfall and the Sault Ste. Marie, Ontario STP, respectively. Along the U.S. shore, ammonia was comparable with the background levels and the Michigan State standard. No significant changes in ammonia levels near the Canadian shore were observed in the period 1970-74.

Whereas ammonia levels accounted for <5% of the total nitrogen in the headwaters of the river, it constituted up to 65% and 40% of the total nitrogen downstream from Algoma Steel main trunk sewer and the STP, respectively. The elevated ammonia levels exhibited no adverse effect on the oxygen balance in the river.

CYANIDE

Cyanide loadings attributable to Algoma Steel amounted to 2280 kg/d during 1974. Cyanide averaged 0.28 mg/ℓ near the Canadian shore just downstream from the main trunk sewer. Levels diminished rapidly to an average concentration of 0.06 mg/ℓ near the Canadian shore at 1 km downstream from the Algoma Steel outfall and to 0.03 mg/ℓ in the Lake George Channel (Figure 4.3-6). Along the U.S. shore levels were comparable with those at the headwaters of the river (0.01 mg/ℓ). In general, levels near Algoma Steel outfall during 1973-74 were higher than those in the previous years mainly due to the prevailing low flows in recent years. Levels along the Canadian shore do not violate the Ontario criterion for raw water with the exception of an area extending to 300 m downstream from the Algoma Steel outfall.

HEAVY METALS

Levels of both zinc and iron were examined as they are common constituents in steel mill effluents (4). Filtered zinc reached an average of 15 μg/ℓ near Algoma Steel and then declined farther downstream to background levels of 5 μg/ℓ. No variation in filtered zinc levels (4-5 μg/ℓ) was observed along the U.S. shore. Total iron along the Canadian shore approached the Water Quality Agreement objective of 300 μg/ℓ downstream from Algoma Steel. Average levels of 130-250 μg/ℓ were prevalent farther downstream. Along the U.S. side of the river and in Lake Nicolet, levels of 70 μg/ℓ, comparable to the background levels were detected.

The appearance of the high heavy metal concentrations coincided with peaks in phenol, ammonia, and cyanide. While all of these substances are present in the Algoma terminal basin effluent at levels known to be toxic to aquatic life, their simultaneous presence increases concern

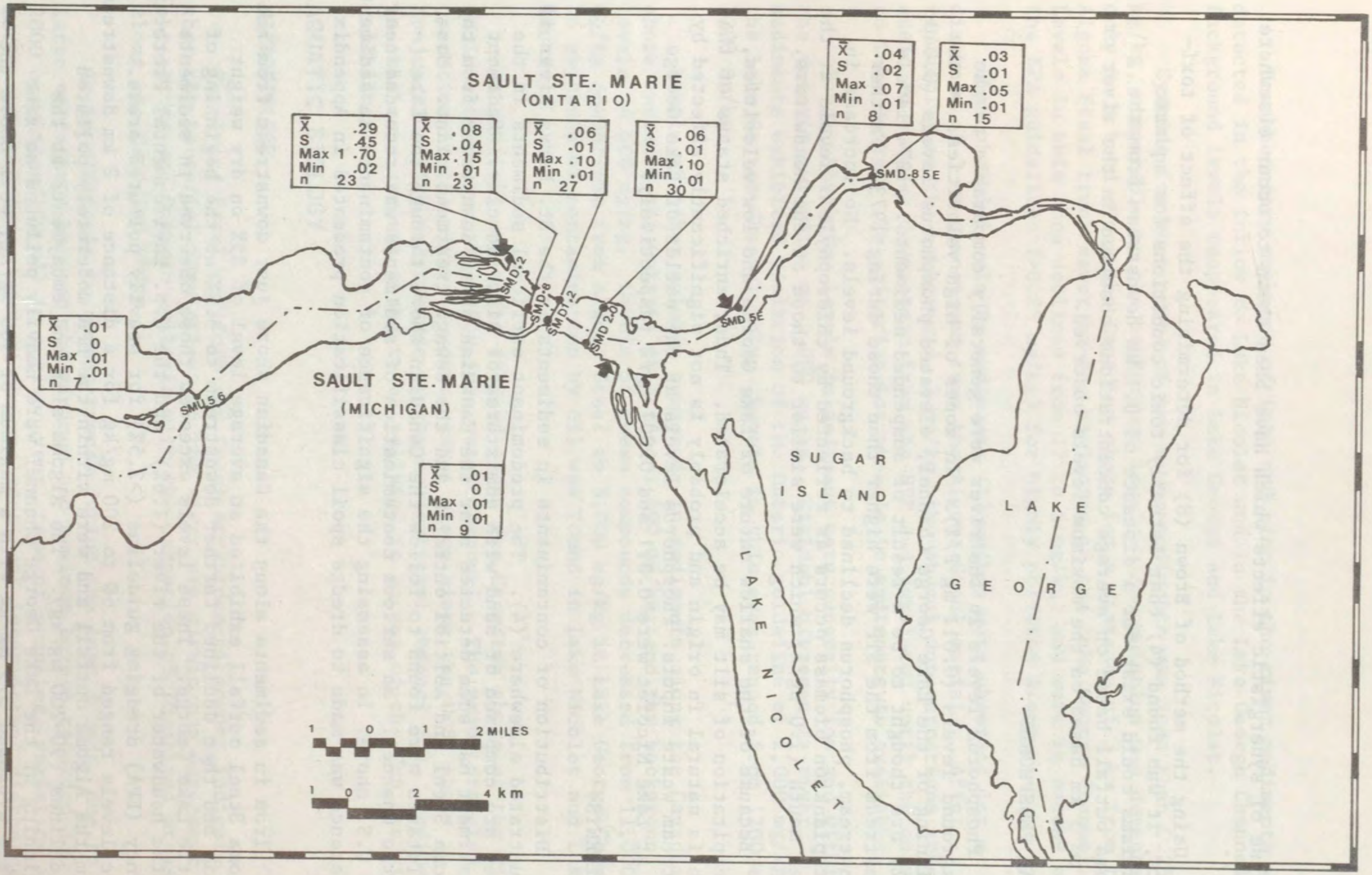

FIGURE 4.3-6 : 1974 STATISTICAL SUMMARY OF CYANIDE DISTRIBUTION mg/ℓ.

because of synergistic effects which have been shown to occur elsewhere (6,7).

Using the method of Brown (8) for determining the effect of toxicants, it was found (4) that lethally toxic conditions for aquatic organisms could exist for a distance of 0.1 km downstream from the Algoma outfall based on average concentrations observed in the river or up to 3 km based on the maximum levels observed.

TOTAL PHOSPHORUS

Phosphorus levels in the river were generally comparable to the background levels (0.011 mg P/ℓ). In zones of high velocities, at the beginning of the Lake George Channel, elevated phosphorus levels (0.040 mg/ℓ) are thought to be a result of suspended sediments. 1974 levels downstream from the STP were higher than those during 1973. Farther downstream, phosphorus declined to background levels. No increase in phytoplankton biomass occurs as reflected by chlorophyll *a* levels at the river mouth (1.0 μg/ℓ) which were similar to those at the headwaters.

Because of the shallow nature of Lake George and low velocities, precipitation of silt may be accelerated. Thus, enriched status of the lake is natural in origin and probably is not significantly affected by upstream waste inputs. Phosphorus levels at the outlet of Lake George and at Lake Nicolet were 0.011 and 0.007 mg/ℓ respectively.

SEDIMENTS

Distribution of contaminants in sediments in the St. Marys River is illustrated elsewhere (4). The predominant surficial sediments in the river are composed of sand with admixtures of silt and clay. Sediment impairment has been detected near the Canadian shore downstream from the Algoma Steel and Abitibi outfalls and the sewage treatment plant. Most pollutants were found to follow the Canadian shore through the Lake George Channel. No serious contamination of sediments was recorded near the U.S. shore. In assessing the significance of contaminants in sediments, reference was made to dredge spoil classification presented in Appendix C.

Iron in sediments along the Canadian shore just downstream from the Algoma Steel outfall exhibited an average level of 35% on dry weight basis and then declined farther downstream to 3.5% at the beginning of Little Lake George. These levels exceeded those observed in sediments of the headwater of the river (1.6%) and the U.S. Environmental Protection Agency (EPA) dredging guideline (>2.5%) for heavily polluted areas. Zinc levels ranged from 60 to 200 mg/kg for a distance of 2 km downstream from the Algoma outfall and were within the EPA moderately polluted guidelines (90-200 mg/kg). The Algoma slip and embayments at the beginning of the Lake George Channel were heavily polluted as zinc levels averaged 375 mg/kg with a maximum of 500 mg/kg, well above the EPA guideline (>200 mg/kg).

Transboundary movement of iron and zinc in the river sediments was detected in the inflow to Lake Nicolet and in the Lake George Channel. Background levels reappeared in Lake George and Lake Nicolet.

Cyanide for most parts of the river sediments was less than 0.25 mg/kg, comparable to the background levels. Accumulation was detected only in a band along the Canadian shore for a distance of 3 km from the Algoma Steel trunk sewer to the beginning of the Lake George Channel. Levels in this zone declined from 12 to 5 mg/kg, and were in excess of the EPA guidelines (>0.25 mg/kg) for highly polluted areas.

High phenol levels in sediments (13 mg/kg) were observed for a distance of 5 km downstream from the Algoma Steel outfall. After recovering to the background, 3 mg/kg, the phenol concentrations rose again to 6 mg/kg downstream from the STP and persisted until the entrance to Lake George. No criterion for phenols in sediments is available.

Total phosphorus levels in sediment were generally low and within the Ontario guideline of 1,000 mg/kg. Kjeldahl nitrogen in river sediments exhibited violation of the Ontario guideline of 2,000 mg/kg in the Lake George Channel only. Levels in this area ranged from 1200 to 7200 mg/kg.

Levels of ether soluble compounds in sediments along the Canadian shore exceeded the Ontario guideline 1,500 mg/kg, and the background levels of 600 mg/kg. Levels of these compounds decreased from 11,000 mg/kg downstream from Algoma Steel to 3,000 mg/kg in Lake George Channel. No evidence of contamination by oil was found in Lake Nicolet and Lake George.

In general, sediments dredged along the Canadian shore of the river would not be acceptable for open water disposal. The major dredging operation in the river, however, takes place along the U.S. shore in conjunction with maintenance of the navigational channel (9). Sediments in this area are not found to be polluted in excess of the EPA dredging guidelines.

AQUATIC BIOLOGY

MICROBIOLOGY

Total and fecal coliform and fecal streptococci counts indicate that the bacterial populations in the river are within the Agreement objectives and Ontario criteria with the exception of localized areas along the Canadian shore.

It is difficult to assess trends during the last decade, due to the large variations between the minimum and maximum levels recorded (30-2000 organisms/100 mℓ) in a given year, time of sampling, variation in media and techniques used in the analyses, and intermittent discharges from storm and overflow sewers.

Seasonal variations in levels of bacterial parameters during 1974 are illustrated in Figures 4.3-7 and 4.3-8 (Spring-May and June; Summer-July and August; Fall-September and October). Peaks in total coliform, fecal coliform, and fecal streptococci levels were noticed along the Canadian shore, in the immediate vicinity of overflow sewers, and downstre from the STP outfall in Lake George Channel.

Levels declined farther downstream in the Lake George Channel, except heterotrophic bacterial counts which were at elevated levels near Little Lake George, reflecting the abundance of decomposing organic matter. Transboundary movement from Ontario sources was evident in Lake George Channel where counts of heterotrophic bacteria were similar across the width of the channel.

The fecal coliform to fecal streptococci ratio near the urban areas of Sault Ste. Marie, Michigan and Ontario during the summer was <0.7 indicating storm water sources of contamination (10). Farther downstream, and in Lake George Channel, the ratio changed to values >4 indicating sewage contamination. Along the U.S. shore and in Lake Nicolet Channel levels of all bacterial parameters were within the Agreement objectives confirming insignificant waste inputs from the U.S. shore and the confinement of waste discharges from the Canadian shore to the north side of Sugar Island.

Pseudomonas aeruginosa counts in the river during 1974 indicated a possible health hazard along the City of Sault Ste. Marie, Ontario, waterfront. This pathogen is often the cause of upper respiratory infections in swimmers. Sewage and storm drainage represent the major inputs of *P. aeruginosa* appearing in surface waters. Hoadley (11) indicated that populations of 1-10 *P. aeruginosa* organisms/100 mℓ may be expected in streams with low, but definite levels of contamination. Levels of *P. aeruginosa* (20-30 organisms/100 mℓ) exceeded the above levels and the background levels (4 organisms/100 mℓ) in the vicinity of storm and overflow sewers of Sault Ste. Marie, Ontario.

Levels declined farther downstream but reached another peak (15 organisms/100 mℓ) in the Lake George Channel downstream from the sewage treatment plants.

PHYTOPLANKTON

The structure of the phytoplankton community in the St. Marys River has been studied by the Ministry of the Environment (MOE) during the period 1965-74. Phytoplankton samples were collected on a bimonthly basis from the water works intake of the City of Sault Ste. Marie, Ontario and nearby Gros Cap in Whitefish Bay (12). The distribution pattern of phytoplankton in these locations is illustrated in Volume III, Chapter 4. Phytoplankton biomass has been expressed as areal standard units per mℓ (a.s.u./mℓ).

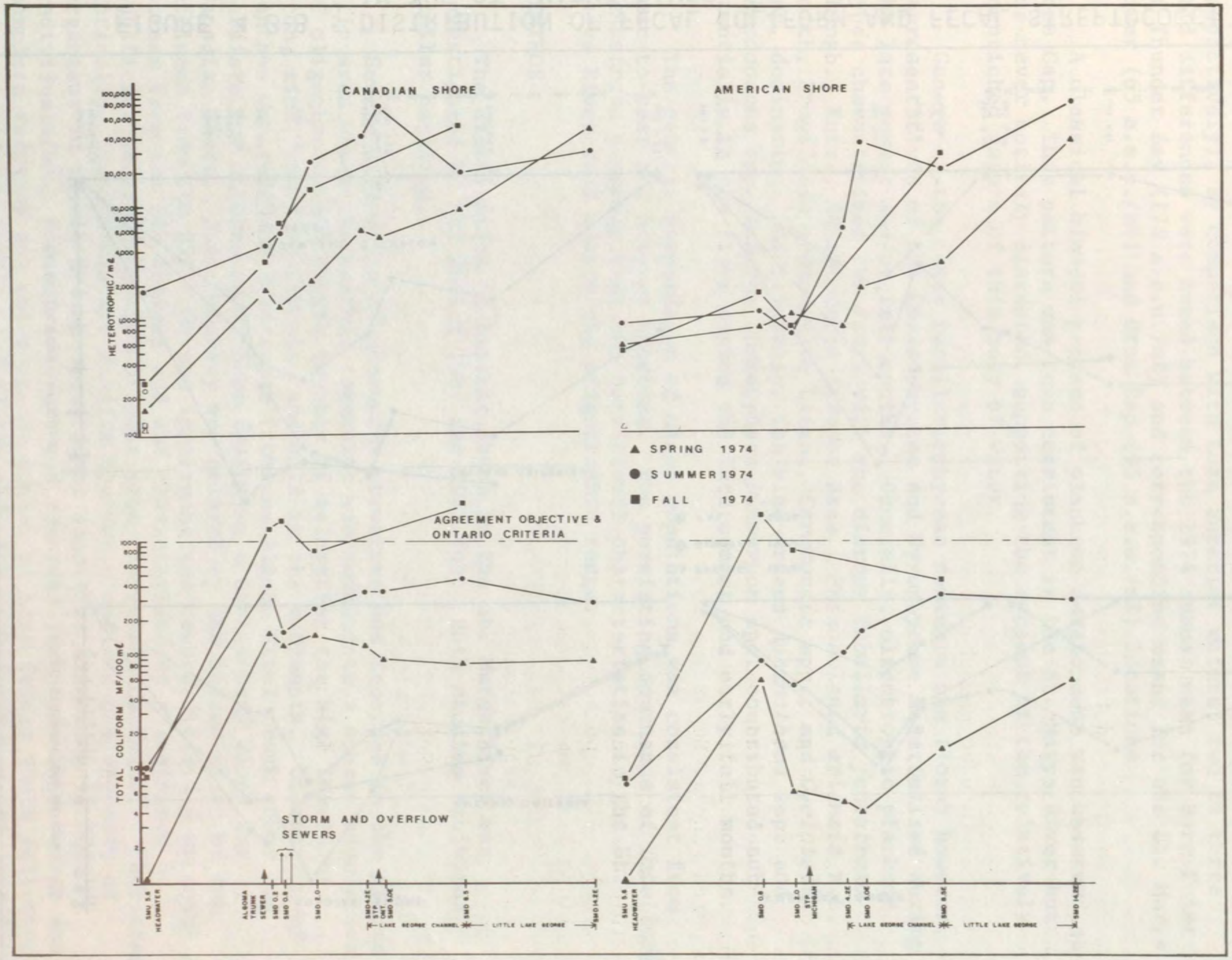

FIGURE 4.3-7 : DISTRIBUTION OF TOTAL COLIFORM AND HETEROTROPHS IN THE ST. MARYS RIVER

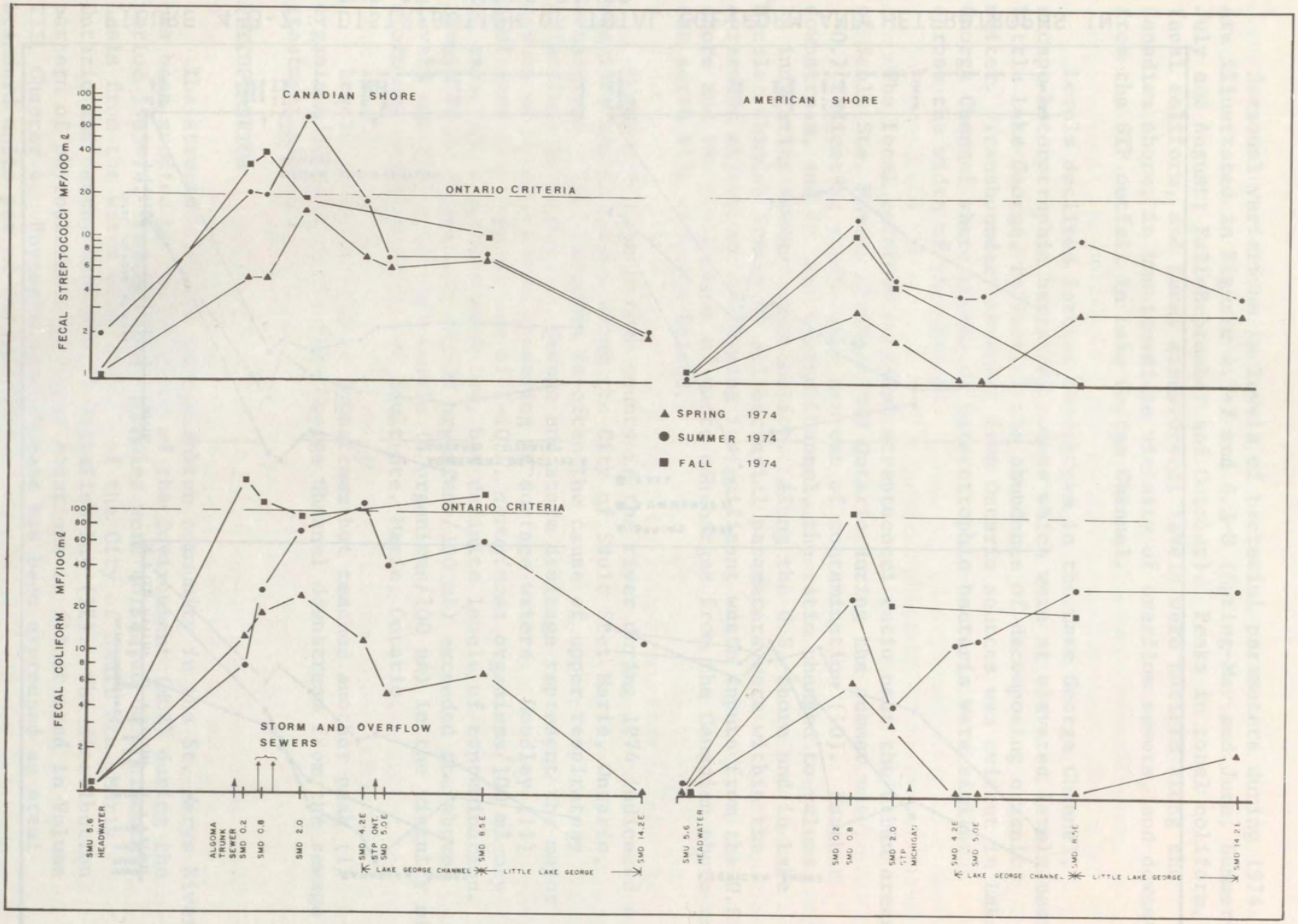

FIGURE 4.3-8 : DISTRIBUTION OF FECAL COLIFORM AND FECAL STREPTOCOCCI IN THE ST. MARYS RIVER

Low a.s.u. averages characterized the yearly phytoplankton stocks. Year-to-year variations are minimal. Long-term averages for the St. Marys River and Gros Cap sites are similar (109 a.s.u./mℓ and 114 a.s.u./mℓ, respectively). By comparison with Lake Superior waters, two to three fold differences were noted between the 1974 annual mean for Bare Point at Thunder Bay (178 a.s.u./mℓ) and corresponding means for the St. Marys River (65 a.s.u./mℓ) and Gros Cap (95 a.s.u./mℓ) locations.

A classical bimodal pattern of plankton development was observed at Gros Cap. This pattern was less consistent in the St. Marys River but was never entirely disrupted, supporting the concept of the relatively unenriched nature of this body of water.

Genera of the class Bacillariophyceae dominate the flora; however, representatives of the Chrysophyceae and Myxophyceae materialized during the late summer and/or fall months. Generally, oligotrophic plankton types characterized the flora with the diatoms *Tabellaria fenestrata* (Lyngb.) Kutz., *Asterionella formosa* Hass., *Rhizosolenia eriensis* H.L. Smith, *Fragilaria crotonensis* Kitton, *Ceratoneis* spp., and *Cyclotella* spp. dominating. Additionally, the blue-greens *Aphanothece* spp. and *Chroococcus* spp. and the chrysophyte *Dinobryon* spp. contributed substantially to the flora during the late summer and early fall months.

The generic composition of algal populations was consistent from year-to-year and between stations. The persisting dominance of *Tabellaria fenestrata* suggests that the nutritional characteristics in the St. Marys River fall within the oligotrophic range.

BENTHOS

The distribution of benthic fauna in the St. Marys River was investigated by MOE during 1967 and 1973 (4). Both studies exhibited similar patterns.

Severe disruption of community structure was recorded in the Algoma slip area where the benthic community was reduced to a sparse population of oligochaetes and midges capable of tolerating the high levels of iron, zinc, cyanide, phenols, and oils in the sediments. Disruption of benthos was recorded downstream from the Algoma Steel trunk sewer and persists for a distance of 3 km following a narrow band along the Canadian shore. Full recovery was delayed by the introduction of the effluent from the STP. Severe impairment was recorded for 1.6 km downstream from the STP outfall and was characterized by a dominance of tubificids to the exclusion of most other invertebrate forms. Characteristically, *Limnodrilus* and *Tubifex* species comprised the majority of organisms in this area and occurred at densities exceeding 10,000 individuals/m^2. Partial recovery was recorded in Little Lake George and complete recovery was noted at the outlet of Lake George where pollution tolerant midges, snails, and clams exhibited weak dominance and sensitive organisms such as mayflies and caddisflies returned to colonize the area.

No impairment was noted in the Lake Nicolet channel owing to the fact that the major transport of pollutants takes place along the north side of Sugar Island through Lake George Channel.

ZOOPLANKTON

The composition and relative proportions of the major zooplankton species were similar at a location immediately below the Great Lakes Power plant on the Canadian side of the river (13) to those observed in eastern Lake Superior. The average density of total crustacean and mean organic weight were 4,600 organisms/m^3 and 19 mg/m^3, respectively.

The seasonal pattern of abundance and biomass did not closely correspond because average size of the animals changed greatly during the season. For example, total biomass in January and July of 1972 were nearly equal (18 mg/m^3), whereas abundance of animals in July (16,000 organisms/m^3) was 5.5 times that of January (3,000 organisms/m^3).

METALS AND ORGANIC CONTAMINATION IN FISH

Heavy metals, pesticides, and PCB's were analyzed in the edible flesh of fish collected from Lake George (14). Residue levels of these contaminants in sport or commercial fish species were lower than those observed in fish of the same species, i.e. white sucker, northern pike, and yellow perch from Lake Huron. Levels in fish from Lake George could not be compared with those in fish from Lake Superior since species collected from the latter basin were different. Cause-and-effect relationships cannot be established due to the lack of information on mobility of fish in the St. Marys River.

Heavy metals in fish flesh from Lake George exhibited low levels and were in compliance with recommended limits of the Canadian Federal Food and Drug Directorate. Levels of PCB's and pesticide residues in fish flesh were low, but the ratio of contamination between white sucker and the predator species, northern pike, was 2:1. The above pattern was likely due to the difference in oil content between these species. The oil content of white suckers was five times that of the northern pike.

SUMMARY OF EXISTING AND DEVELOPING PROBLEMS

EXISTING PROBLEMS

The major instances where existing water quality interferes with or is likely to interfere with beneficial water use in the St. Marys River are summarized below.

BACTERIAL CONTAMINATION

Bacterial counts along the Sault Ste. Marie, Ontario waterfront and for a short distance downstream of the sewage treatment plant have been found to exceed Agreement objectives and Ontario recreational use criteria. This contamination which results from sewer overflows and inadequate effluent disinfection at the STP has forced the closure of this section of shoreline to swimming.

ORGANIC CONTAMINANTS

The concentration of phenolic substances below the Algoma Steel Corporation main outfall exceeded the Agreement objectives and Ontario criterion over an 11 km stretch of shoreline and extending to Little Lake George. Transboundary movement was evident in the Lake George Channel where phenol levels exceeding the objective were found in U.S. waters. There have been no confirmed reports of fish tainting or taste and odour problems in water supplies.

INORGANIC CONTAMINANTS

Cyanide levels downstream of the Algoma Steel Corporation main outfall exceeded the Ontario permissible criterion for public water supply in 1974 for a distance of about 0.8 km; however, no existing supplies are threatened.

SEDIMENT CONTAMINATION

Phenolic substances, oil, cyanide, iron, and zinc were found in concentrations exceeding guidelines (EPA and/or Ontario) for dredged spoil disposal (Appendix C) for distances of 11, 3, 4, 11, and 11 kilometres, respectively, below the main Algoma Steel Corporation outfall. Contamination in excess of the guidelines did not extend across the international boundary and the contaminated areas are not generally subject to maintenance dredging. Disruption of the benthic macroinvertebrate community was, however, observed in the Algoma Steel Corporation's and downstream of the main outfall for a distance of about 3 km and extending to a maximum of 300 m from the Canadian shore. The Lake Nicolet Channel, which is dredged at intervals of one to five years, has been found to be free of abnormal contamination.

DEVELOPING PROBLEMS

An expected steady growth in population and industrial development along the St. Marys River will place demands on the river requiring pollution control measures exceeding those required to solve existing problems.

The cities of Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan have been growing at an approximate annual rate of 3 to 4% over the past 15 to 20 years (Chapter 1). Officials of the Ontario Sault are presently studying improvements to the sewerage collection system and expansion of the sewage treatment facilities to correct existing problems of bacterial contamination and provide for urban growth. Similarly, the Michigan Sault is investigating treatment needs to meet U.S. federal requirements.

TABLE 4.3-1

ABATEMENT PROGRAMS

WASTE SOURCES	EXISTING TREATMENT	EXISTING PROBLEMS	ABATEMENT PROGRAMS	FURTHER REQUIREMENTS
INDUSTRIAL				
Algoma Steel Corp Ltd.	No treatment presently available for coke oven byproduct plant effluent discharge via terminal settling basins.	Elevated levels of phenol, cyanide, sulphide, and ammonia; potential toxicity towards aquatic life in the river.	Company under Ministerial order to install facilities for: i. removal of naphthalene, suspended solids; ii. reduction of cyanide, phenol, ammonia and sulphide to 0.047 mg/ℓ, 0.058 mg/ℓ, 0.35 mg/ℓ and 0.075 mg/ℓ, respectively, by the end of 1976.	In order to protect downstream uses and to alleviate the effect of combined amount of toxicants reduction of iron and zinc in the effluent should be implemented.
Abitibi Paper Co. Ltd.	Screening	Suspended solids	Construction of flotation units completed July 1976.	
Domtar Chemical Ltd.	Storage tank condensates treated in oil separator	Phenol - average daily flow during Sept. 1975, was 41 m^3/d at a concentration of 393 mg/ℓ	Wastes discharged to sanitary sewer system	Reduction of phenol levels in oil separator effluent required before discharging to sanitary system.
MUNICIPAL				
Water Pollution Control Plant - Sault Ste. Marie, Ontario	Primary and chlorination (mainly separate sanitary system) (0.6 m^3/s)	Elevated levels of ammonia, phenol, and bacterial parameters. Potential formation of organochlorine compounds.	Expansion completed in June 1974 by constructing two clarifiers.	MOE developing terms of reference for plant expansion.
Water Pollution Control Plant - Sault Ste. Marie, Michigan	Primary and chlorination (combined sanitary system)	Plant is hydraulically overloaded during runoff periods.		City of Sault Ste. Marie, Michigan carrying out a study to develop most effective treatment to meet U.S. federal requirements.

The St. Marys River is a major commercial navigation waterway and vessel waste discharges will constitute a continuing potential health hazard until international agreement is reached on holding tank or waste treatment requirements for vessels. Characteristics and quantities of waste inputs from vessels are described in Chapter 3.

The annual steel production by Algoma Steel Corporation is expected to increase by about 64% to 4.5×10^6 t/a in 1985. As part of the abatement measures required under a 1974 MOE ministerial order, the company is planning to introduce effluent recycling in the coke oven byproduct plant which will reduce waste flows from about 0.24 m^3/s to 0.02 m^3/s by the end of 1976. Improved treatment facilities are intended to reduce loading of phenolic substances, cyanide, and free ammonia by 92, 99, and 99% respectively to 17, 14, and 100 kg/d.

Oil spills present a continuing threat to water quality in the St. Marys River. In 1973 and 1974, losses from Algoma Steel Corporation accounted for more than half the observed spills with bilge water discharges accounting for a major portion of the remainder. The Province of Ontario has an ongoing contingency plan for spills of oil and other hazardous materials (15). This plan, which is designed to deal with major pollutional spills, supplements the joint Canada-U.S. Marine Pollution Contingency Plan and the Canadian Interim Federal Contingency Plan. Further details on spills and vessel waste discharges are given in Chapters 3.

Table 4.3-1 outlines municipal and industrial abatement programs presently underway, as well as future requirements needed to restore and protect water quality in the St. Marys River.

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Table 4.3-4 outlines municipal and industrial abatement programs presently underway, as well as future requirements needed to restore and protect water quality in the St. Marys River.

4.4 NEARSHORE - OFFSHORE EXCHANGE

INTRODUCTION

The understanding of the mass exchange from the nearshore waters to the open lake is an important tool for water quality management. Improvement of this understanding allows a better definition of the assimilative capacity of coastal waters and thus serves to protect water use and to better define needed pollution control.

For the purpose of this discussion, the nearshore region is defined as that part of the lake where water quality is changed due to material inputs compared to the open lake quality.

METHODS FOR ESTIMATING MASS EXCHANGE

The mass exchange is the transport of material from one spatial location to another. This transport is affected by winds, tributary flows, stratification, surface elevation differences, shoreline geometry, bottom topography, and lake assimilative (biological, chemical, physical) reactions to name the more important ones. The most primitive prediction of mass exchange is a statistical approach. In this method, one compares water quality at various times and/or locations and makes statistical inferences. In its simplest form it can be used for indicating differences; however, it is possible to evolve a predictive capability by applying techniques like multivariate (1) or factor analysis (2) or a spectral method like the Box and Jenkins (3) technique. The efficiency of these methods depends on the completeness of the input data and intelligent manipulation of these data.

The next level in the prediction hierarchy consists of models which are quasi-deterministic. In these methods, forms of the operative rate equations are solved by obtaining a solution which matches survey field data. Typically, these are box or element type models (4-6) which meet boundary conditions. Sharing this level in the hierarchy, it is possible to include selective systems or process models such as trophic state models which are based on total phosphorus loadings, chlorophyll α (7-9) and/or secchi disc (10), and dissolved oxygen budget (11-13) analysis (Chapter 6.1). In some instances these selective systems or process models may be the highest level in the model predictions provided the major water quality problem is identified. These methods are problem specific and limited as a general water management instrument. The ultimate level in prediction is the solution of the deterministic equations for water chemistry (14) and phytoplankton (15,16).

Forms of predictive models at all levels have been employed with some success in estuaries and lakeshore regions to determine mass exchange and could be used to estimate the nearshore-offshore exchange mechanisms. The importance of estimating the exchange merits the trial application of many more established procedures by scientists. The Saginaw Bay study is one of the few studies where more than one method was applied and the results compared. More details can be found in the Saginaw Bay section of this volume (Chapter 4.2) and also the Thunder Bay section (Chapter 4.2, Volume III).

CONCLUSION

At present, with existing data, it is only possible to quantify the mass exchanges for some particular coastal regions and these estimates are crude, in the 25 to 50% accuracy range. Quantifying mass exchanges between the nearshore and offshore regions requires detailed understanding of the complex coastal processes and loading characteristics. Research is needed to provide better determination of horizontal and vertical eddy diffusion coefficients which are used in hydrodynamic models to obtain the details of the water movements and thus estimate exchange. The effect of waves in the nearshore, both directly in sediment resuspension and indirectly in formation of longshore currents, has yet to be quantified. Obviously, research into these processes must continue and be directed at generating estimates of the exchange rates for conservative and non-conservative substances, heat, and bacteria. At the same time, research efforts should be undertaken to utilize existing water quality data to determine mass exchanges. For example, it may be possible to use long-term water quality data in a region to indicate the long-term mass exchanges between the nearshore and offshore regions. The importance of this research for the Upper Lakes, where general lake water quality is good but localized water quality degradations are affecting water use, is obvious.