1977-03-01

Waters of Lake Huron and Lake Superior: Volume 3, Part A: Lake Superior: Report to the International Joint Commission by the Upper Lakes Reference Group

Upper Lakes Reference Group

Recommended Citation

Upper Lakes Reference Group (1977). Waters of Lake Huron and Lake Superior: Volume 3, Part A: Lake Superior: Report to the International Joint Commission by the Upper Lakes Reference Group. *International Joint Commission (IJC) Digital Archive*. https://scholar.uwindsor.ca/ijcarchive/137

1977-03-01

Waters of Lake Huron and Lake Superior: Volume 3, Part A: Lake Superior: Report to the International Joint Commission by the Upper Lakes Reference Group

Upper Lakes Reference Group

Recommended Citation

Upper Lakes Reference Group (1977). Waters of Lake Huron and Lake Superior: Volume 3, Part A: Lake Superior: Report to the International Joint Commission by the Upper Lakes Reference Group. *International Joint Commission (IJC) Digital Archive*.
http://scholar.uwindsor.ca/ijcarchive/137

~~A L C Watson~~

UPPER LAKES
REFERENCE GROUP

Missing-NOS → so Keep.

INTERNATIONAL
JOINT
COMMISSION

THE WATERS OF LAKE HURON AND LAKE SUPERIOR
VOLUME III (Part A)
LAKE SUPERIOR

THE WATERS OF
LAKE HURON
AND
LAKE SUPERIOR

VOLUME III (Part A)

LAKE SUPERIOR

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

WINDSOR, ONTARIO
1977

FIRST PRINTING (MARCH 1977)

Volume III available from:

Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue
Windsor, Ontario N9A 6T3

Unites States Section
International Joint Commission
1717 H Street, N.W.
Washington, D. C. 20440

Canadian Section
International Joint Commission
151 Slater Street
Ottawa, Ontario K1P 5H3

TABLE OF CONTENTS

PART A

PART B

CHAPTER TITLE PAGE NUMBER

6 (cont'd)

CHAPTER TITLE PAGE NUMBER

6 (cont'd)

LIST OF TABLES

PART A

PART B

TABLE PAGE NUMBER

TABLE PAGE NUMBER

LIST OF FIGURES

PART A

FIGURE PAGE NUMBER

PART B

FIGURE PAGE NUMBER

FIGURE PAGE NUMBER

FIGURE PAGE NUMBER

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; and 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, 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 III summarizes the results of many individual project reports on Lake Superior and provides the basis for discussion, conclusions, and recommendations provided in Volume I. Lake Superior and its drainage basin are shown in Figure 1-1.

PHYSICAL FEATURES

CLIMATE

Lake Superior is located near the continental centre of North America 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 40% of the time. It is during these occurrences that extremely high temperatures may be recorded; on one such occasion an extreme of 42°C was measured (1). Occasional periods of uncomfortably hot, humid, tropical weather are caused by air masses which originate over the Gulf of Mexico. Stations north of the lake have fewer than four months with mean temperatures above 10°C. In winter, mean daily temperatures below freezing may last for six months in the

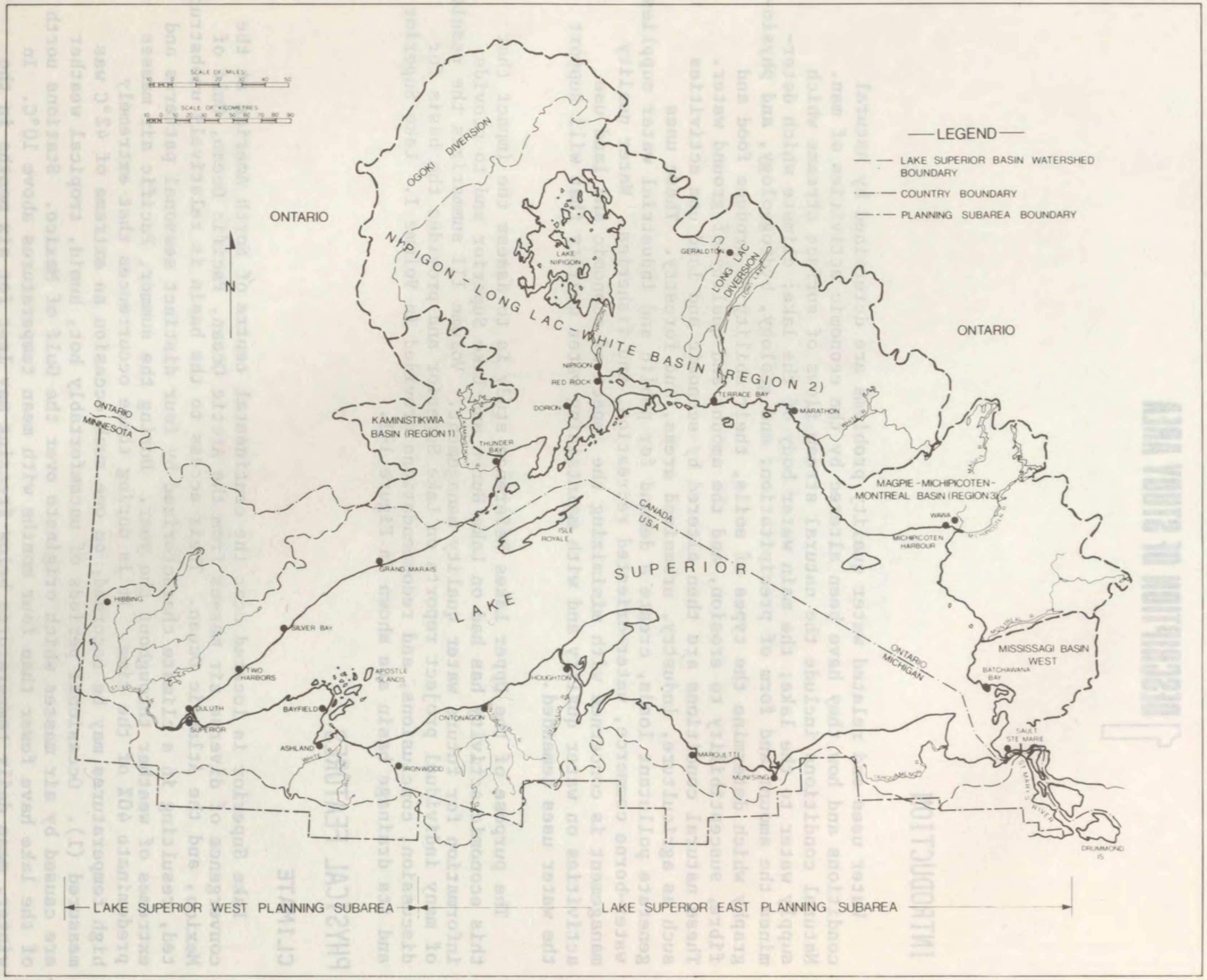


FIGURE 1-1 LAKE SUPERIOR BASIN AND STUDY AREA.

northern part of the basin. Extreme lows of -52°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. Spring and autumn are periods of transition. An average of five or six storms a month produces changeable weather as frontal systems move rapidly, bringing considerable cloud cover and frequent, widespread rain. Between storms, warm sunny days and crisp, cool nights make these pleasant times of the year.

Due to its immense size, Lake Superior dominates the climate around it. With its 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 number of ways, including moderation of temperature, augmentation or suppression of precipitation, formation of fog, 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 79.5 cm. Evaporation has an important effect on the availability of water and on the heat budget since it is a cooling process. Average evaporation is about 45.7 cm to 53.3 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 Superior is the largest and uppermost of the Great Lakes, with a volume at low water datum of 11,920 km^3 and a water surface area of 82,103 km^2 (2). It has a maximum depth of 406 m and a mean depth of 145 m. The States of Minnesota, Wisconsin, and Michigan and the Province of Ontario border on Lake Superior, and contain a total land drainage area of 127,687 km^2. The total shoreline length, including islands, is 4,388 km, about 54 % of which is in Canada. The long-term average annual precipitation over the Lake Superior drainage basin for the period 1900-1972 was 75.2 cm (2). More than half, 39.4 cm, of the annual precipitation over the land portion of the basin is lost by evaporation and evapotranspiration. Over the lake surface an estimated 45.7 cm to 53.3 cm of annual precipitation is lost to evaporation.

The streams that drain into Lake Superior consist of a large number of small tributaries which drain small areas. The seasonal distribution of runoff is influenced by seasonal patterns of precipitation and basin storage and losses. High runoff usually occurs in May when the snow melts and evaporation is low. Some streams experience low flow in January or February during winter freezeup. Low runoff may also occur in August through October due to increased loss by evaporation. Runoff in some streams is influenced by pumped mine drainage and storage reservoirs for hydroelectric projects. Lake Superior discharges through the St. Marys River into Lake Huron. Since the completion of the gated dam at the head of the St. Marys Rapids in 1921, the outflow from Lake Superior has been completely controlled. The mean annual outflow for the period 1900-1972 was 2,100 m^3/s, and the mean annual elevation was 183.04 m, International Great Lakes Datum.

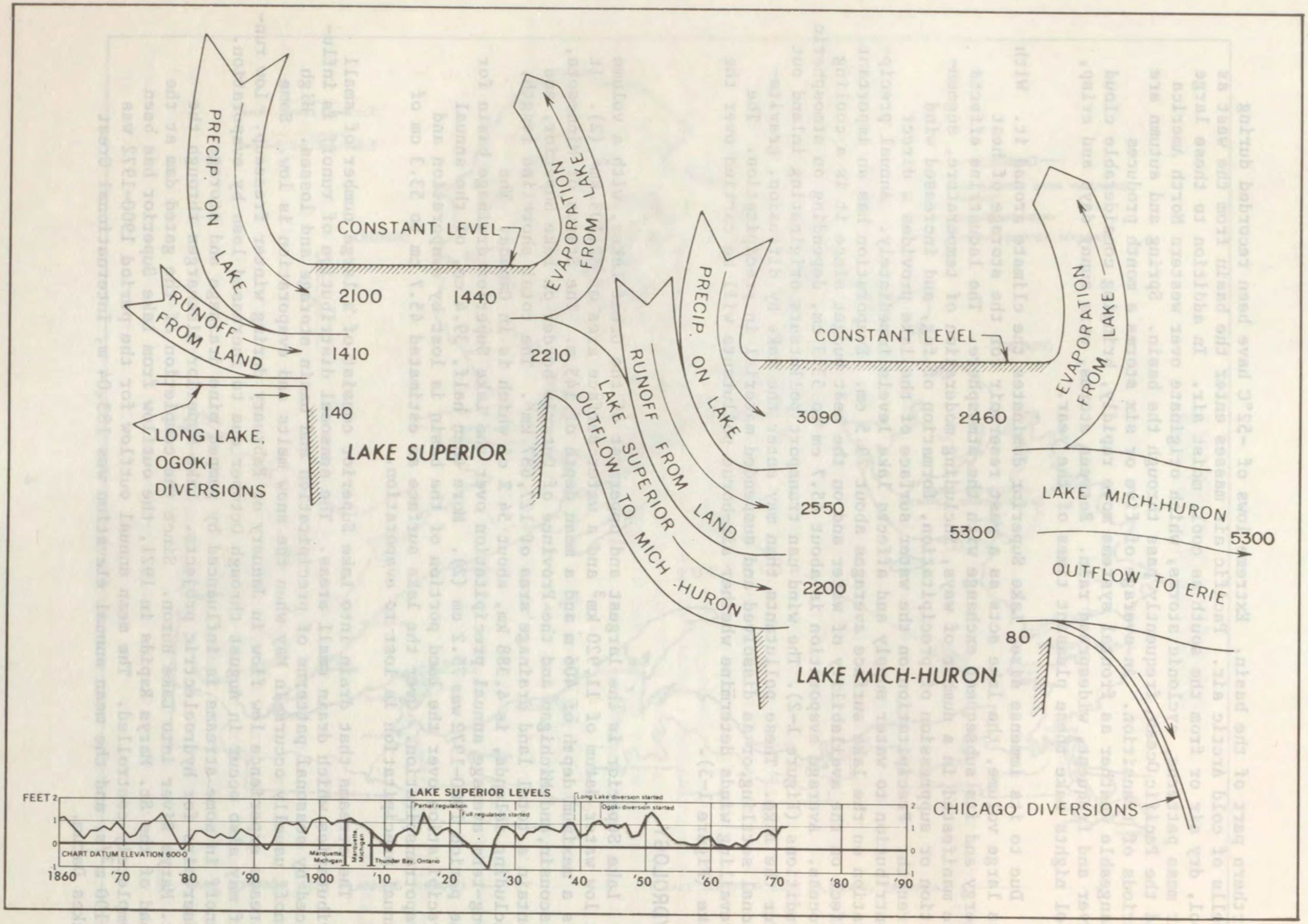


FIGURE 1-2 WATER BALANCE FOR THE UPPER LAKES.

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.

per second.

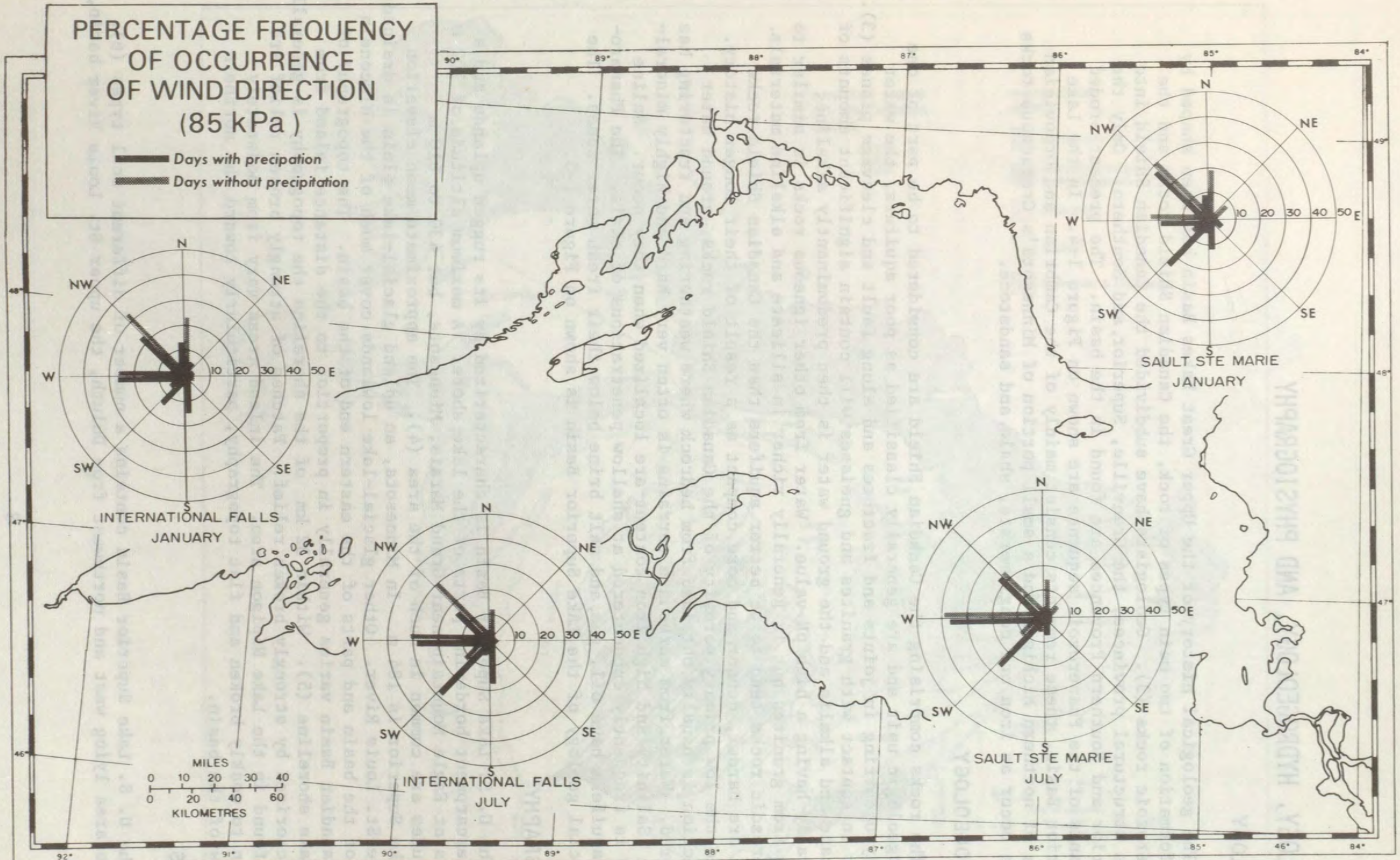


FIGURE 1-3

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 (3). Geologists have subdivided the Canadian Shield into three structural provinces, the Grenville, Superior, and Southern. Only the Superior and Southern Provinces are found in the basin. The present eroded remnants of the Phanerozoic sequence are shown on Figure 1-4. In the Lake Superior Basin, these remnants consist mainly of the Cambrian and Ordovician rocks of northern Michigan and a small portion of Minnesota's Cretaceous rocks which occur as iron ore conglomerate, shale, and sandstone.

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 (3). 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 which are harder, denser, and more compact as a result of their longer history. Due to the low primary porosity of the Canadian Shield rocks, ground water production is usually obtained from bedrock where weathering and fracturing has 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 fresh water zones. The surficial geology of the Lake Superior Basin is shown on Figure 1-5.

TOPOGRAPHY

The U. S. Lake Superior Basin is characterized by its rugged uplands and a rock escarpment bordering parts of the lake shore. A maximum altitude of 702 m occurs at Eagle Mountain near Grand Marais, Minnesota, but 430 to 610 m altitudes are common in much of the area (4). The approximate mean elevation of Lake Superior is 184 m. In Minnesota, an upland glacial-lake plain is drained by the St. Louis River. Other glacial-lake lowlands cover much of the Wisconsin part of the basin and parts of the eastern end of the basin. The topography of the Canadian Basin varies generally in proportion to the distance inland from the lake shoreline (5). Within 32 km of the shoreline the topography is generally characterized by strongly broken relief. Patches of strongly broken relief are also found in the Lake Nipigon area. The inland areas vary from moderately broken to weakly broken and flat topography, particularly toward the northern limits of the basin.

SOILS

The U. S. Lake Superior Basin contains a number of different soil types (6). In the area lying west and northwest from Duluth, the upper St. Louis River basin,

FIGURE 1-4 BEDROCK GEOLOGY OF THE GREAT LAKES BASIN. Information from Reference (3).

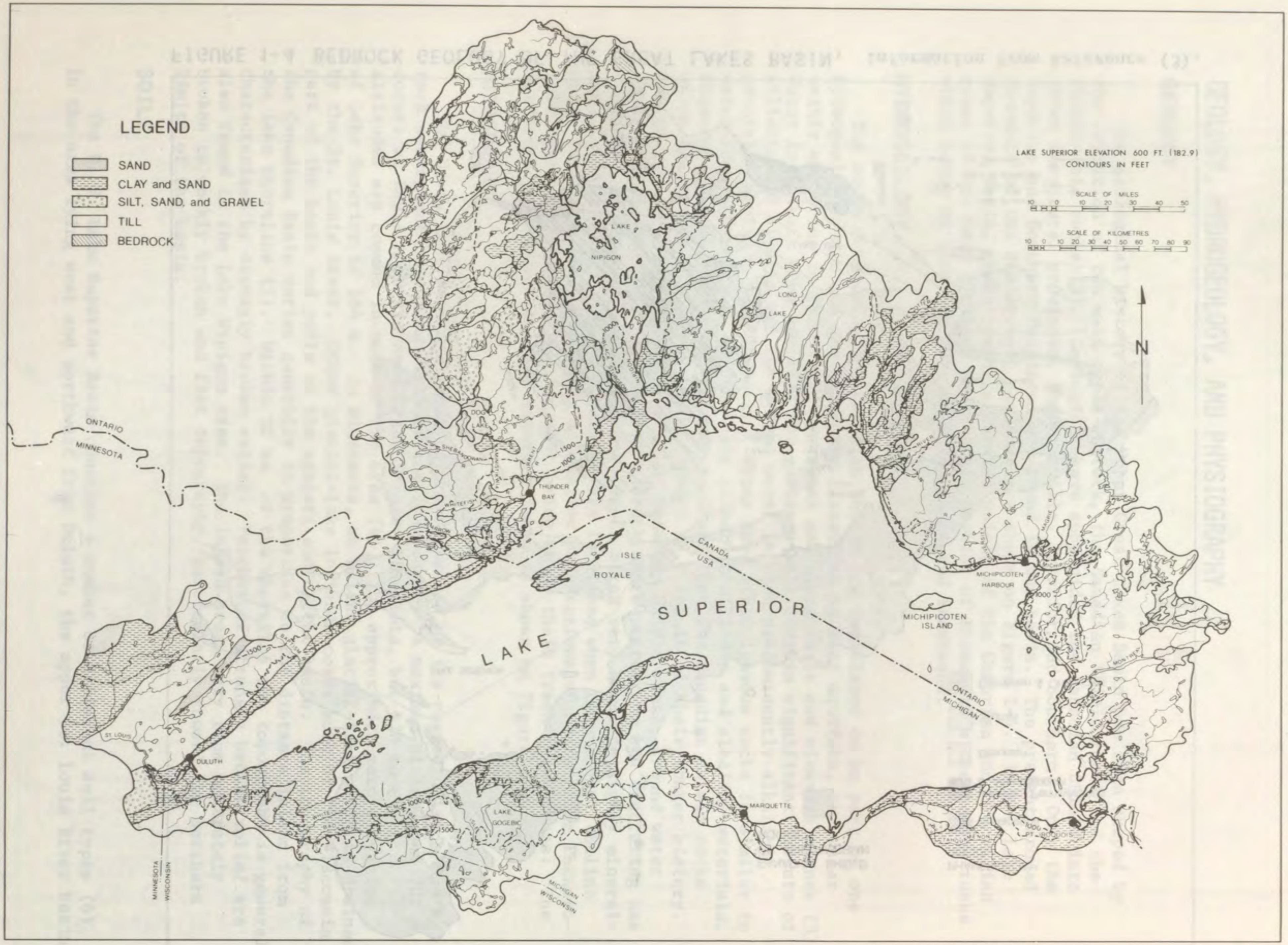


FIGURE 1-5 SURFICIAL GEOLOGY-LAKE SUPERIOR DRAINAGE BASIN.

Canadian information is from Reference (7); U.S. information from the soils include extensive areas of peat and muck which are poorly drained and acid. Northeast of Duluth, the Superior Slope section, the soils include well drained sandy loams, sandy clay, and sandy clay loam tills. South and east of Duluth to the northern part of Ashland County, Wisconsin is the "red clay area," which contains red-brown clays and silty clays. The northwestern part of the Upper Peninsula of Michigan consists of poorly drained soils developed in calcareous clay loam till and laucustrine silts and clays. The northeastern part of the Upper Peninsula consists largely of sandy soils.

The surficial geology of the Canadian Lake Superior Basin is characterized by extensive ground moraine of silty to sandy till texture (7). This ground moraine is interrupted by a several-kilometre-wide coastal zone of bare bedrock eroded by lake action which extends north from Sault Ste. Marie to Nipigon Bay. The coastal area between Nipigon Bay and the U. S. border south of Thunder Bay consists of ground moraine interrupted by several large lacustrine deposits of varved or massive clay and silt. Farther inland, patches of bare bedrock are located to the north of Lake Nipigon and in the basin area to the northeast of Marathon, Ontario. Lacustrine deposits of clay and sand are also found in the area northeast of Marathon and along the north shoreline of Lake Nipigon. Areas of sandy deposits are found to the west and southwest of Lake Nipigon.

VEGETATION

The vegetative cover of the U. S. Lake Superior Basin is predominantly a northern spruce-fir forest (4). Bogs and the associated plant species are common as are aspen stands. Wetlands in the basin, with the exception of the St. Louis River areas and a few others, are of low quality to water fowl. The harsh climate and poor soils have hindered agricultural activity which has resulted in the maintenance of large forested areas. The Canadian Lake Superior Basin is generally forest covered throughout (8). In the southern part of the basin the principal tree species are pine, hemlock, birch, maple, and oak. Logging and recent fires have brought balsam fir and white spruce into prominence as well. The remainder of the basin is dominated by white and black spruce, balsam fir, jack pine, white birch, and aspen.

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 Superior Basin is summarized as follows:

Population
(thousands)

Year	United States	Canada	Total
1950	513	94	607
1970	533	147	680
2000	528	169	697
2020	532	180	712

The total population of the Lake Superior Basin was about 680,000 in 1970 and is projected to increase to about 712,000 in 2020, an increase of about 5% (9,10). In 1970, the Canadian population was about 22% of the total, and the United States population was about 78%. The projected 2020 population does not show a major change in the population distribution between the two countries. The 1970 population of the U.S. Lake Superior Basin was about 41% rural and 59% urban. Comparable figures for the Canadian Basin were about 25% rural and 75% urban. Soil and climatic conditions limit agricultural productivity and restrict the growth of rural population. The population distribution of the Lake Superior Basin is summarized on Figure 1-6.

In the Canadian Lake Superior Basin, isolated urban communities scattered along road and rail routes dot the largely undeveloped hinterland (11). Principal industries are mining, forestry, and tourism. They do not support large population centres. Most significant centres of population are located along the Lake Superior shoreline. The Thunder Bay Census Metropolitan Area (CMA) or area of significant urban and economic development is the only major population centre. Its 1971 population of 112,093 was about 76% of the Canadian Lake Superior Basin population. In contrast to parts of the Canadian Lake Huron Basin, concentrations of non-resident or seasonal population are not significant in the Canadian Lake Superior Basin. The maximum cottage population is estimated at less than 10% of the total population.

In the U. S. Lake Superior Basin, most of the population is located around the western tip of the lake in the Duluth-Superior, Minnesota-Wisconsin area. The Duluth-Superior Standard Metropolitan Statistical Area (SMSA), or area of significant urban and economic development, had a 1970 population of 266,484 which was about 50% of the U. S. Lake Superior Basin population. The nine counties in the eastern part of the U.S. Lake Superior Basin declined in population about 4% during the 30-year period 1940-1970. In this area, the urban population is concentrated in the counties of Chippewa, Gogebic, Houghton, and Marquette. Most future population growth is expected to occur in or near the present urban areas.

LAND USE AND DEVELOPMENT

The land use patterns in the Lake Superior Basin are shown on Figure 1-7. Land use and development are discussed below under the categories of agriculture, industrial, municipal, and forestry. The Lake Superior 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 severe climate limit agricultural productivity in the Lake Superior Basin. Few crops are grown, with most farm sales coming from livestock and dairying, which is the most important agricultural activity. The general trend shows a decline of field and forest products, and an increasing greenhouse and nursery production. It also shows a decrease in total area under cultivation,

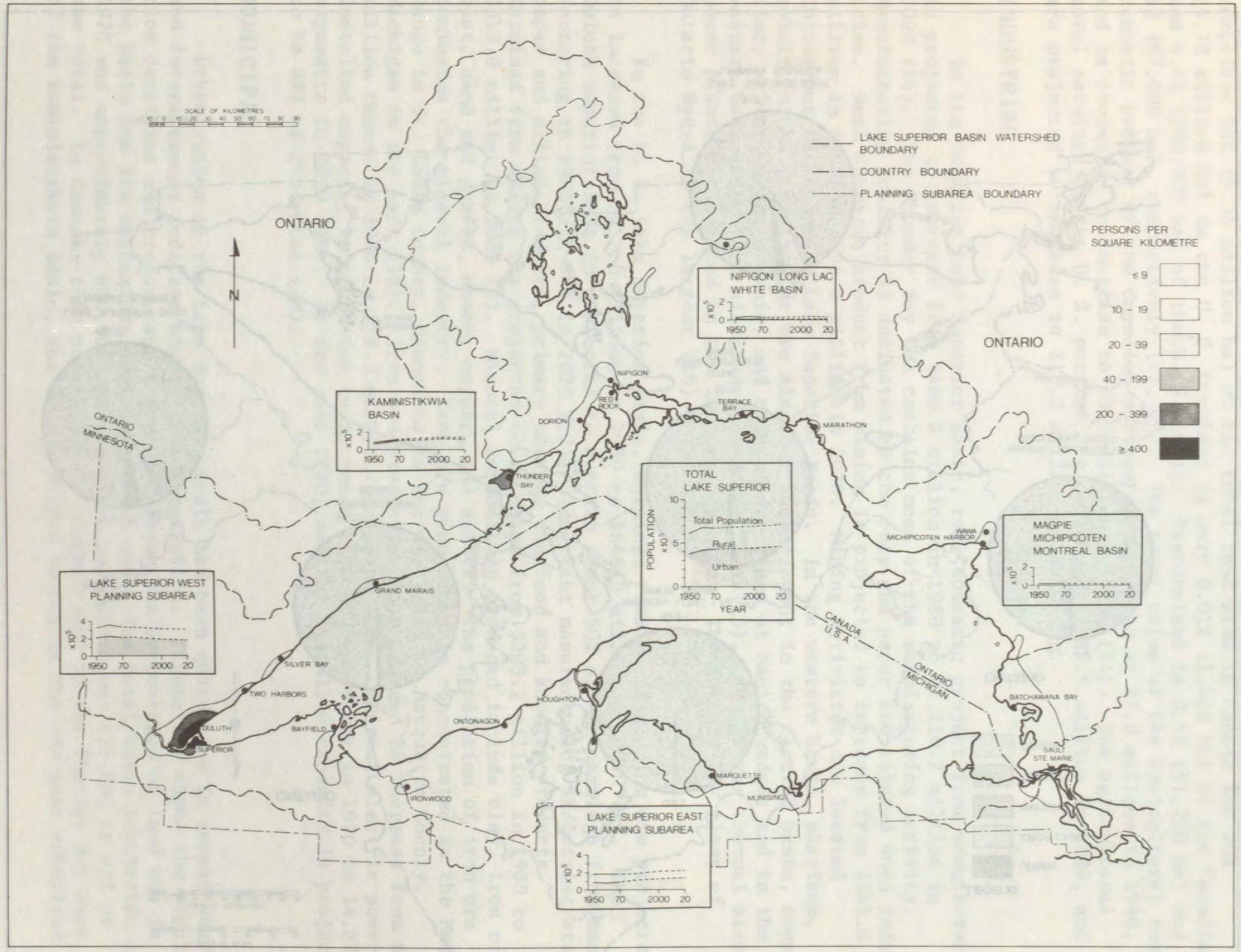


FIGURE 1-6 POPULATION DENSITY DISTRIBUTION AND TRENDS IN THE LAKE SUPERIOR BASIN.
Information from References (10) and (11).

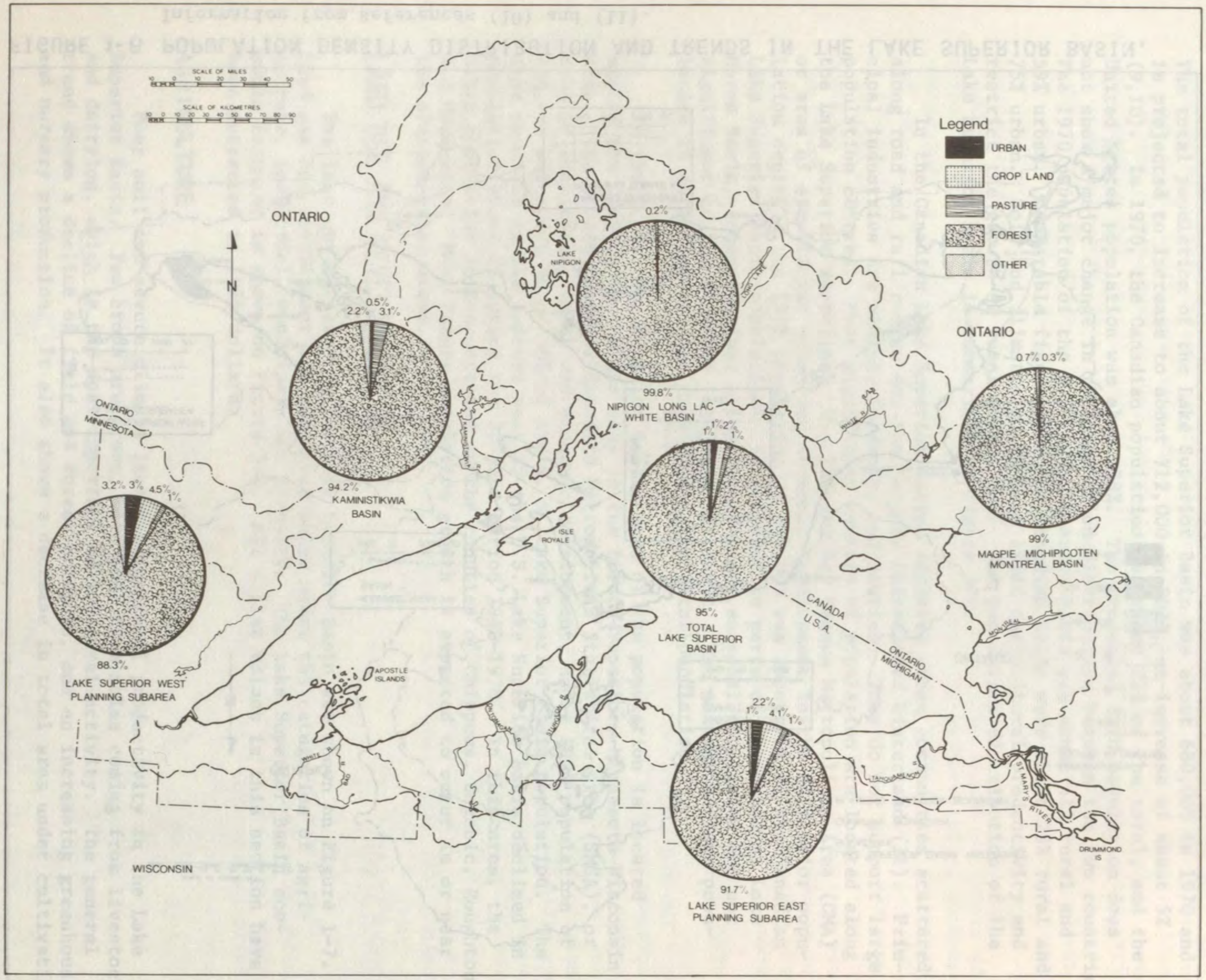


FIGURE 1-7 LAKE SUPERIOR BASIN-LAND USE.

U.S. information from Reference (12); Canadian information from Reference (13).

fewer farms, and increased average farm size. Forest range and undeveloped land comprises 99% (9.35 million ha) of the total land area in Canada and 90% (5.78 million ha) in the U. S. Cropland is only 0.01% (1,400 ha) of the Canadian, and 4.4% (280,000 ha) of the U. S. total. Pastureland is 0.5% (51,200 ha) and 1% (67,000 ha), respectively (12, 13). The total value of the agricultural real domestic product of the Canadian portion is estimated at $2.0 million in 1980, and is projected to increase to $8.8 million by 2020 (14). The agricultural total earnings in the U. S. portion are estimated at $9.9 million in 1980, and are projected to increase to $16.2 million by 2020 (9).

INDUSTRIAL

In the Canadian Lake Superior Basin, real domestic project from manufacturing is projected to increase from $486.2 million in 1980 to $2,210.2 million in 2020 (14). The Thunder Bay CMA contains most of the manufacturing activity. Manufacturing activity is dominated by the pulp and paper and related wood industries. Real domestic product from mining is projected to increase from $141.0 million in 1980 to $894.2 million in 2020. Mining activities are located throughout the Canadian Lake Superior Basin. In the western basin, platinum, cobalt, nickel, and copper are mined at Shebandowan; in the central basin, copper, zinc, silver, lead, arsenic, and cadmium are mined at Manitouwadge; and in the eastern basin, iron and silver are mined at Wawa (15). The larger thermal electric power plants are located in the Thunder Bay area. The Thunder Bay plant of Ontario Hydro is the largest (16).

In the U. S. Lake Superior Basin, earnings from manufacturing are projected to increase from $252.3 million in 1980 to $646.0 million in 2020 (9). The Duluth-Superior SMSA is projected to contain about 50% of the earnings from manufacturing in 1980 and 44% in 2020 (17). Important manufacturing industries are paper and allied products, primary metals, and food and kindred products. Earnings from mining are projected to increase from $205.2 million in 1980 to $313.0 million in 2020 (9). Mineral commodities produced include clay, iron ore, peat, sand and gravel, stone, copper, and silver. The production of iron ore dominates the mineral industry. Iron ore production is concentrated in the Mesabi Range in St. Louis County, Minnesota in the west, and in Marquette County, Michigan in the east (18). Iron ore production is projected to increase from 62.6 million tonnes in 1980 to 118.3 million tonnes in 2020. Thermal electric power installed capacity is projected to increase from 659 megawatts in 1970 to 14,273 megawatts in 2020 (19). By the year 2020, nuclear installed capacity is projected to be 89% of the total (18).

MUNICIPAL

Urbanization in the Lake Superior Basin has been quite slow in recent years and future trends indicate similar characteristics. Figure 1-6 shows the population densities and trends, and 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 680,000 and the urban population was 425,600 or 63% of the total. In Canada, this population is concentrated in the Thunder Bay area of the Kaministikwia Basin, and in the United States in the two most urbanized

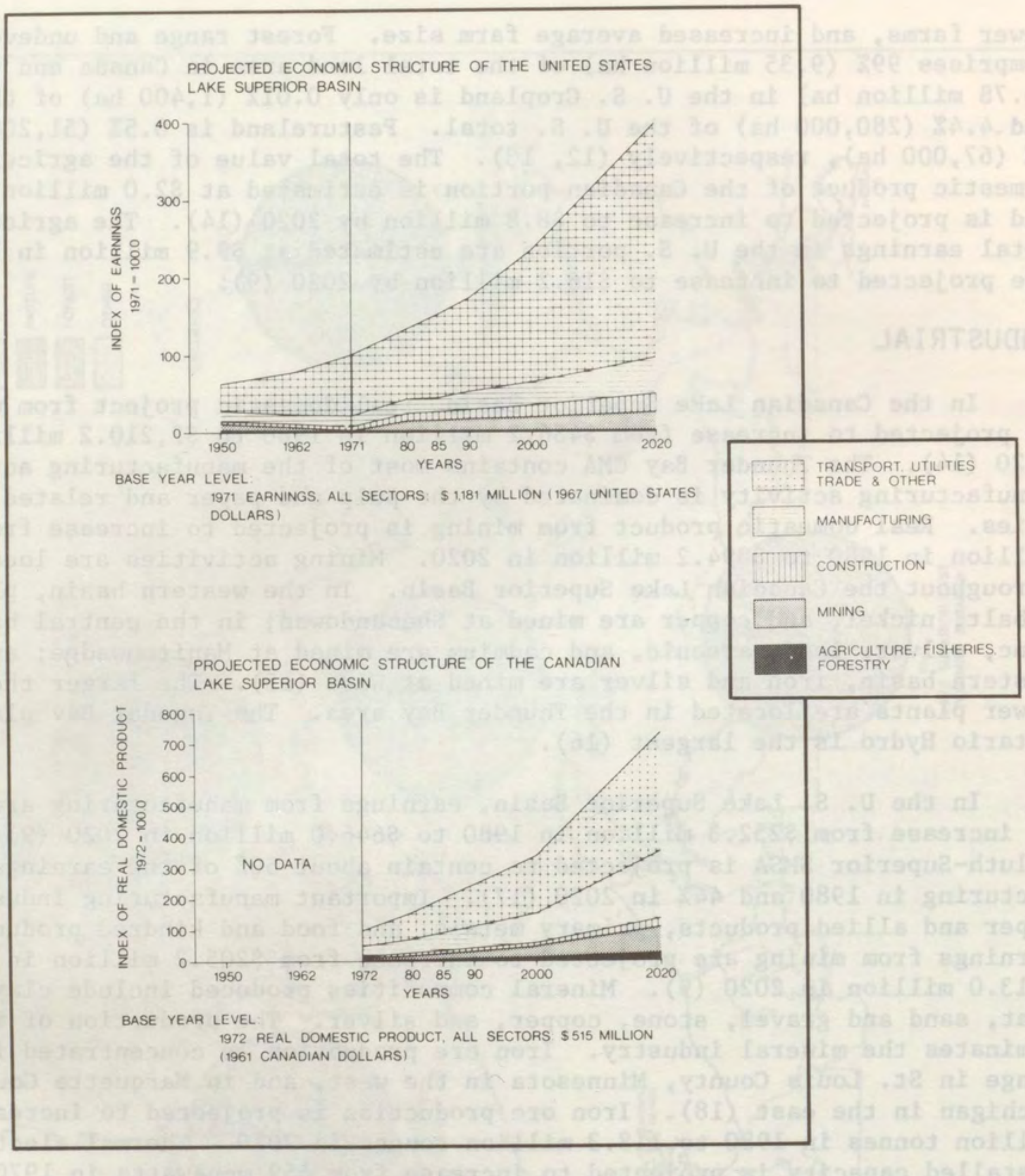


FIGURE 1-8 LAKE SUPERIOR BASIN-ECONOMIC FORECAST.

U.S. information from Reference (17); Canadian information from Reference (14).

counties, St. Louis and Marquette. Of the 159,050 km^2 of land area only 1,800 are urban. Table 1-1 summarizes the sewage treatment provided by the municipalities in the basin. There is one small tertiary facility in Hibbing, St. Louis County, Minnesota. These sewered communities represent a population of 375,400 or 88% of the urban population.

FORESTRY

Forests cover over 90% of the Canadian Lake Superior Basin. Principal tree species are pine, hemlock, birch, maple, oak, spruce, fir, and aspen (8). Over 90% of the forest land is under crown ownership. Forestry is an important industry and supports the related paper and allied products manufacturing industries (15). The Canadian real domestic product from the forestry industry is projected to increase from $50.2 million in 1980 to $208.4 million in 2020 (14). The U. S. Lake Superior Basin is also over 90% forest covered, with tree species similar to those in the Canadian portion (12). The forests were originally exploited and abused during the original settlement of the area. They are now being developed under forest management practices and support a forest-based industry. The harvested value of forest production in the U. S. Lake Superior Basin is projected to increase from $43.7 million in 1980 to $70.6 million in 2020 (20).

WATER USES

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

MUNICIPAL WATER SUPPLY

Municipal water supplies in the United States Lake Superior Basin used 183,200 m^3/d of water in 1970 and served 382,900 people (21). This total included 91,400 m^3/d taken directly from Lake Superior to supply 178,000 people. The largest single municipal user is the city of Duluth, Minnesota, which presently takes an average of 56,800 m^3/d of water from Lake Superior and serves 114,000 people. Superior, Wisconsin takes water from well points located along the shoreline. Cloquet, Minnesota takes water from Lake Superior during peak summer demands, but the regular supply is from wells. Because of asbestos in mine tailing discharges from Reserve Mining Company at Silver Bay, the city of Duluth, Minnesota has installed facilities to remove asbestos fibres; Silver Bay and Two Harbors, Minnesota are planning facilities to remove asbestos fibres; and Cloquet, Minnesota is investigating the need for removal of asbestos fibres. The largest demand for municipal water is for domestic and commercial use, although about 39,200 m^3/d was supplied to industry in 1970. Projections of municipal water 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 305,900 m^3/d in 2020, serving 508,600 people. Most of this water will come from Lake Superior.

The Canadian Lake Superior Basin is not heavily populated and does not have a large municipal water demand. The only large user is Thunder Bay, Ontario, which takes 69,600 m^3/d of water from Lake Superior and serves 102,500 people (16).

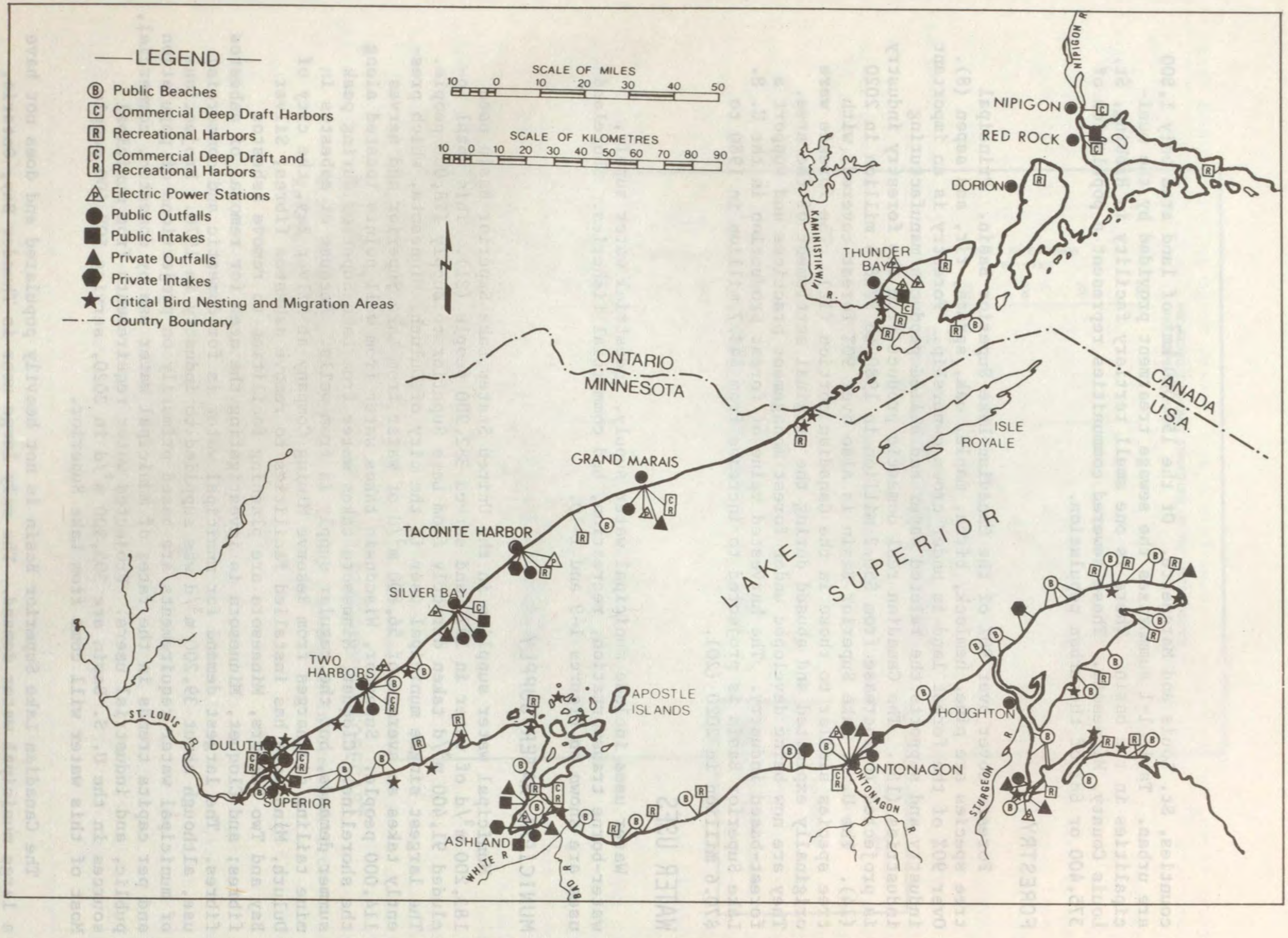


FIGURE 1-9 WESTERN LAKE SUPERIOR - SHORELAND USES

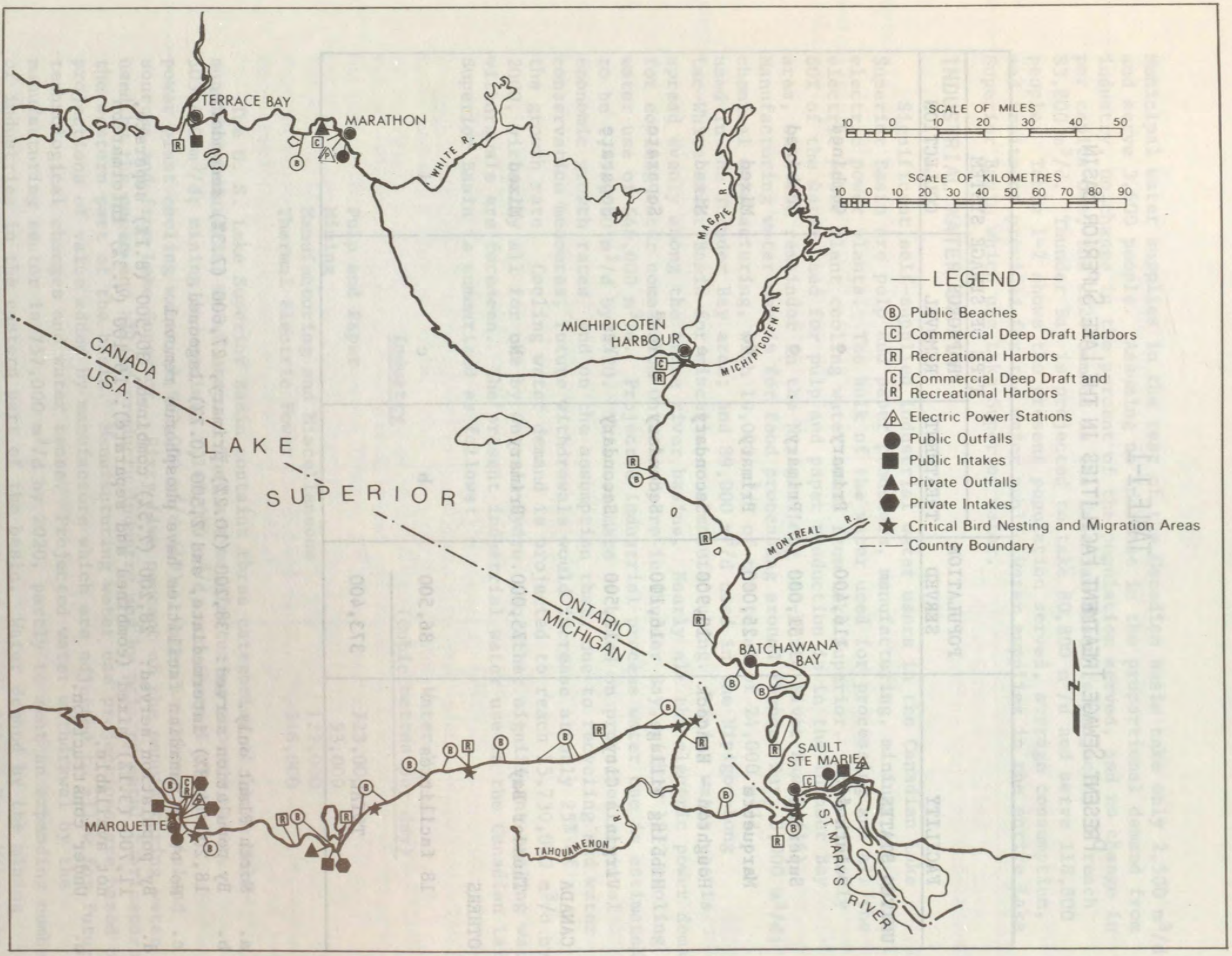


FIGURE 1-10 EASTERN LAKE SUPERIOR - SHORELAND USES

TABLE 1-1

PRESENT SEWAGE TREATMENT FACILITIES IN THE LAKE SUPERIOR BASIN

FACILITY	POPULATION SERVED	TYPE OF SEWAGE SYSTEM		
		TREATMENT	PHOPHORUS REMOVAL	COLLECTION
UNITED STATES				
Duluth #4	116,400	Primary	e	Combined
Superior	31,000	Primary	e	Combined
Marquette	25,000	Primary	No	Mixed
Houghton - Hancock	10,900	Secondary	e	Mixed
Hibbing Village	16,100	Secondary	Yes[a]	Separate
Virginia City	12,500	Secondary	Yes	Separate
CANADA				
Thunder Bay	75,000	Primary	No	Mixed
OTHERS				
18 facilities	86,500	b	c	d
TOTAL	373,400			

a. North Plant only.

b. By population served: 38,200 (10.2%) primary, 27,600 (7.3%) secondary, 18,200 (4.8%) intermediate, and 2,500 (0.7%) lagooned.

c. No other Canadian facilities have phosphorus removal.

d. By population served: 28,200 (7.5%) combined, 30,500 (8.1%) separate, 11,700 (3.1%) mixed (combined and separate), 16,100 (4.3%) information not available.

e. Under construction.

Municipal water supplies in the rest of the Canadian Basin take only 2,500 m^3/d and serve 3,600 people. Assuming no increase in the proportional demand from industry, no change in the percent of the population served, and no change in per capita use, the 2020 demand in the Canadian Basin is projected to reach 83,800 m^3/d. Thunder Bay is projected to take 80,800 m^3/d and serve 118,800 people. Table 1-2 shows the present population served, average consumption, and treatment provided for the major public water supplies in the entire Lake Superior Basin which use Lake Superior water.

INDUSTRIAL WATER SUPPLY

Significant self-supplied industrial water users in the Canadian Lake Superior Basin are pulp and paper producers, manufacturing, mining, and thermal electric power plants. The bulk of the water used for processing and all the electric power plant cooling water comes from Lake Superior. Approximately 60% of the water used for pulp and paper production is in the Thunder Bay area, with the remainder in the Nipigon-Long Lac-White River Basin (16). Manufacturing water use is for food processing around Thunder Bay, 3,000 m^3/d; chemical manufacturing, with 19,000 m^3/d of the total of 24,000 m^3/d used in the Thunder Bay area; and 89,000 m^3/d used in the Nipigon-Long Lac-White River Basin for miscellaneous manufacturing. Mining water use is spread evenly among the three river basins. Nearly all the electric power demand for cooling water comes from Ontario Hydro in Thunder Bay, with a 1972 cooling water use of 546,000 m^3/d. Projected industrial process water use is estimated to be 1,498,000 m^3/d by 2020. This estimate is based on projected regional economic growth rates and on the assumption that, due to recycling and water conservation measures, future withdrawals would increase at only 25% of the growth rate. Cooling water demand is projected to reach 15,730,000 m^3/d by 2000, virtually all for use by Ontario Hydro. No other significant cooling water withdrawals are foreseen. The present industrial water use in the Canadian Lake Superior Basin is summarized as follows:

Industry	Water Use (Cubic metres per day)
Pulp and Paper	723,000
Mining	53,000
Manufacturing and Miscellaneous	122,000
Thermal Electric Power	546,000

The U. S. Lake Superior Basin contains three categories of large self-supplied industrial water users. They are manufacturing process water, 503,400 m^3/d; mining industries, 2,165,000 m^3/d; and thermal electric power plant cooling water, 1,953,000 m^3/d (19). Water is taken from inland sources and from Lake Superior. Sixty five percent of the manufacturing water is used by the paper and allied products industry and by primary metal fabricators in the western 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. Projected water withdrawal by the manufacturing sector is 757,000 m^3/d by 2020, partly to meet an expanding number of industries in the eastern part of the basin. Water demand by the mining industry comes largely from the Reserve Mining Company's Silver Bay, Minnesota, taconite plant which used 1,908,000 m^3/d in 1968. The remaining mining water

TABLE 1-2

LAKE SUPERIOR PUBLIC WATER SUPPLY SUMMARY

LOCATION	POPULATION SERVED	AVERAGE CONSUMPTION (CUBIC METRES PER DAY)	TREATMENT
UNITED STATES			
Minnesota			
Beaver Bay	360	114	Filtration, Fluoridation, Disinfection
Duluth[a]	114,000	56,775	Fluoridation, Disinfection
Grand Marais	1,300	568	Filtration, Fluoridation, Disinfection
Silver Bay[b]	3,500	2,650	Filtration, Fluoridation, Disinfection
Two Harbors[b]	4,400	3,066	Fluoridation, Disinfection
Cloquet[c]	8,600	3,596	Fluoridation, Disinfection
Wisconsin			
Ashland	9,600	4,504	Filtration, Fluoridation, Disinfection
Washburn[d]	2,000	795	Fluoridation, Disinfection
Michigan			
Baraga	1,100	643	Purification[e], Fluoridation
Copper Harbor[f]	500	189[g]	Disinfection
Eagle Harbor[f]	300	76	Disinfection
L'Anse	2,600	2,082	Disinfection
Marquette	22,000	11,355	Disinfection, Fluoridation
Munising	3,800	1,968	Disinfection, Fluoridation
Ontonagon	2,500	908	Taste and Odour, Purification
White Pine	1,200	2,157	Fluoridation, Purification
Total UNITED STATES	177,760	91,446	
CANADA			
Ontario			
Thunder Bay[h]	102,500	69,600	Disinfection
Red Rock	1,700	1,200	Purification, Fluoridation
Terrace Bay	1,900	1,300[g]	Disinfection
Total CANADA	106,100	72,100	

a. Duluth has a $7.9 million filtration plant under construction.

b. Plans are being developed for filtration facilities.

c. Cloquet presently uses over 95% well water; Lake Superior supply is used only during peak periods (~10-15% of summer consumption); filtration facilities are being considered.

d. Lake Superior supply used as standby.

e. Purification includes disinfection, coagulation, sedimentation, filtration.

f. Seasonal supply, closed in winter.

g. Estimated.

h. Filtration plant under construction.

demand is for iron ore and copper mining in the area east of the Wisconsin-Michigan border and for crushed limestone mining east of Marquette, Michigan. Projected water demand for the mining industry is 2.98 million m^3/d by 2020, with 81% used in the western part of the basin. Six of the nine thermal electric power plants are in the Wisconsin-Minnesota part of the basin, and they used 1,181,000 m^3/d of water in 1970. Two of the remaining plants are near Marquette, Michigan, and the last is south of Keweenaw Bay. The 2020 projections for cooling water for the electric power industry range from 410,000 m^3/d for all supplemental cooling to over 25,000,000 m^3/d if flow-through cooling is used. The present industrial water use in the U. S. Lake Superior Basin is summarized as follows:

Industry	Water Use (Cubic metres per day)
Manufacturing	503,400
Mining	2,165,000
Thermal Electric Power	1,953,000

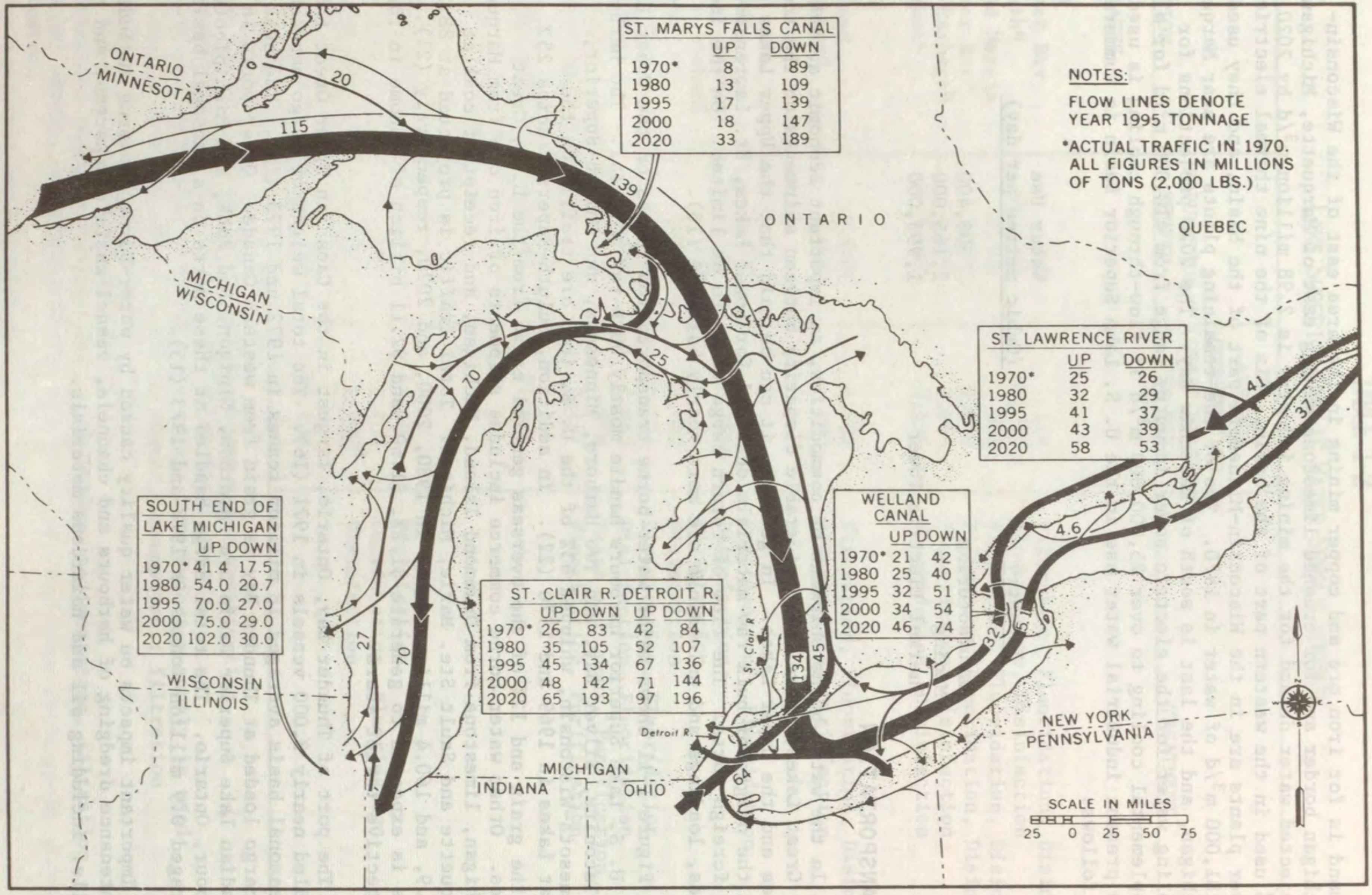
TRANSPORTATION

In the water-borne shipment of commodities, an important economic activity on the Great Lakes, there is considerable disparity between shipments on the Lower Lakes and the Upper Lakes. In general, it can be said that the Upper Lakes ports are the origin of bulk raw materials destined for Lower Lakes, St. Lawrence River, and foreign ports. The flow of return cargo tends to be limited. On the Lower Lakes, loadings and unloadings are more nearly balanced (16).

Figure 1-11 shows major water-borne transportation routes on the Great Lakes. The U. S. Lake Superior harbours handle mostly bulk raw material. The harbours of Taconite, Silver Bay, and Two Harbors, Minnesota, and Duluth-Superior, Minnesota-Wisconsin, shipped 63% of the U. S. iron ore traffic on the Great Lakes in 1969 and 1970 (22). In addition, Duluth-Superior ships 25% of the grain and 12% of the overseas general cargo from the U. S. Great Lakes. Other water-borne commerce includes shipments of iron ore from Marquette, Michigan, limestone from Drummond Island, Michigan, and receipt of coal at Marquette and Sault Ste. Marie, Michigan. Total traffic is projected at 88.2, 121.9, and 160.4 million tonnes in 1980, 2000, and 2020, respectively (21). This is expected to generate \$1.23, \$1.60, and \$2.11 billion of income in these respective target years.

The port of Thunder Bay, Ontario, largest in the Canadian Upper Great Lakes, handled nearly 3,000 vessels in 1971 (16). The total weight of cargo handled on a seasonal basis averaged 18 million tonnes in 1972 and 1973 (15). The bulk of cargo loaded at Thunder Bay is grain from western Canada. Other ports in the Canadian Lake Superior Basin are Marathon, Nipigon, Red Rock, and Michipicoten Harbour, Ontario. The total cargo handled at these ports on a seasonal basis averaged 0.9 million tonnes in 1972 and 1973 (15).

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.



NOTES:

FLOW LINES DENOTE YEAR 1995 TONNAGE

*ACTUAL TRAFFIC IN 1970. ALL FIGURES IN MILLIONS OF TONS (2,000 LBS.)

ST. MARYS FALLS CANAL

	UP	DOWN
1970*	8	89
1980	13	109
1995	17	139
2000	18	147
2020	33	189

ST. LAWRENCE RIVER

	UP	DOWN
1970*	25	26
1980	32	29
1995	41	37
2000	43	39
2020	58	53

WELLAND CANAL

	UP	DOWN
1970*	21	42
1980	25	40
1995	32	51
2000	34	54
2020	46	74

SOUTH END OF LAKE MICHIGAN

	UP	DOWN
1970*	41.4	17.5
1980	54.0	20.7
1995	70.0	27.0
2000	75.0	29.0
2020	102.0	30.0

	ST. CLAIR R.		DETROIT R.	
	UP	DOWN	UP	DOWN
1970*	26	83	42	84
1980	35	105	52	107
1995	45	134	67	136
2000	48	142	71	144
2020	65	193	97	196

FIGURE 1-11 GREAT LAKES SHIPPING TONNAGE

RECREATION

The U. S. Lake Superior Basin contains high quality recreational areas. consisting of large tracts of forests, numerous small inland lakes, and scenic rivers, as well as the lake and its shoreline. Many areas of the basin are dependent on income from the recreation industry, estimated to be $50 million in 1964 (4). Because of the rather severe winter climate, the recreation industry has been very seasonal, with most of the activity occurring in the warm summer months. Recently winter sports have attracted an increasing number of participants.

The principal water-oriented activities are swimming, camping, boating, and sport fishing. However, a large part of these activities are met on inland waters and not on the open lake. For example, it is estimated that only 30% of the recreational boating takes place on the lake. Important recreational shoreline areas are shown on Figures 1-9 and 1-10. Due to the high quality recreational land and water in the basin, a greater future demand will be put on these resources. Increased demand is expected to come from more recreational boating; registered boats are estimated to increase from 61,000 boats in 1968 to 81,000 in 2020 (23). Increased demand for sport fishing, largely on inland waters (24), and a doubling of other water-oriented recreation by the year 2020, such as picnicking, camping, hiking and sightseeing are also expected. The aesthetic and natural beauty of much of the Lake Superior shoreline makes sightseeing particularly attractive. Water-oriented recreational requirements for the U. S. Lake Superior Basin are estimated to increase from about 4 million recreation days in 1970 to 10 million in 2020 (4).

In the last two decades there has been a substantial increase in outdoor recreation in the Canadian Lake Superior Basin (15). Provincial parks with numerous amenities for the camper and outdoor recreationalist are being developed rapidly while sport fishing is becoming increasingly popular, accounting for the bulk of recreational expenditures. These recreational opportunities occur throughout the Canadian Lake Superior Basin and generally within reasonable reach of the Trans-Canada Highway. In response to the growing demand, the government has set aside additional recreational reserves and intensified development of facilities such as the provincial park system. A considerable portion of the demand for recreational facilities comes from out of the province - particularly from Manitoba and the States of Minnesota, Wisconsin, Illinois, and Michigan. Out-of-province tourists tend to spend more per person, hence accounting for more than half of the recreational expenditures. Unfortunately, the limited use of recreational facilities in the winter makes the tourist industry highly seasonal. The cottage population numbers in the order of 12,000 people, most of whom are concentrated in the western part of the basin in the vicinity of Thunder Bay. This represents less than 10% of the Canadian basin population. Approximately three-quarters of the cottagers originate from the Thunder Bay area with most of the remainder originating from the State of Minnesota.

Water-oriented recreational activities on the Canadian side of Lake Superior are limited relative to those on the U. S. side. The rugged rocky coastline offers panoramic views within easy reach of the Trans-Canada Highway but limits the potential of the area for boating and swimming. The potentially rough water of the lake combined with its generally low productivity limits sport fishing to shallower bays such as Thunder Bay and Nipigon Bay. As indicated from Figures 1-9 and 1-10, recreational activities are confined mainly to these two bays and to Terrace Bay, Marathon, Michipicoten Harbour, and Batchawana Bay. Despite the natural constraints, water-oriented recreational activities along the northern shoreline of Lake Superior can be expected to increase significantly over the next 50 years due to increase in population and leisure time.

Water quality problems associated with recreation have a minor impact on Lake Superior 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.

COMMERCIAL FISHERIES

In the early years of the Lake Superior fishing industry, whitefish and lake trout dominated landings, but by 1915 the lake herring was number one in annual production (24). In spite of dramatic recent declines in lake herring landings, that species still contributes more by weight to the fishery than any other species. Since 1952 fishing for smelt has grown, and that species now ranks second in total annual yield. 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 the 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. It bypassed Niagara Falls via the Welland Canal by the 1920's and subsequently spread throughout the Upper Great Lakes. It is a parasite living on the blood of other fish and is particularly destructive to large fish. The alewife is another marine invader that entered the Great Lakes via the same route as the sea lamprey. However, Lake Superior has not suffered as much from the alewife dieoff problem as Lakes Huron and Michigan.

The International Great Lakes Fishery Commission choose Lake Superior as the first Great Lake to receive sea lamprey control and lake trout restocking. Chemical sea lamprey control and lake trout fingerling stocking of tributaries began in 1958. Restocking programs for steelhead trout and coho and chinook salmon have also been started. They have thrived well, partly because of the abundance of alewives which are similar to their food in the ocean environment.

WASTE ASSIMILATION

Waste Assimilation from both point and diffuse sources occurs throughout the basin. Important areas of waste assimilation from point source waste discharges are the Duluth-Superior area on the U. S. side and the Thunder Bay area on the Canadian side. 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. The most notable example of waste assimilation from nonpoint sources occurs along the extreme southwestern shore of the lake where heavy sediment loads enter the lake from erosion in the red clay area.

CHAPTER 2

LEGISLATIVE BASIS FOR WATER QUALITY MANAGEMENT

shallower bays such as Thunder Bay and Nipigon Bay. As indicated from Figures 1-9 and 1-10, recreational activities are confined mainly to those two bays and to Terrace Bay, Marathon, Michipicoten Harbour, and Batchawana Bay. Despite the natural constraints, water-oriented recreational activities along the northern shoreline of Lake Superior can be expected to increase significantly over the next 50 years due to increase in population and leisure time.

Water quality problems associated with recreation have a minor impact on Lake Superior 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.

COMMERCIAL FISHERIES

In the early years of the Lake Superior fishing industry, whitefish and lake trout dominated landings, but [illegible] herring was number one in annual production (26). In spite of [illegible] declines in lake herring landings, that species still contributes more to the [illegible] fishery than any other species. Since 1952 fishing for [illegible] has grown, and that species now ranks [illegible] in total annual yield. Although fishing was intense and frequently caused [illegible] exploitation, the invasion of the sea lamprey was the major factor in the [illegible] of the catch and the change in species after 1940. The lamprey was pre[illegible] to have entered the Great Lakes in the late 1800's from its native ocean habi [illegible] Canal. It bypassed Niagara Falls via the Welland Canal by the 1920's [illegible] spread throughout the Upper Great Lakes. It is a parasite living [illegible] of other fish and is particularly destructive to large fish. The [illegible] marine invader that entered the Great Lakes via the same route [illegible]. However, Lake Superior has not suffered as much from the [illegible] invasion as Lakes Huron and Michigan.

[illegible] Great Lakes Fishery Commission choose Lake Superior as the [illegible] to receive sea lamprey control and lake trout restocking. [illegible] lamprey control and lake trout fingerling stocking of tributaries [illegible] stocking programs for steelhead trout and coho and chinook [illegible] were started. They have thrived well, partly because of the [illegible] which are similar to their food in the ocean environment.

WASTE ASSIMILATION

[illegible] from both point and diffuse sources occurs throughout the [illegible] areas of waste assimilation from point source waste discharges [illegible] area of the U. S. side and the Thunder Bay area on the [illegible]. Waste assimilation from nonpoint sources occurs throughout the [illegible] are carried to the lake in land drainage or in wash-out [illegible]. The most notable example of waste assimilation [illegible] occurs along the extreme southwestern shore of the lake where [illegible] enter the lake from erosion in the red clay area.

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, Minnesota, Wisconsin, 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.

MINNESOTA

MAJOR LEGISLATION AND SALIENT FEATURES

In 1945, the Water Pollution Control Act (Minn. Stat. Chapter 115) established the Water Pollution Control Commission, the precursor of the Minnesota Pollution Control Agency. The Commission was charged with enforcing the state's water pollution laws, cooperating with other governmental bodies, and setting up a permit system for and gathering information on disposal systems.

In 1967, the Minnesota Pollution Control Agency was created by Minn. Stat. Chapter 116 which abolished the Water Pollution Control Commission and transferred its functions and powers to the Agency. The Agency was also given authority over air quality control and solid waste management.

In 1969, citizens were put under an affirmative duty to notify the Agency of discharges and to recover the pollutants (Minn. Stat. 115.061) and the Agency was given power to direct the immediate discontinuance or abatement of pollution in emergency situations, where there is an "imminent and substantial danger to the health and welfare of the state" (Minn. Stat. 116.11).

In 1971, a special fund was created (Minn. Stat. 116.18) to be granted and disbursed by the Agency to municipalities and agencies of the state in aid of the construction of wastewater treatment facilities.

In 1973, the Agency was given authority to enforce orders, permits, standards, and regulations by criminal prosecution, civil penalties, injunctive relief, or actions to compel performance (Minn. Stat. 115.071). In addition, the Agency obtained authority to enforce the provisions in any NPDES permit issued by the Agency.

MAJOR AGENCIES, THEIR FUNCTIONS AND INTERRELATIONSHIPS

The agencies primarily responsible for the protection of the Great Lakes environment in Minnesota include the Minnesota Pollution Control Agency, Department of Natural Resources, Department of Health, and the Environmental Quality Council.

The Minnesota Pollution Control Agency is responsible for preserving, protecting, and restoring the waters of the state for their designated uses through a program of data collection, standards establishment, NPDES and state disposal permits, requirements for treatment plant construction, compliance monitoring, and enforcement. Under the federal and state assisted construction grants program, monies are available to eligible municipal applicants for the construction of waste treatment works. Enforcement actions are taken when upgrading of pollution sources is not undertaken or is considered inadequate.

The Department of Natural Resources is responsible for the preservation and propagation of fish and wildlife in the state. This includes sampling of fish and chemical parameters to evaluate suitability of waters. In conjunction with this responsibility, they become concerned with fish and wildlife habitat and water levels in all forms of water bodies.

The Department of Health is responsible for the identification and control of human health problems in the state. This includes the sampling for pathogens or toxic parameters in water bodies which are used for domestic consumption or whole body contact.

The Environmental Quality Council was established in 1973 (Minn. Stat. Chapter 116C) as the coordinating body for agencies concerned with natural resources in the state. The council also has authority over the preparation of environmental impact statements and the siting of power plants. The Director of the Minnesota Pollution Control Agency has a permanent seat on the council.

FEDERAL AND STATE RELATIONSHIPS

In Minnesota the federal-state relationship for the abatement of pollution mainly exists between the Minnesota Pollution Control Agency and the U.S. EPA. The primary impetus for the federal program is PL 92-500. This Act, while preserving the constitutional rights of the states, expanded the federal roles in water pollution control. The result has been an unprecedented level of state and federal cooperation in pollution abatement programs. This cooperation is displayed in the state administration of the federal grants program, the national permit program, and state use of the national data system for water quality information. In addition, state regulations have been developed which insure that effluent standards are applied which incorporate the requirements of both federal and state governments.

IMPLEMENTATION PROGRAMS

The Administration of the NPDES permit program is the tool used to regulate point source discharges to the waters of the state and a permit is required for all discharges. NPDES permits have been issued to all dischargers in the state except in those cases where hearings are pending to resolve challenges. The effluent limitations contained in the NPDES permits are based on the most restrictive criteria from a variety of regulations and guidelines. These include the U.S. EPA best practicable control technology requirement, the federal secondary treatment requirement, state effluent standards, and limitations developed by appropriate waste load allocation studies to protect water quality standards. In those cases where a discharger is not in compliance with the limitations specified in the permit, a compliance schedule is incorporated. Based on these permits and compliance schedules, a systematic process is available to insure compliance with federal and state requirements.

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 15% of the eligible costs. The

Minnesota Pollution Control Agency administers both the state program and the federal program in cooperation with the U.S. EPA. The federal allotment to the state for fiscal year 1976 was approximately $172,000,000. Since grant money is limited, it is dispensed on a priority basis. The annual Project List names the projects to be funded for a given year and reflects the state's priority in providing funds for constructing municipal treatment plants. The Municipal Needs List is a listing of all communities that have inadequate sewage treatment facilities and are being considered for state and federal grant monies.

ENFORCEMENT MECHANISMS

Effluent from treatment facilities is monitored by the Minnesota Pollution Control Agency and, in addition, the discharger is required by the NPDES permit to conduct regular monitoring. Any discharge of pollutants above the amount specified in the NPDES permit or any violation of the compliance schedule is considered a violation and 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, citations for violations, "show cause orders" to appear before the Agency Board, stipulated settlements, and, as a final action, litigation against a discharger. Litigation may be used to recover civil penalties of up to $10,000 a day or criminal penalties of up to $25,000 and/or imprisonment for one year. These same types of enforcement actions can be taken against a non-permitted discharge such as an oil spill. In those cases where a permit has not been issued as a result of a disagreement over permit requirements, public hearings are conducted to resolve the contested permit requirements.

WISCONSIN

MAJOR LEGISLATION AND SALIENT FEATURES

The Water Resources Act (Chapter 614, Laws of 1965) transferred water quality and regulatory activities to the Department of Resource Development. A further consolidation of state government on July 1, 1968 established the Wisconsin Department of Natural Resources. The Department has authority to issue orders (Chapter 144, Wisconsin Statutes). It may issue general orders and adopt rules applicable throughout the state for the construction, installation, use, and operation of practicable and available systems, methods, and means for preventing and abating pollution of waters of the state. Chapter 144 also established the state grant program for funding municipal projects. A seven-member Natural Resources Board appointed by the governor provides policy and general direction for the Department. The Wisconsin Department of Justice is the enforcement agency for order and permit violations.

The Wisconsin Environmental Policy Act (Section 1.11, Wisconsin Statutes), which became effective on April 19, 1972, requires all agencies of the state to prepare environmental impact statements on all major proposals for legislation or other major activities. This is in parallel with the requirements of the federal National Environmental Policy Act.

Chapter 147 of the Wisconsin Statutes was enacted in response to PL 92-500 and authorizes the Department to administer the NPDES permit program. This authority was given to the Department by the U.S. EPA on February 4, 1974.

Chapter 33 of the Wisconsin Statutes authorizes the Department to establish the Inland Lakes Protection and Rehabilitation Council to advise the Department regarding inland lakes and provides funds for studies and demonstration projects. Chapter 30 requires boat holding tanks, makes it unlawful to divert water from lakes or streams without a permit, and requires a permit for construction in or near navigable waters. Chapter 29 prohibits throwing refuse, abandoning automobiles, and discharging deleterious substances to the waters of the state. It authorizes the Department to recover damages for fish kills. Chapter 59 requires zoning of shorelands in unincorporated areas. Chapter 87 requires municipalities to adopt floodplain regulations. Chapter 146 requires the Department to regulate the disposal of septic tank pumpage.

MAJOR AGENCIES, THEIR FUNCTIONS AND INTERRELATIONSHIPS

Agencies responsible for the protection of the Great Lakes environment in Wisconsin include the Wisconsin Department of Natural Resources (DNR), the Wisconsin Department of Health and Social Services, the Board of Soil and Water Conservation Districts, and the Department of Justice (Attorney General).

The Wisconsin DNR is the lead agency and is responsible for preserving, protecting, and restoring the waters of the state for their designated uses through programs of data collection, standards establishment, NPDES permits, orders, municipal construction grants, and compliance monitoring.

The Department of Justice enforces by civil or criminal actions compliance with Wisconsin DNR orders and permit requirements.

The Department of Health and Social Services is responsible for the installation of plumbing including septic tank absorption systems, swimming beaches and pools, boat toilet facilities, and the Radiation Protection Code.

The Board of Soil and Water Conservation Districts has authority in land management and has potential to control nonpoint source pollution.

FEDERAL AND STATE RELATIONSHIPS

The federal-state relationship for the abatement of pollution mainly exists between the Wisconsin Department of Natural Resources and the U.S. EPA. The primary impetus for the federal program is PL 92-500. This Act, while preserving the constitutional rights of the states, expanded the federal role in water pollution control. The result has been an unprecedented level of state and federal cooperation in pollution abatement programs. This cooperation is displayed in the state administration of the federal grants program and the national permits program. In addition, state regulations have been developed which insure that effluent standards are applied which incorporate the requirements of both federal and state governments. An example of this is the Wisconsin Environmental Protection Act which parallels the National Environmental Policy Act.

IMPLEMENTATION PROGRAMS

Since 1950, Wisconsin has employed a systematic approach to pollution control in each of the state's 28 major drainage basins. In each basin, on a four-to-seven year cycle, investigations were made over a one year period on all point sources of pollution to determine their impact on receiving waters. Following the field investigations, a comprehensive report was prepared and a hearing held during which testimony under oath was presented and witnesses were subject to examination by interested parties. Orders were issued to municipal and industrial dischargers on the basis of the report and the hearings.

This system was modified during 1974 when the state assumed responsibility for the NPDES program. The issuance of orders has been substantially replaced by the issuance of permits. The scope of the surveys is being enlarged to consider nonpoint as well as point sources of pollution and the reports are used primarily for planning purposes. A total of 1,576 NPDES permits have been issued in the state, including 997 industrial and 579 municipal permits. The effluent limitations contained in these permits are based on criteria from a variety of regulations and guidelines. These include the U.S. EPA best practicable control technology, federal secondary treatment requirements, and state effluent standards and limitations developed by waste load allocation studies. When a discharge is not in compliance with the limitations specified in the permit, a compliance schedule is incorporated.

Grants are available from the state and federal governments to assist municipalities in planning and constructing the wastewater facilities required to meet permit conditions. Municipalities may apply for federal grants to cover 75% of the eligible costs. State grants are available for 25% of project costs where federal funding is not available. Wisconsin received a federal allocation of $145,327,400 during 1976 for municipal planning and construction grants. These funds are dispersed on a priority basis according to a priority list maintained by the Wisconsin DNR.

ENFORCEMENT MECHANISMS

NPDES permits require dischargers to periodically monitor their discharges and report the results to the Wisconsin DNR, which verifies the self-monitoring results by periodic monitoring of the discharges. Discharge of pollutants above the amount specified in the permit or not meeting the compliance schedule is a violation and subjects the discharger to possible enforcement action. This action consists of one or a combination of several remedies including enforcement letters, notices of noncompliance, citations for violations, "show cause orders", stipulated settlements, and referral to the Wisconsin Department of Justice for civil or criminal prosecution. Since May 1974, there have been 40 such referrals to that agency.

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 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 implemented. 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.

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 [illegible] the [illegible] development phase under the Canada-Ontario Agreement [illegible] and implementation has begun. Two projects have been [illegible] information on legislative and regulatory [illegible] Canada. The most effective of these [illegible] proposals for implementation in Ontario. [illegible] together with supplementary guidelines [illegible] developments and existing [illegible] review.

[illegible]

[illegible] The objective is [illegible] the Ministry of the Environment will accept [illegible] as an interim measure. The [illegible] is prohibited.

SPILLS

Ontario has a Contingency Plan for Spills of Oil and Other Hazardous Materials. Annex [illegible] 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, Fisheries Act, Public Lands Act, Drainage Act, Gasoline Handling Act, [illegible] 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 is considered 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 implemented. 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.

CHAPTER 3

MATERIAL INPUTS

3.1 INTRODUCTION AND MATERIAL BALANCE

INTRODUCTION

Chapter 3 describes material inputs to Lake Superior. This first section introduces and summarizes the remainder of Chapter 3. Included are material balances for certain selected parameters. Chapters 3.2 through 3.10 present the study results for the various input categories. These input categories are direct municipal and direct industrial wastewater discharges, tributaries, atmospheric deposition, shoreline erosion, thermal discharges, radioactivity discharges, dredging activities, vessel waste discharges, and spills. Chapter 3.11 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 Superior. The balances are essentially tabulations of the material inputs to and outputs from the lake. 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 this large lake as a whole system. The balances are not expected to be exact models of the whole lake. Neither can they be expected to simulate the problems of Lake Superior 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 Lake Superior is 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 Superior. 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 Superior 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 Superior. 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 Superior 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.

INTERLAKE TRANSPORT ESTIMATES

In order to prepare the material balances, the amounts of materials transported out of Lake Superior via the St. Marys River were needed. These have been estimated as follows, in tonnes per year:

Total Phosphorus = 402
Total Nitrogen = 21,900
Reactive Silicate (as SiO_2) = 150,000
Total Dissolved Solids = 4,020,000
Chloride = 76,700

These were calculated using the average 1973 flow of the St. Marys River, 2060 m^3/s (2). Concentrations were measured by the Ontario Ministry of the Environment and the Canada Centre for Inland Waters in Whitefish Bay in 1973. The data are given in Chapters 4.1 and 5.3.

MATERIAL BALANCE TABULATIONS

The material balance tabulations are shown in Tables 3.1-1 through 3.1-5. Observations and comments are listed on each table. The tables are arranged in the following order:

Parameter	Total Phosphorus	Total Nitrogen	Reactive Silicate	Total Dissolved Solids	Chloride
Location	3.1-1	3.1-2	3.1-3	3.1-4	3.1-5

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.

The only direct-discharging industry for Minnesota is Reserve Mining Company. Inputs shown for Reserve Mining are the amounts available to the lakewater, rather than total inputs, which are shown for other municipal and industrial sources. This was done because of the huge amount of non-available crushed rock in the Reserve discharge.

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 3.4). In general, confidence in the atmospheric input estimates is not as great as the tributary, municipal, and industrial input estimates. There is also a greater lack of confidence in the shoreline erosion input estimates due to the difficulty in measuring them.

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 wastes are discussed in detail in Chapter 3.9. They are a significant portion of the total inputs only for chloride and total dissolved solids, which result from dumping of salt water ballast. These two parameters are shown in the summary tables; the other parameters are not shown for vessel wastes.

Dredging inputs (Chapter 3.8) 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.

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

MATERIAL BALANCE SUMMARY

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

(1) Tributaries are the largest input source for all parameters except nitrogen. Atmospheric inputs are the largest source of nitrogen.

(2) Direct municipal and industrial sources are a minor input in all cases. Thus, Lake Superior is quite different from Lake Erie and Ontario.

(3) There is a net accumulation of the nutrients phosphorus, nitrogen, and silicon. This is probably due to the sedimentation of dead algae.

(4) There is also a net accumulation of total dissolved solids and chloride. Accumulation will probably result in increasing concentrations in the lake for these parameters.

TABLE 3.1-1

LAKE SUPERIOR MATERIAL BALANCE FOR TOTAL PHOSPHORUS (As P)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	22	6	206	63	297
WISCONSIN	60	2	485	456	1,000
MINNESOTA	14	3	496	27	540
ONTARIO	36	88	920	178	1,220
ATMOSPHERIC INPUTS					800
SHORE EROSION INPUTS					280
TOTAL INPUTS					4,140
TOTAL OUTPUTS (VIA THE ST. MARYS RIVER)					402

OBSERVATIONS AND COMMENTS

1. Tributaries account for 68% of the total inputs.

2. *Direct* municipal and industrial point sources account for only about 6% of the total inputs. Independent calculations show that about 11% of the phosphorus entering the lake via tributaries originates from upstream municipal and industrial sources. Thus, about 13% of the total inputs originate from *all* municipal and industrial discharges. Phosphorus removal facilities now planned at wastewater treatment plants on the U.S. side will reduce the total municipal and industrial contribution from 13% to about 7%.

3. Atmospheric inputs account for about 19% of the total.

4. Reserve Mining Company is the only Minnesota industry included. The phosphorus input shown is for only that portion which is available to the biota. It is a relatively minor input.

5. About 10% of the input phosphorus is measured as output. This seems somewhat low. However, sedimentation of phosphorus is usually quite significant in oligotrophic 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.

6. The loadings from municipal, industrial, and tributary sources are projected to increase 21% 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

LAKE SUPERIOR MATERIAL BALANCE FOR TOTAL NITROGEN (AS N)

SOURCE	LOADINGS IN TONNES PER YEAR				TOTAL
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		
			SAMPLED	UNSAMPLED	
MICHIGAN	50	65	4,050	1,470	5,640
WISCONSIN	149	6	3,060	3,070	6,290
MINNESOTA	50	39	7,230	551	7,870
ONTARIO	249	456	14,700	2,420	17,800
ATMOSPHERIC INPUTS					56,000
SHORE EROSION INPUTS					1,600
				TOTAL INPUTS	95,200
				TOTAL OUTPUTS (VIA THE ST. MARYS RIVER)	21,900

OBSERVATIONS AND COMMENTS

1. Atmospheric inputs account for 59% of the total.

2. Tributary inputs account for 38% of the total, which is about equally divided between the U.S. and Canada.

3. It does not appear that any significant portion of the present nitrogen inputs are subject to control.

4. The measured output is about 23% of 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 34% 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

LAKE SUPERIOR MATERIAL BALANCE FOR REACTIVE SILICATE (AS SiO_2)

SOURCE	LOADINGS IN TONNES PER YEAR				
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
MICHIGAN	45	0	36,100	22,200	58,300
WISCONSIN	49	32	43,400	44,100	87,600
MINNESOTA	26	8,810	47,300	5,860	62,000
ONTARIO	118	1,150	176,000	37,200	214,000
ATMOSPHERIC INPUTS					26,100
SHORE EROSION INPUTS					14,400
				TOTAL INPUTS	462,000
		TOTAL OUTPUTS (VIA THE ST. MARYS RIVER)			150,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 89% of the total inputs, about equally divided between U.S. and Canadian sources. Other sources are relatively minor.

2. The measured output is about 32% of the total inputs.

3. Tributary loadings depend primarily on their flow rates. Concentrations are relatively constant and do not seem to depend on human civilization. This would indicate that the lake may be closer to steady state for silicate 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.

4. The loadings from municipal, industrial, and tributary sources are projected to increase 5% 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

LAKE SUPERIOR MATERIAL BALANCE FOR TOTAL DISSOLVED SOLIDS

SOURCE	LOADINGS IN TONNES PER YEAR				TOTAL
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		
			SAMPLED	UNSAMPLED	
MICHIGAN	1,300	9,640	456,000	239,000	706,000
WISCONSIN	2,130	3,520	631,000	668,000	1,300,000
MINNESOTA	631	30,100	365,000	28,700	424,000
ONTARIO	3,760	222,000	3,100,000	511,000	3,840,000
ATMOSPHERIC INPUTS					120,000
SHORE EROSION INPUTS					192,000
VESSEL WASTE INPUTS					21,000
				TOTAL INPUTS	6,600,000
				TOTAL OUTPUTS (VIA THE ST. MARYS RIVER)	4,020,000

OBSERVATIONS AND COMMENTS

1. Tributaries account for 91% of the total inputs. About 60% of the tributary inputs are from the Canadian side.

2. Inputs from tributaries are primarily natural rather than cultural. This would indicate that the lake is now reasonably close to steady state. However, outputs are only about 61% of inputs. Assuming that no removal of dissolved solids occurrs within the lake, the lake concentration would increase by more than 60% at steady state. The true concentration at steady state will probably be somewhere in between.

3. The loadings from municipal, industrial, and tributary sources are projected to increase 33% 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

LAKE SUPERIOR MATERIAL BALANCE FOR CHLORIDE

SOURCE	LOADINGS IN TONNES PER YEAR				TOTAL
	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		
			SAMPLED	UNSAMPLED	
MICHIGAN	193	1,240	36,900	3,530	41,900
WISCONSIN	283	116	8,800	8,430	17,600
MINNESOTA	84	1,240	46,400	1,780	49,500
ONTARIO	639	28,800	97,100	9,310	136,000
ATMOSPHERIC INPUTS					55,000
SHORE EROSION INPUTS					800
VESSEL WASTE INPUTS					11,300
TOTAL INPUTS					312,000
TOTAL OUTPUTS (VIA THE ST. MARYS RIVER)					76,700

OBSERVATIONS AND COMMENTS

1. Tributaries account for about 68% of the total, about equally divided between U.S. and Canadian sources.

2. Atmospheric sources account for about 18% of the total inputs.

3. Dumping of salt water ballast from vessels accounts for a surprisingly high 4% of the total inputs.

4. Measured outputs are only about 25% of total inputs. Chloride ion is easily measured and does not tend to change form or settle to the lake bottom. Therefore, the wide discrepancy between inputs and outputs indicates that the lake is not at steady state for chloride. Accumulation would be expected to result in higher concentrations in the lake. Concentrations in the lake will have to increase by a factor of 4 for outputs to equal inputs. However, due to the large volume of Lake Superior the approach to equilibrium will be very slow. For example, it will take about 75 years for the concentration to double from the present 1.2 mg/ℓ to 2.4 mg/ℓ.

5. The loadings from municipal, industrial, and tributary sources are projected to increase 12% 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.

FIGURE 3.1-1

LAKE SUPERIOR MATERIAL BALANCE SUMMARY

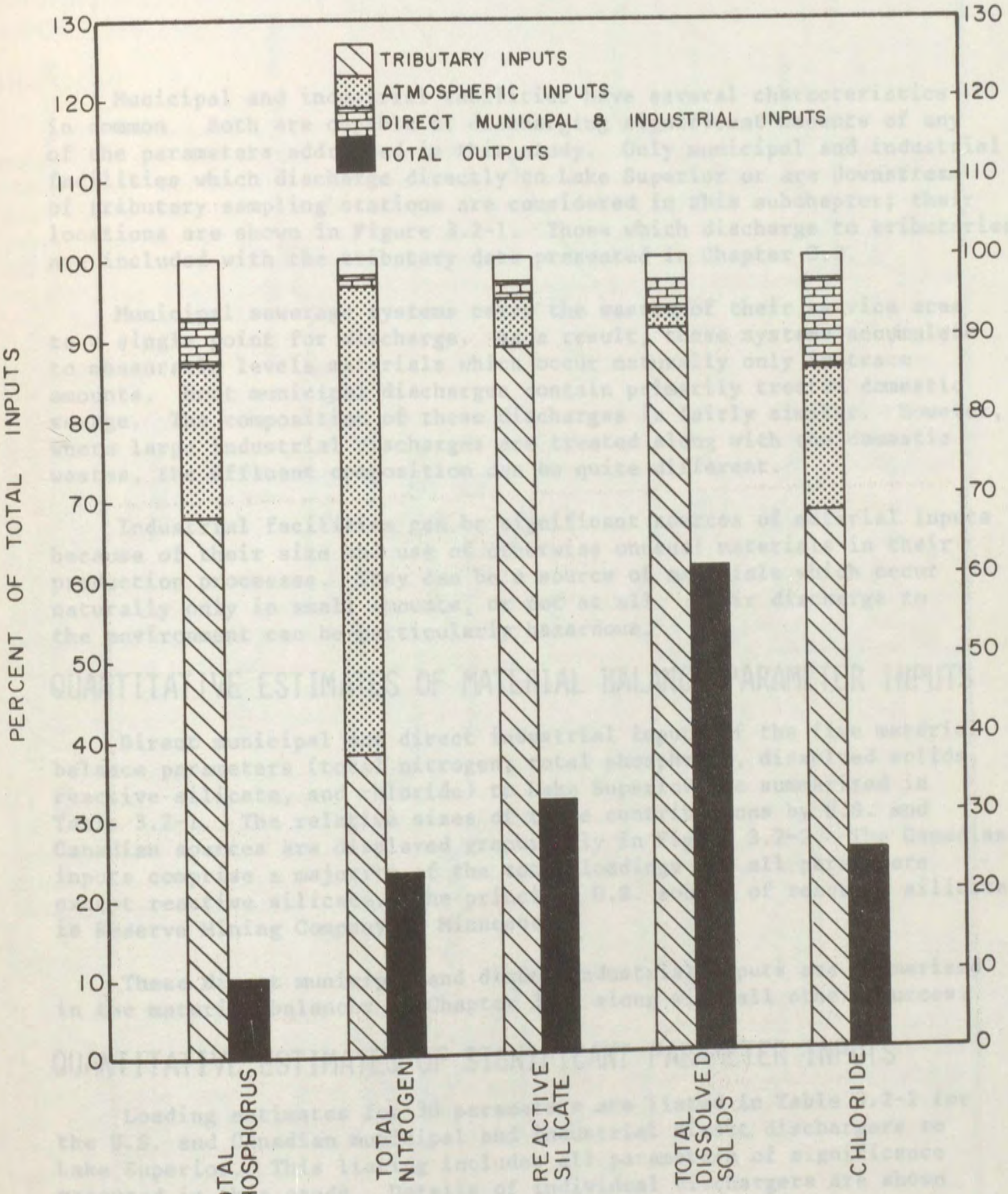


TABLE 3.1-5

LAKE SUPERIOR MATERIAL BALANCE FOR CHLORIDE

SOURCE	LOADINGS IN TONNES PER YEAR				
	[illegible] MUNICIPAL	DIRECT INDUSTRIAL	TRIBUTARY		TOTAL
			SAMPLED	UNSAMPLED	
[illegible]	[illegible]	[illegible]	38,900	2,530	41,900
[illegible]	[illegible]	[illegible]	[illegible]	8,400	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2,780	[illegible]
[illegible]	[illegible]	[illegible]	97,300	9,310	[illegible]
[illegible]					55,000
[illegible]					800
[illegible]					[illegible]
				TOTAL INPUTS	311,000
			[illegible] OUTPUTS VIA THE ST. MARYS RIVER		[illegible]

OBSERVATIONS AND COMMENTS

1. [illegible] about 46% of the total, about equally divided between [illegible].

2. [illegible] account for about 18% of the total inputs.

3. [illegible] accounts for a surprisingly high [illegible] total inputs.

4. Measured outputs [illegible] of total inputs. Chloride ion is easily measured and does not [illegible] form or settle to the lake bottom. Therefore, the large discrepancy between inputs and outputs indicates that the lake is not [illegible] with chloride. Accumulation would be expected to result in higher concentrations in the lake. Concentrations in the lake will have to increase by a factor of 4 for outputs to equal inputs. However, due to the large volume of Lake Superior the approach to equilibrium will be very slow. [illegible] years for the concentration to double from [illegible] mg/l.

5. [illegible] tributary loadings are projected to increase [illegible] by [illegible]. This assumes that the present general level of waste treatment continues, and that nonpoint source inputs remain constant. Therefore, the projected increase is entirely due to the forecast population increases and industrial expansion. No loading projections have been made for the [illegible] atmospheric inputs.

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 Superior 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 Superior 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 Canadian inputs comprise a majority of the total loadings for all parameters except reactive silicate. The principal U.S. source of reactive silicate is Reserve Mining Company in Minnesota.

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 38 parameters are listed in Table 3.2-2 for the U.S. and Canadian municipal and industrial direct dischargers to Lake Superior. This listing includes all parameters of significance measured in this study. Details of individual dischargers are shown in the project reports (1, 2).

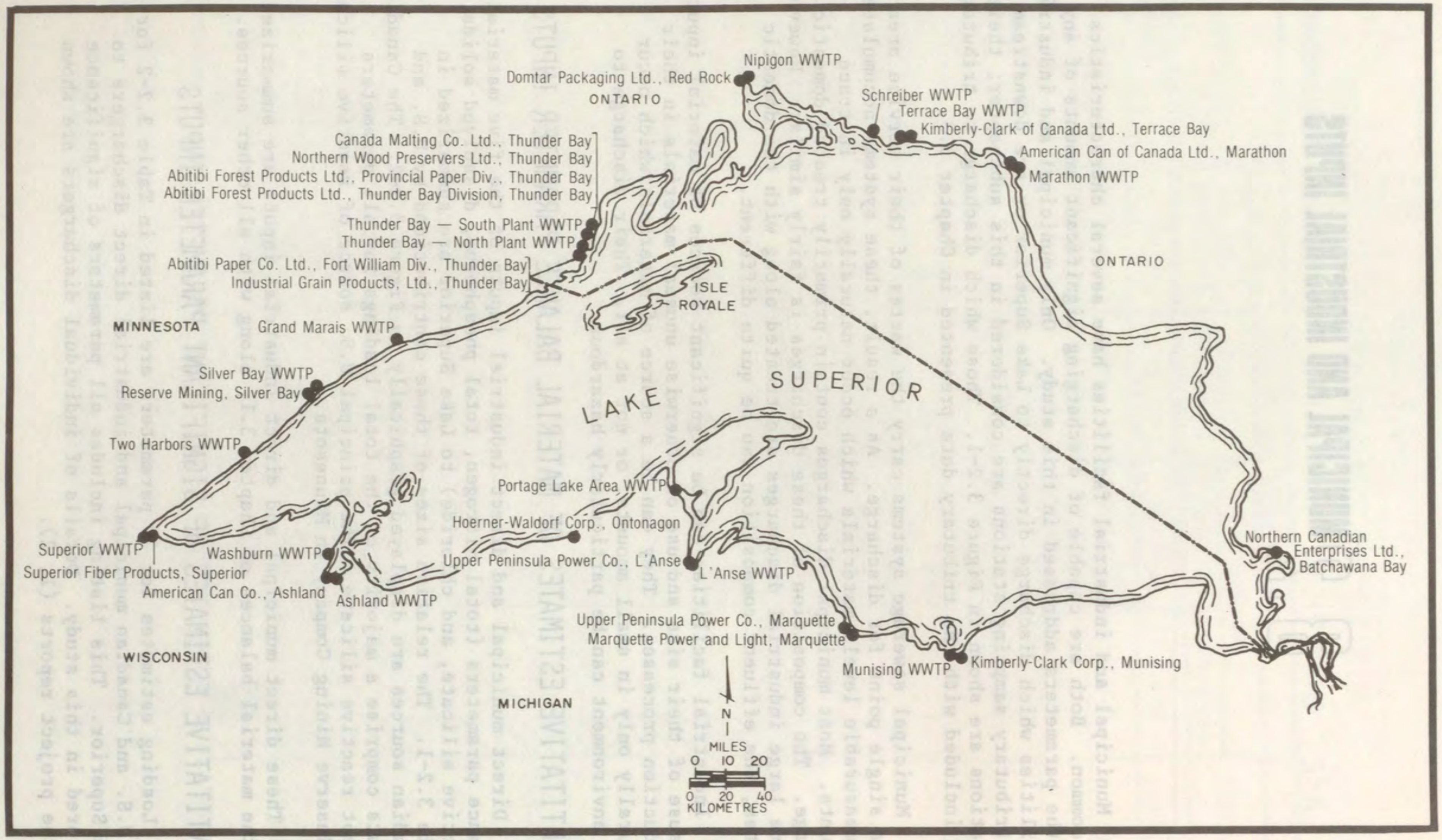


FIGURE 3.2-1
LAKE SUPERIOR BASIN MUNICIPAL AND INDUSTRIAL DIRECT DISCHARGERS
U.S. AND CANADIAN FACILITIES SURVEYED
JULY 1973 - JUNE 1975

METHODS OF LOADING ESTIMATION

Michigan, Wisconsin, Minnesota, and Ontario all computed estimates of their respective municipal and industrial inputs to Lake Superior. The sampling methods varied for each, and are dedcribed 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.

WISCONSIN

The data for Wisconsin's discharges were collected by the state in single, 24-hour surveys. During surveys, samples were composited over time and proportioned for flow. Loading products were computed as for Michigan.

MINNESOTA

Minnesota's sampling was done monthly by the state using either composite or grab samples. The composite sampling was done four times per year. The samples were composited over time and proportioned for flow, using Serco samplers. The grab sampling surveys were performed eight times per year, alternating with the composite surveys. Loading products were computed as for Michigan.

The Reserve Mining Company's discharge to Lake Superior was estimated by the U.S. Environmental Protection Agency, based on data they compiled (3). The estimates used for Reserve Mining are the amounts of material "available" to the lakewater, rather than total discharges as used for the other inputs. This is because the vast majority of the material is settleable and not available for solution.

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.

TABLE 3.2-1

MUNICIPAL AND INDUSTRIAL DIRECT DISCHARGES OF MATERIAL BALANCE PARAMETERS TO LAKE SUPERIOR

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)								Total Loading (kg/d)
	Ontario (2)		Michigan (1)		Wisconsin (1)		Minnesota (1)		
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	
Total Nitrogen as N	682	1,250	138	177	407	16.8	138	108	2,920
Total Phosphorus as P	98	240	61.6	16.8	165	4.80	38.4	9.00	634
Dissolved Solids	10,300	608,000	3,570	26,400	5,840	9,640	1,730	82,500	748,000
Reactive Silicate as SiO_2	321	3,140	125	0	135	89	73	24,200	28,100
Chloride	1,750	78,800	530	3,400	774	317	231	3,400	89,200

FIGURE 3.2-2

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

U.S. AND CANADIAN MUNICIPAL AND INDUSTRIAL DIRECT LAKE DISCHARGES

JULY 1973 - JUNE 1975

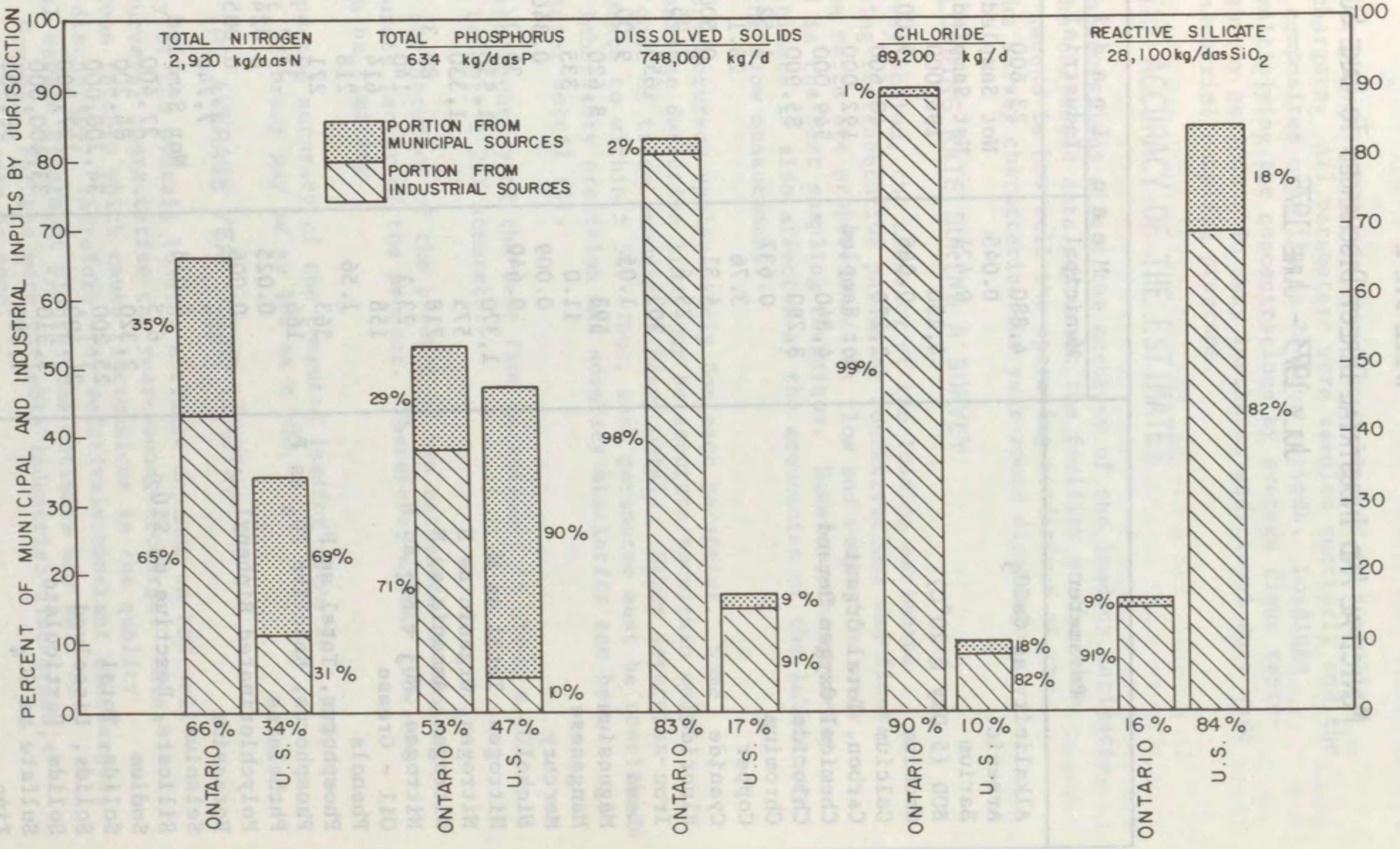


TABLE 3.2-2

MUNICIPAL AND INDUSTRIAL DIRECT DISCHARGES TO LAKE SUPERIOR

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)		
	Municipal	Industrial	Total
Alkalinity as $CaCO_3$	4,880	33,600	38,500
Arsenic	0.045	Not Sampled	0.045
Barium	0.421	Not Sampled	0.041
BOD (5 Day @ 20°C)	4,250	196,000	200,000
Cadmium	0.066	9.00	9.07
Calcium	2,270	40,600	42,800
Carbon, Total Organic	Not Sampled	192,000	192,000
Chemical Oxygen Demand	4,840	549,000	554,000
Chloride	3,290	85,900	89,200
Chromium	0.637	1.52	2.16
Copper	3.76	28.1	31.9
Cyanide	4.31	0.500	4.81
Fluoride	25.6	7.95	33.6
Iron	203	655	858
Lead	1.05	9.00	10.1
Magnesium	593	8,620	9,220
Manganese	11.0	335	346
Mercury	0.009	0.340	0.349
Nickel	0.640	30.0	30.6
Nitrogen, Total as N	1,370	1,550	2,920
Nitrogen, Organic as N	575	1,330	1,900
Nitrogen, Ammonia as N	718	89.3	807
Nitrogen, $NO_3 + NO_2$ as N	73.1	140	213
Oil - Grease	158	614	772
Phenols	1.56	218	220
Phosphorus, Total as P	363	271	634
Phosphorus, Reactive PO_4 as P	166	33.6	200
Phthalates	0.025	0.024	0.049
Polychlorinated Biphenyl	0.006	0.005	0.011
Potassium	484	7,740	8,230
Selenium	0.013	Not Sampled	0.013
Silicate, Reactive as SiO_2	655	27,400	28,100
Sodium	2,320	84,200	86,500
Solids, Total	25,200	34,200,000	34,200,000
Solids, Dissolved	21,400	727,000	748,000
Solids, Particulate	3,310	33,400,000	33,400,000
Sulfate as SO_4	1,680	59,400	61,100
Zinc	4.18	175	179

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

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.

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 by 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 (4).

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 least accurate factor of the product. Therefore, either flow or concentration 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) characterize 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 largest industrial inputs to Lake Superior are the pulp and paper mills on the Canadian side and Reserve Mining Company on the U.S. side. Large municipal inputs are the Thunder Bay area in Ontario and the Duluth-Superior area in Minnesota and Wisconsin. The effects of these discharges on the receiving waters are discussed in Chapter 4.

In general, the municipal and industrial point sources make up a relatively small portion of the total loadings to Lake Superior, as discussed in Chapter 3.1. This is due to the small amount of population in the Lake Superior Basin. This is in contrast to the Lower Lakes which have many large inputs from municipal and industrial sources.

3.3 TRIBUTARY INPUTS

Tributaries are the largest source of material inputs to Lake Superior. 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 Superior 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 Superior 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 Superior. This listing includes all parameters of significance measured in this study. Details of individual tributaries are shown in the project reports (1, 2).

METHODS OF LOADING ESTIMATION

Michigan, Wisconsin, Minnesota, and Ontario computed estimates of their respective land drainage and tributary inputs to Lake Superior. The computations varied somewhat for each agency, and are described below.

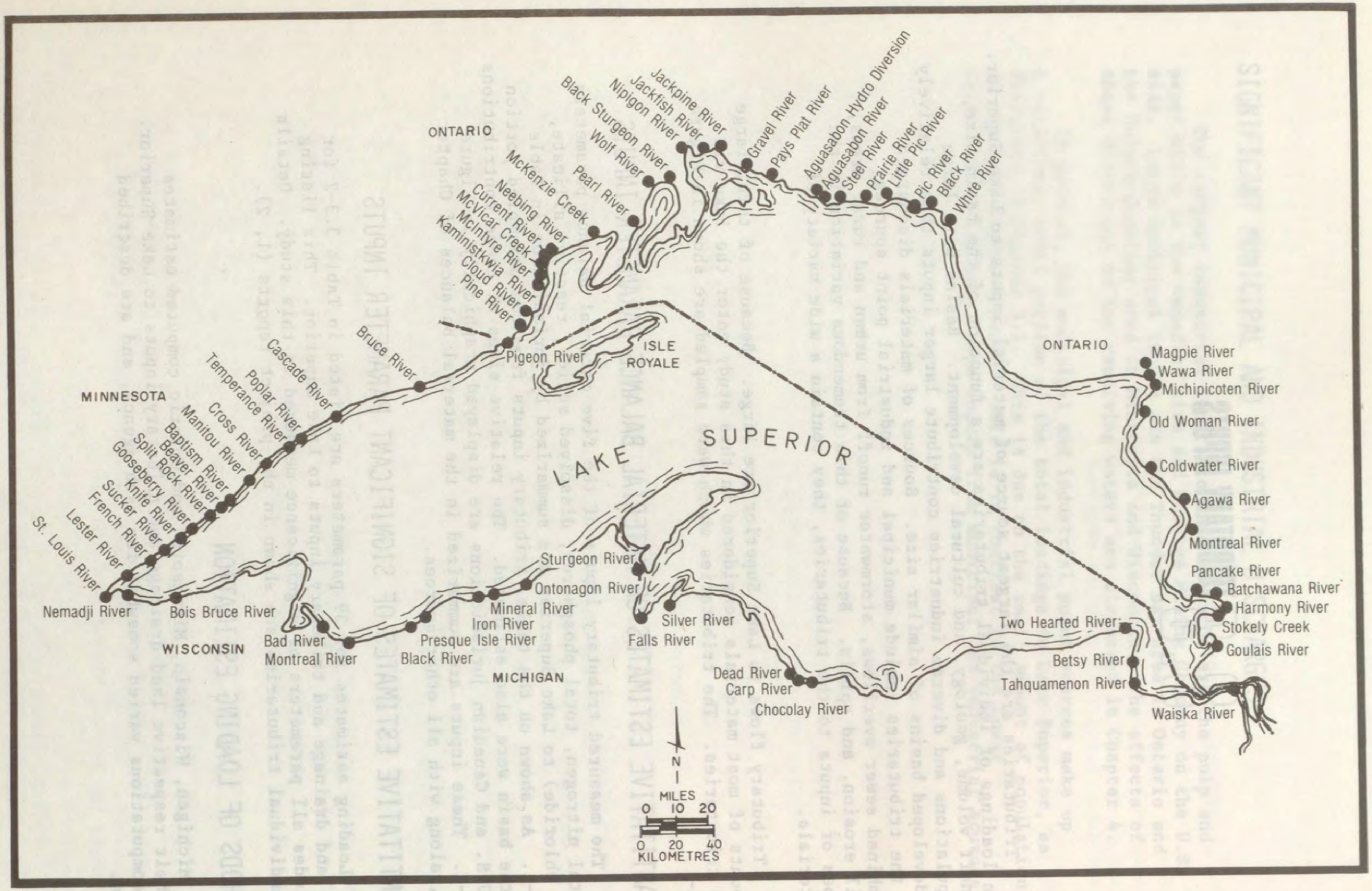


FIGURE 3.3-1

LAKE SUPERIOR BASIN LAND DRAINAGE AND TRIBUTARY INPUTS
U.S. AND CANADIAN TRIBUTARIES SAMPLED
JULY 1973 - JUNE 1975

MICHIGAN, MINNESOTA, AND WISCONSIN

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 streamflow on the days when samples were taken was 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 streams sampled did not comprise the entire Lake Superior Basin. Therefore, the unsampled land drainage loading contribution was estimated by using concentrations and flows per unit of drainage area from sampled streams having similar geographic characteristics. Loading was then determined by multiplying unsampled drainage area 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, an estimate of the average study period flow was made based on a nearby stream gage. 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 daily 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%, as in the case of trace amounts of heavy metals. Other determinations

TABLE 3.3-1

TRIBUTARY INPUTS OF MATERIAL BALANCE PARAMETERS TO LAKE SUPERIOR

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)								Total Loading (kg/d)
	Ontario (2)		Michigan (1)		Wisconsin (1)		Minnesota (1)		
	Sampled	Unsampled	Sampled	Unsampled	Sampled	Unsampled	Sampled	Unsampled	
Total Nitrogen as N	40,200	6,620	11,100	4,030	8,380	8,420	19,800	1,510	100,000
Total Phosphorus as P	2,520	489	565	172	1,330	1,250	1,360	74.0	7,760
Dissolved Solids	8,490,000	1,400,000	1,250,000	656,000	1,730,000	1,830,000	1,000,000	78,500	16,400,000
Reactive Silicate as SiO_2	481,000	102,000	99,000	60,700	119,000	121,000	130,000	16,100	1,130,000
Chloride	266,000	25,500	101,000	9,680	24,100	23,100	127,000	4,890	581,000

FIGURE 3.3-2

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

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

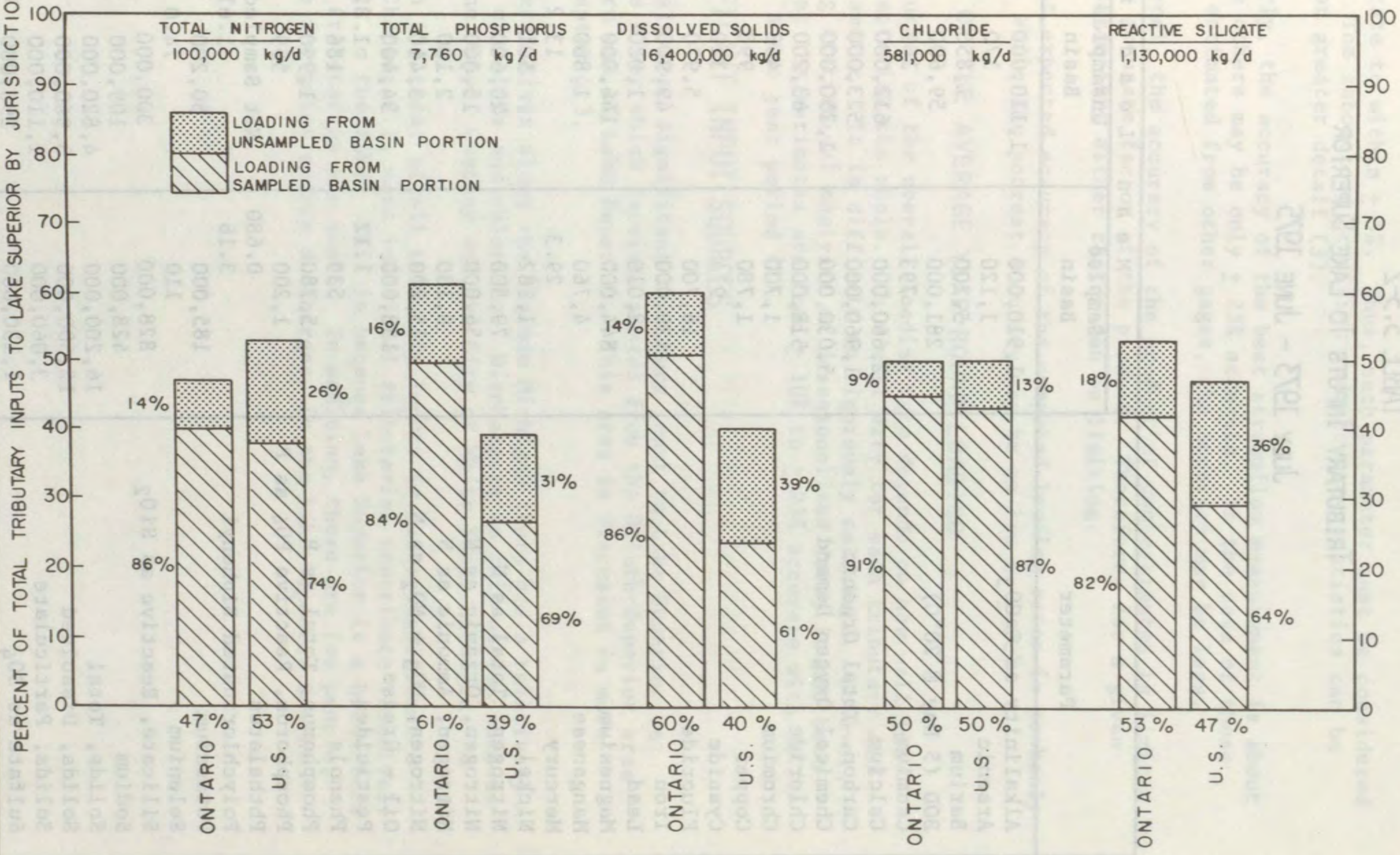


TABLE 3.3-2

TRIBUTARY INPUTS TO LAKE SUPERIOR

JULY 1973 - JUNE 1975

Parameter	Mean Loading (kg/d)		
	Sampled Basin	Unsampled Basin	Total
Alkalinity as $CaCO_3$	1,910,000	1,110,000	3,020,000
Arsenic	1,120	170	1,290
Barium	5,200	1,850	7,050
BOD (5 Day @ 20°C)	281,000	59,600	340,000
Cadmium	793	169	962
Calcium	2,660,000	612,000	3,270,000
Carbon, Total Organic	1,960,000	523,000	2,490,000
Chemical Oxygen Demand	5,030,000	1,250,000	6,280,000
Chloride	518,000	63,200	581,000
Chromium	1,700	468	2,170
Copper	1,780	998	2,780
Cyanide	974	310	1,280
Fluoride	16,700	5,970	22,600
Iron	129,000	49,900	179,000
Lead	2,010	1,020	3,030
Magnesium	844,000	146,000	990,000
Manganese	4,760	1,860	6,620
Mercury	29.3	13.2	42.5
Nickel	1,182	501	1,680
Nitrogen, Total as N	79,500	20,600	100,000
Nitrogen, Organic as N	56,000	15,000	71,000
Nitrogen, Ammonia as N	8,130	2,100	10,200
Nitrogen, $NO_3 + NO_2$ as N	15,200	3,410	18,600
Oil - Grease	153,000	34,400	187,000
Pesticides	1.12	1.87	2.99
Phenols	539	186	725
Phosphorus, Total as P	5,780	1,990	7,760
Phosphorus, Reactive PO_4 as P	1,200	559	1,760
Phthalates	0.680	Not Sampled	0.680
Polychlorinated Biphenyl	3.16	1.61	4.77
Potassium	185,000	50,200	236,000
Selenium	110	74.0	184
Silicate, Reactive as SiO_2	828,000	300,000	1,130,000
Sodium	428,000	109,000	537,000
Solids, Total	16,200,000	4,820,000	21,000,000
Solids, Dissolved	12,500,000	3,960,000	16,400,000
Solids, Particulate	3,060,000	1,110,000	4,170,000
Sulfate as SO_4	1,130,000	296,000	1,430,000
Zinc	2,720	1,040	3,760

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

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 single most significant tributary input to Lake Superior is the St. Louis River which receives wastes from the Duluth-Superior area at the western end of Lake Superior. This area is discussed in more detail in Chapter 4.3.

The Mineral River along the western Michigan shore has a relatively high loading of solids and chlorides. Dischargers to this stream include the White Pine Copper Company and the City of White Pine, Michigan.

Although the total of all tributary inputs is quite significant as shown in Chapter 3.1, most individual tributaries contribute relatively small loadings to the lake. This is because Lake Superior is a headwaters lake and its tributaries are small. In addition, there are few people, and therefore few point source discharges, in the Lake Superior Basin.

TABLE 3.3-2

[illegible]

JULY 1973 - JUNE 1975

Parameter	[illegible] Basin	[illegible] Basin	Total
Alkalinity	[illegible]	[illegible]	[illegible]
Arsenic	1,120	170	1,290
Barium	[illegible]	[illegible]	[illegible]
BOD (5 Day @ 20°C)	281,000	59,600	340,000
Cadmium	[illegible]	[illegible]	962
Calcium	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Chloride	[illegible]	[illegible]	[illegible]
Chromium	[illegible]	[illegible]	[illegible]
Copper	1,780	998	2,780
Cyanide	[illegible]	[illegible]	[illegible]
Fluoride	16,700	5,970	22,600
Iron	[illegible]	[illegible]	179,000
Lead	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Manganese	4,760	[illegible]	[illegible]
Mercury	29.3	13.2	42.5
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Nitrogen, Ammonia as N	8,130	2,100	10,200
[illegible]	[illegible]	[illegible]	15,600
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	2.99
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Phosphorus, Reactive PO4 as P	1,200	559	1,760
Phthalates	0.680	Not Sampled	0.680
Polychlorinated Biphenyl	3.16	1.61	4.77
Potassium	[illegible]	50,200	236,000
Selenium	110	74.0	184
Silicate, Reactive as SiO_2	[illegible]	300,000	1,130,000
Sodium	[illegible]	109,000	537,000
Solids, Total	[illegible]	4,820,000	21,000,000
Solids, Dissolved	[illegible]	3,960,000	16,400,000
Solids, Particulate	[illegible]	1,110,000	4,170,000
Sulfate as SO_4	[illegible]	296,000	1,430,000
Zinc	[illegible]	1,040	3,760

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

3.4 ATMOSPHERIC INPUTS

The term "bulk precipitation" is used to describe the total of wet deposition via rain and snowfall, plus dry deposition through particulate fallout and gas adsorption. The study of its effect on lakes is a relatively new area of research. Most results have come from recent studies in Scandinavia and selected regions of Canada and the United States. Early studies were mainly concerned with acid rainfall. Recent studies of atmospheric loadings, including the present study of the Upper Lakes, are also considering nutrient, particulate, and metallic loadings. Atmospheric inputs have a particularly significant impact in Lake Superior since precipitation directly to the lake surface accounts for 54% of the lake's water supply.

These inputs are also of particular significance because of the lesser buffering capacity of Lake Superior water. The impacts from atmospheric inputs have been observed in many of the low-buffered Canadian Shield lakes adjacent to metal smelting areas. In these areas, pH shifts and metal toxicity have totally changed lake population structure (1).

Emissions to the atmosphere are categorized by air pollution source regions. These regions are defined by the U.S. Environmental Protection Agency (EPA) and the Ontario Ministry of the Environment (MOE) for measurement of emissions data. Twenty-two U.S. source regions and eleven Canadian source regions were considered to have impact on Lake Superior loadings. Percentage loadings of sulphate, phosphate, and trace metals which ultimately reach Lake Superior from each source region are shown in Table 3.4-1(2). These percentages provide numerous indications of the long range transport of materials. Contributions to Lake Superior from distant source regions often exceed those from nearby sources. For example, the contributions of trace metals from Chicago or Cincinnati reaching Lake Superior are each greater than the contribution from northern Michigan.

ESTIMATES OF ATMOSPHERIC LOADINGS

Estimates of yearly deposition to Lake Superior are shown in Table 3.4-2. These are best estimates derived primarily from data from the present study as compiled by Acres (2). These tabular values are shown for the eastern and western portions of the lake (87° 50' west longitude is the dividing line). Comparison of this atmospheric component of loading to the total of all inputs to the lake is found in Chapter 3.1.

TABLE 3.4-1

PERCENT OF LOADINGS TO LAKE SUPERIOR BY AIR POLLUTION SOURCE REGION[a]

Air Pollution Source Region[b]	Percent of Total Atmospheric Loading		
	Sulphate	Phosphorus	Trace Metals[c]
Saginaw	4.1	2.1	4.8
Detroit	3.3	3.6	5.5
Port Huron	1.1	0.4	0.5
Lower Michigan	0.8	0.8	1.7
Northern Michigan	2.4	6.1	8.8
St. Louis	7.2	5.2	7.2
Chicago	6.2	13.5	9.8
Central Illinois	5.1	3.7	4.4
Green Bay	2.6	4.5	3.5
Milwaukee	2.3	4.0	3.2
Wisconsin	1.4	5.2	2.4
Duluth	2.2	7.7	3.3
Minneapolis	2.1	2.4	2.5
Toledo	2.0	2.8	4.4
Cleveland	1.8	2.0	2.9
Cincinnati	6.5	7.6	10.4
Ohio	2.1	2.5	4.5
Pittsburgh	3.6	1.1	3.0
Pennsylvania	0.9	0.9	1.9
Rochester	0.1	0.2	0.3
Buffalo	<0.1	0.2	0.2
S.W. New York	0.1	0.1	0.2
Montreal	0.4	3.7	0.9
Toronto	1.2	1.7	0.5
Sarnia	1.1	0.1	0.1
Sudbury	13.0	0.2	0.1
Thunder Bay	2.6	4.3	2.3
Nanticoke	0.2	<0.1	<0.1
Noranda	2.5	0.5	0.3
Sault Ste. Marie	0.6	3.1	4.4
Northern Ontario	19.0	1.6	4.9
Southern Ontario	<0.1	0.5	0.4
Manitoba	1.5	7.7	0.7

a. From Reference (2).

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

c. Cd, Cu, Fe, Ni, Pb

TABLE 3.4-2

ATMOSPHERIC LOADINGS TO LAKE SUPERIOR

Parameter	Loadings, In Tonnes Per Year[a]		
	East	West	Total
Nitrogen (NO_3 + NH_3 as N)	38,000	18,000	56,000
Total Phosphorus	344	456	800
Total Dissolved Solids[b]	68,000	52,000	120,000
Chloride	36,000	19,000	55,000
Reactive Silicate (as SiO_2)	15,000	11,000	26,000
Calcium	15,000	18,000	33,000
Sodium	5,000	10,000	15,000
Magnesium	3,800	1,800	5,600
Potassium	5,000	8,000	13,000
Iron	7,600	2,100	9,700
Lead	360	290	650
Copper	230	140	370
Nickel	67	53	120
Cadmium	43	12	55
Particulate Solids	25,000	16,000	41,000

a. All parameters were determined from actual measurements except for particulate solids values which were calculated from mathematical model results (2).

b. Calculated from conductivity measurements by multiplying by 0.65.

Atmospheric samples were collected by three sampling networks operated by 1) McMaster University, 2) Canada Centre for Inland Waters, and 3) Michigan Department of Natural Resources (with chemical analyses by U.S. EPA). These data were used with the atmospheric transport-deposition models prepared by Acres (2) and Moroz (3) to estimate atmospheric loadings.

The locations of sampling stations are shown in Figure 3.4-1. 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 to June 1975.

Mathematical models were constructed by Acres (2) and Moroz (3). 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 Gaussian plume, coupled with Pasquil-Gifford diffusion curves. Both models use U.S. EPA and MOE source strength data.

ACCURACY OF ESTIMATES

The quantitative loading estimates were obtained from a summary of the experimental measurements with the 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 four laboratories. Several modes of comparison were utilized -- comparison of modelled versus measured results, comparison of winter versus summer results, interlaboratory analytical comparisons, and intercomparison of sample collector types.

Comparisons of modelled versus measured results provide excellent agreement where accurate, adequate emission data are available for model input. Sulphate and nitrate deposition were the most accurate of predicted values. Model results for other parameters, including chlorides and total phosphorus, were poorly predicted, likely due to lack of source emissions strength information.

Higher deposition of all parameters occurs during 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 phosphorus loadings shown in Table 3.4-2 are a modification of the measured data summarized by Acres (2). Because summer bulk sampler measurements were subjected to local source errors, the data were not considered representative of over-lake deposition. Studies by Delumyea (5) 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.

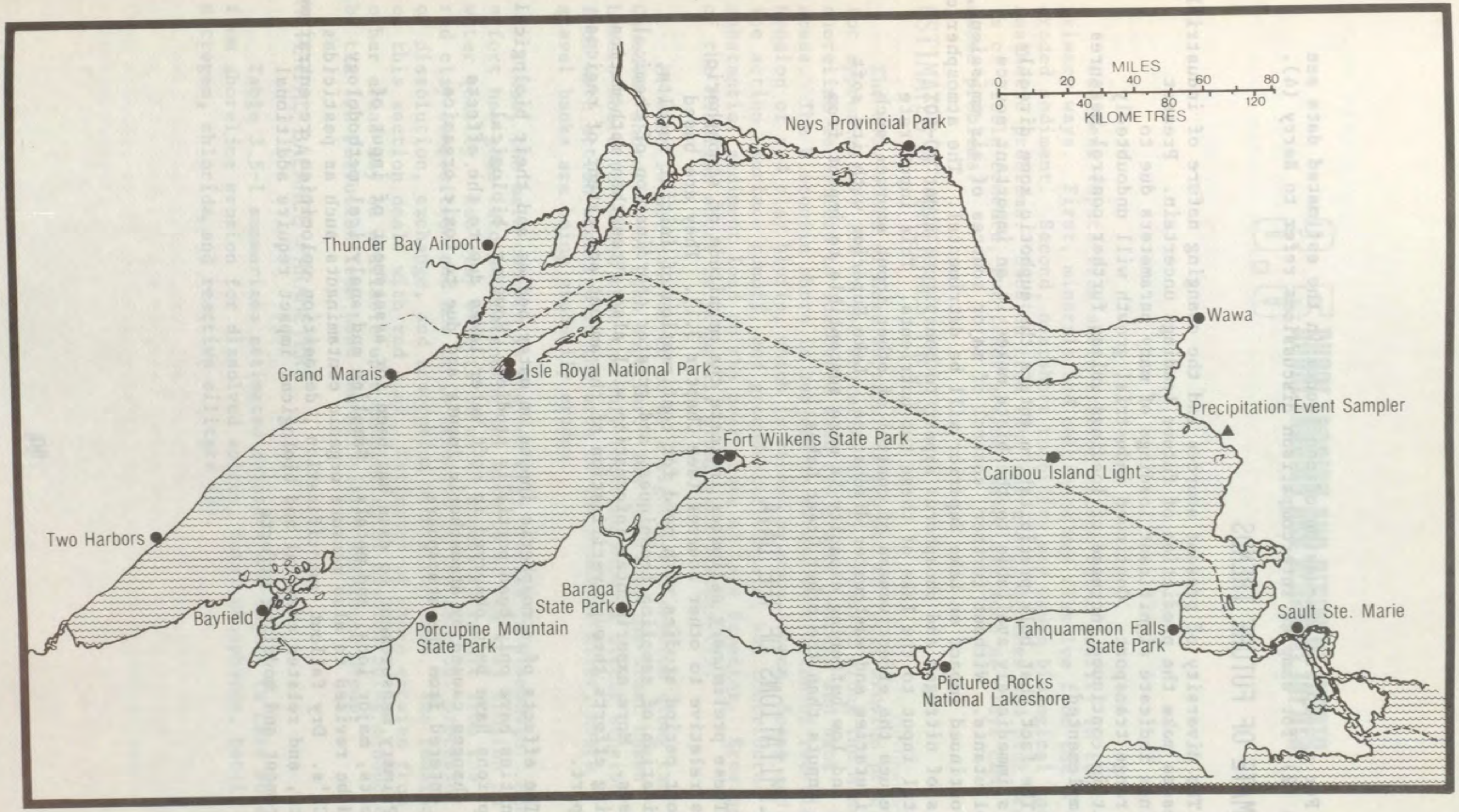


FIGURE 3.4-1   PRECIPITATION CHEMISTRY SAMPLING NETWORK FOR LAKE SUPERIOR

For a complete discussion of confidence in the estimated data see Acres (2); for sampler intercomparison discussions refer to Berry (4).

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 Superior will be detrimental. The atmospheric inputs of nitrogen and phosphorus appear to constitute about 20-60% of 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. Lake Superior with its soft water and low buffering capacity is more susceptible to impact from these inputs than the other Great Lakes.

THE LIMITATIONS OF THE DATA

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

The effects of atmospheric inputs on water bodies and their biological communities have only been partially studied. 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 modeling efforts.

3.5 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 Superior is subject to local erosion problems for approximately 20% of the shoreline (1, 2). Erosion along the Minnesota shoreline is limited to scattered sand and gravel beaches and bank areas. The Wisconsin shore is subject to extensive erosion of red clay. Erosion of red clay bluffs, which is caused by wave action, frost and ice action, surface runoff, and groundwater seepage, has contributed substantial sediment load to the near shore of Lake Superior. Erosion of the Michigan shore is primarily along sand beaches (1).

Erosion is not considered to be a significant problem along the Canadian shoreline of Lake Superior. The report of the Great Lakes Levels Board (2) noted that the only location showing direct erosion from wave action occurred in the area of the Montreal River, where gravel banks are being gradually eroded.

Thus, the main concern is the red clay erosion in Wisconsin. Much effort has gone into understanding the effects of red clay erosion on water quality. Red clay effects on water chemistry result from the red clay composition and how it is affected by the chemical processes of dissolution, exchange, and adsorption within the lake. The remainder of this section deals with red clay. Estimates of shore erosion from other areas may be available upon completion of studies being conducted by the IJC Pollution from Land Use Activities Reference Group.

MATERIAL BALANCE PARAMETERS

Table 3.5-1 summarizes estimated releases and inputs to Lake Superior from shoreline erosion for dissolved solids, total phosphorus, total nitrogen, chloride, and reactive silicate (7).

TABLE 3.5-1

LAKE SUPERIOR INPUTS FROM SHORE EROSION FOR MATERIAL BALANCE PARAMETERS

Parameter	Chemical Release from Clays (mg/g of Sample)	Shore Erosion Inputs (t/a)
Total Dissolved Solids	24 ± 3	192,000 ± 40,000
Total Phosphorus (as P)	0.036 ± 0.020	280 ± 160
Total Nitrogen (as N)	<0.2	<1,600
Chlorides	<0.1	< 800
Reactive Silicate (as SiO_2)	1.8 ± 0.4	14,400 ± 3,200

OTHER PARAMETERS

Table 3.5-2 summarizes the estimated releases and inputs to Lake Superior from shoreline erosion for alkalinity, reactive phosphate, nitrate, sodium, potassium, calcium, and magnesium.

DESCRIPTION OF METHODS OF ESTIMATION

Two independent studies by Hess and Sydor have yielded comparable results in estimating sediment input from the red clay shoreline. Hess (4) used aerial photographs and actual shoreline observations to determine bluff profiles and recession rates. His calculated rate of erosion for the recent past in this area is 3.8×10^6 t/a. Hess estimated that this value accounts for somewhat less than half of the total erosion on Wisconsin's shoreline. Hence, the figure of 8×10^6 t/a was used as an estimate for the total erosion input of sediments.

Sydor's work (3,5,6) covered only the Douglas County portion of Wisconsin shoreline. Hess' estimate for this area is 2×10^6 t/a. Sydor used two methods to arrive at comparable, although slightly lower, estimates. His methods were based on measuring the amount of turbidity in the lakewater.

First, estimates of suspended material in turbidity plumes were made using ERTS image data and shore turbidity measurements. These values were used to determine the estimate of material eroded per storm. The average number of storms (five large storms and six to ten medium storms per year) was then used to calculate the annual inputs. This method yielded an upper value of 2×10^6 t/a, and an average value of 1.5×10^6 t/a, for Douglas County.

The second method involved considering the average turbidity due to suspended fines and dispersion rates for plumes. Satellite observations which pertain to random monitoring of the last part of turbidity events were combined with estimated removal rates for suspended fines. Compensation for re-suspension of sediment yielded an average shoreline erosion rate for Douglas County of 1.4×10^6 t/a.

Determinations of chemical release rates into Lake Superior waters from red clay soil involved two, seven-week leaching experiments using Lake Superior water. Details are explained in reference (7).

EVALUATION OF THE ACCURACY OF THE ESTIMATES

It is significant that three different methods developed in two independent studies have yielded fairly close results in estimating annual sediment inputs to Lake Superior from the red clay shoreline. However, the estimates are based on recent data and therefore may not represent long-term mean values. Hess' work (although based upon questionable records) indicates that over the 114-year period from 1852 to 1966, 47% of the total erosion occurred during the 28 years from 1938 to 1966. Such a change could result from causes such as interference of man or climatic changes.

TABLE 3.5-2

LAKE SUPERIOR INPUTS FROM SHORELINE EROSION FOR MISCELLANEOUS PARAMETERS

Parameter	Chemical Release from Clays (mg/g of Sample)	Shore Erosion Inputs (t/a)
Alkalinity ($CaCO_3$)	23 ± 2	184,000 ± 40,000
Reactive Phosphate (as PO_4)	0.030 ± 0.010	240 ± 80
Nitrate (as NO_3)	0.05 ± 0.05	400 ± 400
Sodium	0.25 ± 0.20	2,000 ± 1,600
Potassium	0.42 ± 0.15	3,400 ± 1,200
Calcium	6 ± 3	48,000 ± 24,000
Magnesium	0.9 ± 0.4	7,200 ± 3,200

The accuracy of the estimates of chemical inputs are, of course, dependent on both the sediment input estimates and estimates of chemical release. The accuracy of the chemical release estimates has not been determined.

ESTIMATE OF FUTURE TRENDS

Due to the uncertainties associated with the change in erosion rates over the study period considered by Hess (4), no estimate of future trends is possible. If current climatic conditions are representative of a long-term norm, and if the extent of human impact does not change, sediment input should also remain about the same. However, the studies performed by Sydor (3) demonstrate that the amount of red clay eroded and resuspended during storms far exceeds that eroded due to changes in lake levels.

Parameter	Chemical Release from Clays ([illegible])	Shore Erosion Inputs (t/a)
Alkalinity ($CaCO_3$)	25 ± 2	184,000 ± 40,000
Reactive Phosphate (as PO_4)	0.030 ± 0.010	240 ± 80
Nitrate (as NO_3)	0.05 ± 0.05	400 ± 400
Sodium	0.25 ± 0.20	2,000 ± 1,600
Potassium	0.42 ± 0.15	3,400 ± 1,200
Calcium	6 ± 3	48,000 ± 24,000
Magnesium	0.9 ± 0.4	7,200 ± 3,200

3.6 THERMAL INPUTS

The largest single industrial use of Great Lakes water is for cooling steam condensers in electric power plants. Table 3.6-1 lists operational data for existing and committed thermal power plants which discharge cooling water to Lake Superior. All of these plants are powered by fossil fuel. Due to the availability of hydroelectric generation in northern Ontario, there is only one steam generating plant in Ontario now discharging to Lake Superior. This is the Thunder Bay Generating Station on Mission Island. There are ten steam electric plants located on the U.S. shoreline discharging to Lake Superior. The largest units (Presque Isle Units 5-9, Reserve Mining, and Taconite Harbor) furnish power for the iron mining industry.

AMOUNT OF HEAT DISCHARGED

As shown in Table 3.6-1, the average total heat discharge to Lake Superior has been about 750 MW between 1971 and 1975. These electrical generating plants have to cease operation periodically for routine maintenance or 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 power plants is slightly over 1000 MW. After the new plants start operating, the potential heat discharge will be about 1800 MW.

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

FUTURE INPUTS

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.

TABLE 3.6-1

THERMAL POWER PLANTS ON LAKE SUPERIOR

Plant Name	Location	Number of Units	Total Generating Capacity (MW electric)	Maximum Design Heat Discharge (MW)	Average Operating Capacity (% of Maximum) (1971-1975)	Average Heat Discharge (MW)
Ontario						
Thunder Bay, Unit 1	Thunder Bay	1	100	142	26.6[a]	38
Thunder Bay, Units 2 and 3 (operational 1980)	Thunder Bay	2	300	470	-	-
Minnesota						
Reserve Mining Company	Silver Bay	2	128	189	b	b
Taconite Harbor	Taconite Harbor	3	225	252	62.0	156
Two Harbors Water & Light	Two Harbors	1	8	3.7	20.8	0.7
Hibbard S.E. Station	Duluth	4	125	261	33.1	87
Wisconsin						
Bayfront	Ashland	6	82	39	38.0	15
Winslow	Superior	2	25	26	41.4	16
Michigan						
Presque Isle (Units 1-6)	Marquette	6	339	548	71	388
Presque Isle (Units 7-9) (operational 1976-1978)	Marquette	3	241	431	-	-
Shiras	Marquette	2	34	31	48	15
Shiras (Unit 3) (operational 1980)	Marquette	1	43	77	-	-
Warden	L'Anse	1	16	40	70	28
Hoerner-Waldorf	Ontonagon	1	9.3	0.2	b	b
Proposed Hoerner-Waldorf (operational 1979)	Ontonagon	2	20		-	-

a. For 1971 - 1974
b. Information not available

3.7 RADIOACTIVITIY INPUTS

PRESENT INPUTS

Radioactivity inputs to Lake Superior arise from two different sources: fallout from nuclear weapons testing and weathering of naturally radioactive minerals. The amount of radioactivity, primarily strontium 90, from weapons testing, is dependent on the number of atmospheric tests conducted.

There are no existing nuclear plants or any facilities under construction on Lake Superior. Therefore, no estimates of radioactive inputs are presented here.

FUTURE INPUTS

A number of potential power plant sites on the Ontario shore of Lake Superior were investigated in 1973 and 1974 for the location of a nuclear-fueled plant of 2,000 MW of electric generating capacity. The nuclear plant is not considered likely until after 2000, and no detailed site selection has been undertaken. In Michigan's Upper Peninsula there are plans for expansion of both the iron and copper mining industry which may require 200 MW of electric generating capacity. A plant to supply this power could be nuclear, but this is highly speculative.

TABLE 3.6-1

THERMAL POWER PLANTS ON LAKE SUPERIOR

Plant Name	Location	Number of Units	Total Generating Capacity (MW)	Maximum Design Heat Discharge (MW)	Average Operating Capacity (% of Maximum) (1971-1975)	Average Heat Discharge (MW)
Ontario						
Thunder Bay, Unit 1	Thunder Bay	[illegible]	[illegible]	[illegible]	26.6^a	38
Thunder Bay, Units 2 and 3 (Operational 1980)	Thunder Bay	[illegible]	[illegible]	[illegible]	-	-
Minnesota						
Reserve Mining Company	Silver Bay	[illegible]	[illegible]	[illegible]	b	b
Taconite Harbor	Taconite Harbor	[illegible]	[illegible]	[illegible]	62.0	156
Two Harbors Water & Light	Two Harbors	[illegible]	[illegible]	[illegible]	20.8	0.7
Hibbard S.E. Station	Duluth	[illegible]	[illegible]	[illegible]	33.4	67
Wisconsin						
Bayfront	Ashland	[illegible]	[illegible]	[illegible]	36.0	15
Winslow	Superior	[illegible]	[illegible]	[illegible]	41.4	18
Michigan						
Presque Isle (Units 1-6)	Marquette	[illegible]	[illegible]	[illegible]	71	388
Presque Isle (Units 7-9) (operational 1976-1978)	Marquette	[illegible]	[illegible]	[illegible]	b	b
Mitras	Marquette	[illegible]	[illegible]	[illegible]	[illegible]	15
Shiras (Unit 3) (operational 1983)	Marquette	[illegible]	[illegible]	[illegible]		
Warden	L'Anse	[illegible]	[illegible]	[illegible]		28
[illegible]-Waldorf	Ontonagon	[illegible]	[illegible]	[illegible]		4
Proposed [illegible]-Waldorf (operational 1979)	Ontonagon	[illegible]	[illegible]	[illegible]		-

a. For 1971 - 1974
b. Information not available

3.8 DREDGING

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

Dredging is conducted irregularly on Lake Superior 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 3.8-1 and shown on Figure 3.8-1.

Maintenance dredging is concentrated at three locations: Duluth-Superior Harbor; Ashland, Wisconsin: and Thunder Bay, Ontario. Duluth-Superior Harbor and Ashland produce 97% of the polluted dredged material from U.S. harbours. Wisconsin and Minnesota have both opposed the disposal of polluted dredged material in Lake Superior. Efforts are being made to require on-land disposal facilities for both of these harbours.

Thunder Bay produces 73% of all Canadian maintenance dredging on Lake Superior. During the past three years, dredging in the bay, which is considered to be polluted by organic materials and mercury, has been minimized, and there has been no open lake disposal of dredged material. A diked disposal area for future dredging is under design.

ESTIMATES OF LOADINGS

The U.S. Environmental Protection Agency (EPA) surveyed all significant U.S. harbours on Lake Superior to determine the chemical quality of maintenance dredgings. The concentrations used in this loading 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).

TABLE 3.8-1

MAINTENANCE DREDGING IN LAKE SUPERIOR (1,2)

HARBOURS	VOLUME (m^3/a)	PERCENT POLLUTED	POLLUTED VOLUME (m^3/a)
UNITED STATES			
Ashland, Wisconsin	46,000	100	46,000
Bayfield, Wisconsin	0	10	0
Big Bay, Michigan	3,500	10	350
Black River, Michigan	2,000	0	0
Cornucopia, Wisconsin	1,500	100	1,500
Duluth-Superior, Minnesota-Wisconsin	607,000	33	203,000
Eagle Harbor, Michigan	0	0	0
Grand Marais, Michigan	0	0	0
Grand Marais, Minnesota	500	0	0
Grand Traverse, Michigan	4,000	10	400
Keweenaw Waterway, Michigan	23,000	0	0
Knife River, Minnesota	200	100	200
Lac La Belle, Michigan	2,000	0	0
LaPointe, Wisconsin	0	0	0
Little Lake, Michigan	25,000	0	0
Marquette, Michigan	26,000	0	0
Ontonagon, Michigan	35,000	10	3,500
Port Wing, Wisconsin	3,000	10	300
Presque Isle, Wisconsin	9,000	30	2,700
Saxon, Wisconsin	5,000	0	0
Two Harbors, Minnesota	600	0	0
Whitefish Point, Michigan	1,200	10	100
Total	794,500		258,000
CANADA			
Michipicoten	700	–	–
Parke Township	44,800	–	–
Thunder Bay	141,000	–	–
Whitefish Bay	6,700	–	–
Total	193,200		

Total phosphorus in nonpolluted sediments from Duluth-Superior and Ashland Harbors averaged 378 mg/kg and total Kjeldahl nitrogen averaged 465 mg/kg (3). The total nonpolluted dredging in U.S. harbours is 536,000 m^3/a. It is assumed that no polluted dredgings will be disposed of in the lake. Although the same type of information is not available for Canadian dredging, the following loading calculations have been made for U.S. dredging.

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

Total phosphorus: Loading = $536 \times 1700 \times 378 \times 10^{-6} = 344$ t/a

Total Kjeldahl nitrogen: Loading = $536 \times 1700 \times 465 \times 10^{-6} = 423$ 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. U.S. EPA and the U.S. 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 6.9).

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.

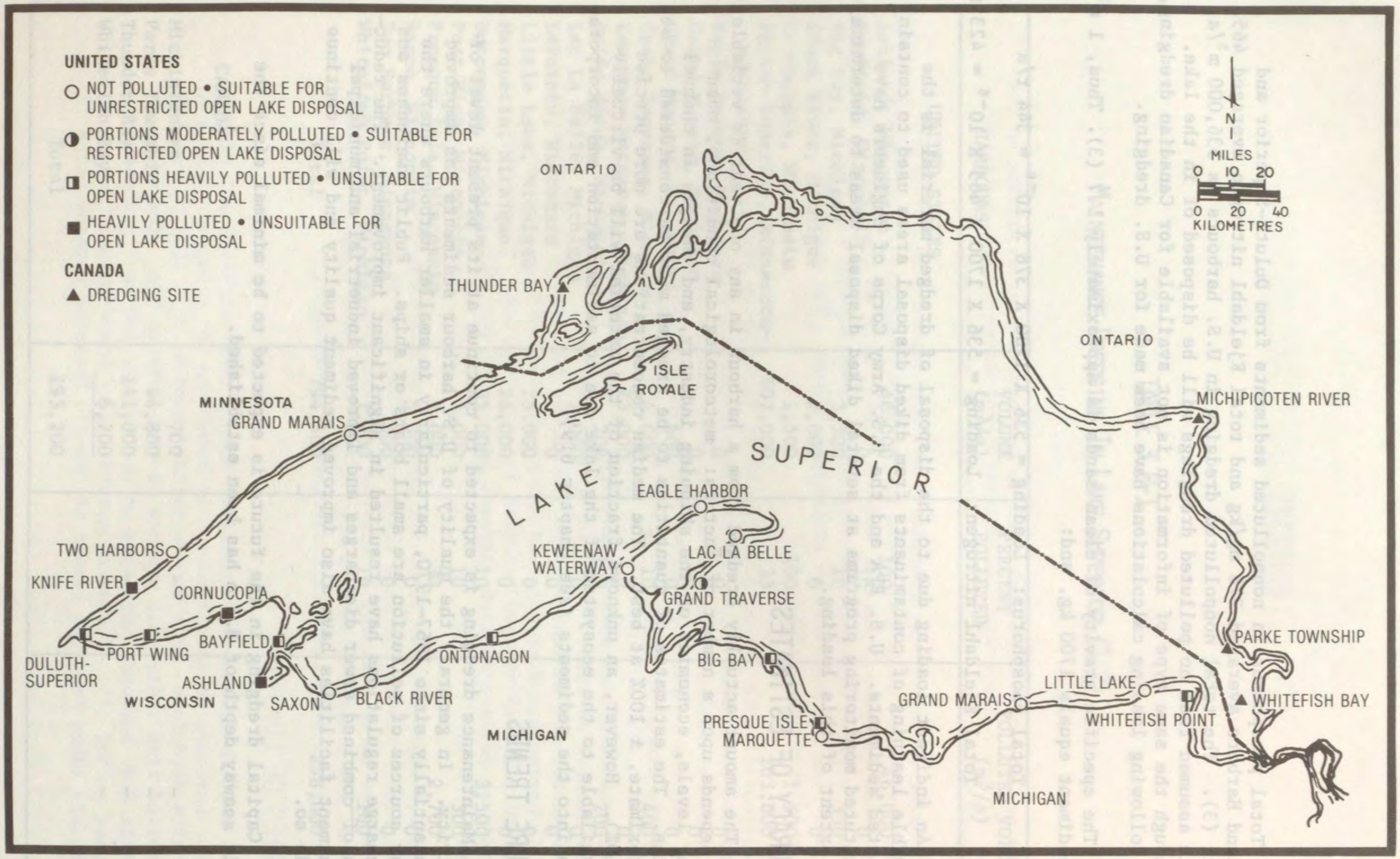


FIGURE 3.8-1 DREDGING SITES ON LAKE SUPERIOR

3.9 VESSEL WASTE DISCHARGES

TYPES OF DISCHARGES

Vessels can be broadly classed as commercial or recreational. Each class contributes to the pollutant load entering Lake Superior. 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 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 Superior 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 Superior as specified by Michigan, Minnesota, 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 3.9-1, based on estimates in Table 3.9-2. 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 solid waste, operational waste, or functional waste. However, most material balance inputs originate from the black and gray water or salt water ballast.

TABLE 3.9-1

ESTIMATED ANNUAL INPUTS FROM VESSELS TO LAKE SUPERIOR

	LOADING, IN TONNES PER YEAR				
	CANADA		U.S.		
PARAMETER	Black and Gray Water	Ballast	Black and Gray Water	Ballast	Total
Chloride	8.2	2,780	20.6	8,500	11,300
Total Phosphorus	0.5	--	1.27	--	1.77
Total Nitrogen	1.6	--	4.1	--	5.7
Total Dissolved Solids	56.9	5,120	142	15,700	21,000
Reactive Silicate (as SiO_2)	1.6	--	3.89	--	5.49

TABLE 3.9-2

ANNUAL INPUTS OF WASTE CATEGORIES TO LAKE SUPERIOR

WASTE CATEGORY	CANADA	U.S.	TOTAL
PERSONAL			
Black and Gray Water	52,700 kℓ	131,600 kℓ	184,300 kℓ
Solid Waste	168 t	463 t	631 t
OPERATIONAL			
Bilges (steamships)	43,200 t	139,900 t	183,000 t
Bilges (motorships)	4,500 t	8,600 t	13,100 t
FUNCTIONAL			
Cargo Spillage	14,900 t	86,800 t	101,700 t

Other significant parameters discharged are oil, pathogens, and flotsam. It is estimated that 3.9 t of oil is discharged to the lake annually. Cargo spillage represents 102,000 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 Superior 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 Superior ports would remain in Lake Superior three days (two days in transit and one day in port).

The calculations were made as follows:

Black & Gray Waters

Volume discharged =

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

Solid Waste

Amount discharged =

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

Bilge Waste (For steamships and motor vessels)

Amount of waste =

Vessel days x percentage of steamships x tons of waste discharged

Cargo Spillage

Amount of spilled cargo =

Tons 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. Values for the following five parameters are based on values for sewage from Michigan cities and are considered to be acceptable values for sewage from vessels. The ranges of variation for each of the five parameters are ± 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.

Other significant parameters discharged [illegible]. It is estimated that 3.9 t of oil is discharged to the lake annually. Cargo spillage represents 102 000 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. Garbage can be a serious problem especially in port areas.

BASIS OF ESTIMATION

Assumptions and information used to estimate loadings from vessels to Lake Superior 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 [illegible] basis of calculation (3).

It was considered that all vessels entering Lake Superior ports would remain in Lake Superior three days (two days in transit and one day in port).

The calculations were made as follows:

Black & Gray Water

Volume discharged =

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

Solid Waste

Amount discharged =

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

Bilge Waste (For steamships and motor vessels)

Amount of waste =

Vessel days x percentage of steamships x tons of waste discharged

Cargo Spillage

Amount of spilled cargo =

Tons 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 =

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

3.10 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 Superior 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 Superior. However, an educated guess can be made as described below.

The U.S. Army Corps of Engineers projected that in 1975 about 648,000 t of petroleum and about 83,000 t of chemicals would be carried to ports in the U.S. portion of Lake Superior. These amounts were expected to increase by 1980 to about 727,000 t of petroleum and about 91,000 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 Superior would have been 648 t of petroleum and 83 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.

3.11 PROJECTED FUTURE WASTE LOADINGS

WASTE LOAD SIMULATION MODEL

DESCRIPTION OF MODEL

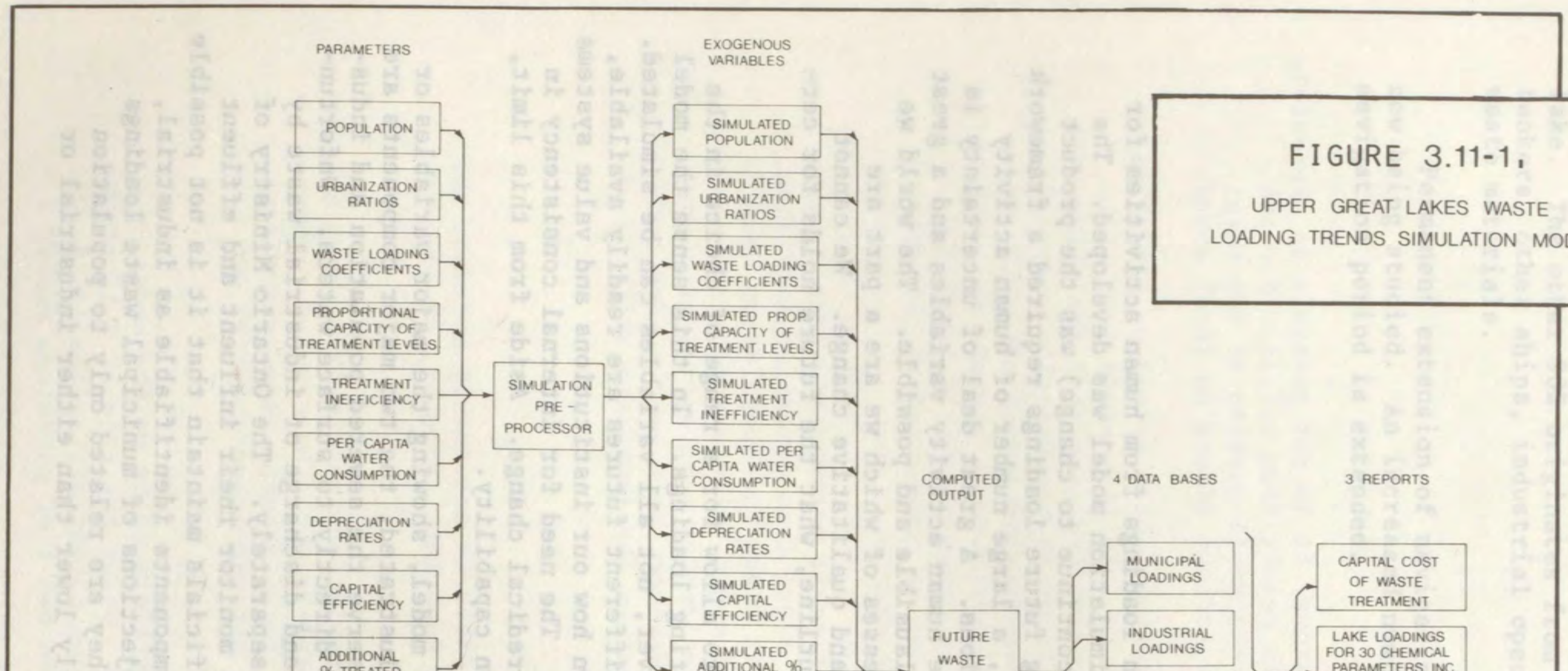
In order to examine future trends in loadings from human activities for their possible impact on the lakes, a simulation model was developed. The model that ultimately evolved (and will continue to change) was the product of many things. The questions concerning future loadings required a framework involving 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 3.11-1 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 3.11-1.

UPPER GREAT LAKES WASTE LOADING TRENDS SIMULATION MODEL



INFORMATION SOURCES

The basic data requirements can be seen in Figure 3.111. 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 3.11-1. For example, the generation of municipal waste loadings by the model is easily followed in Figure 3.11-1. 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 3.11-2 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 3.11-1 shows present and projected total loadings to Lake Superior 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 3.11-2, 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 3.11-2: 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

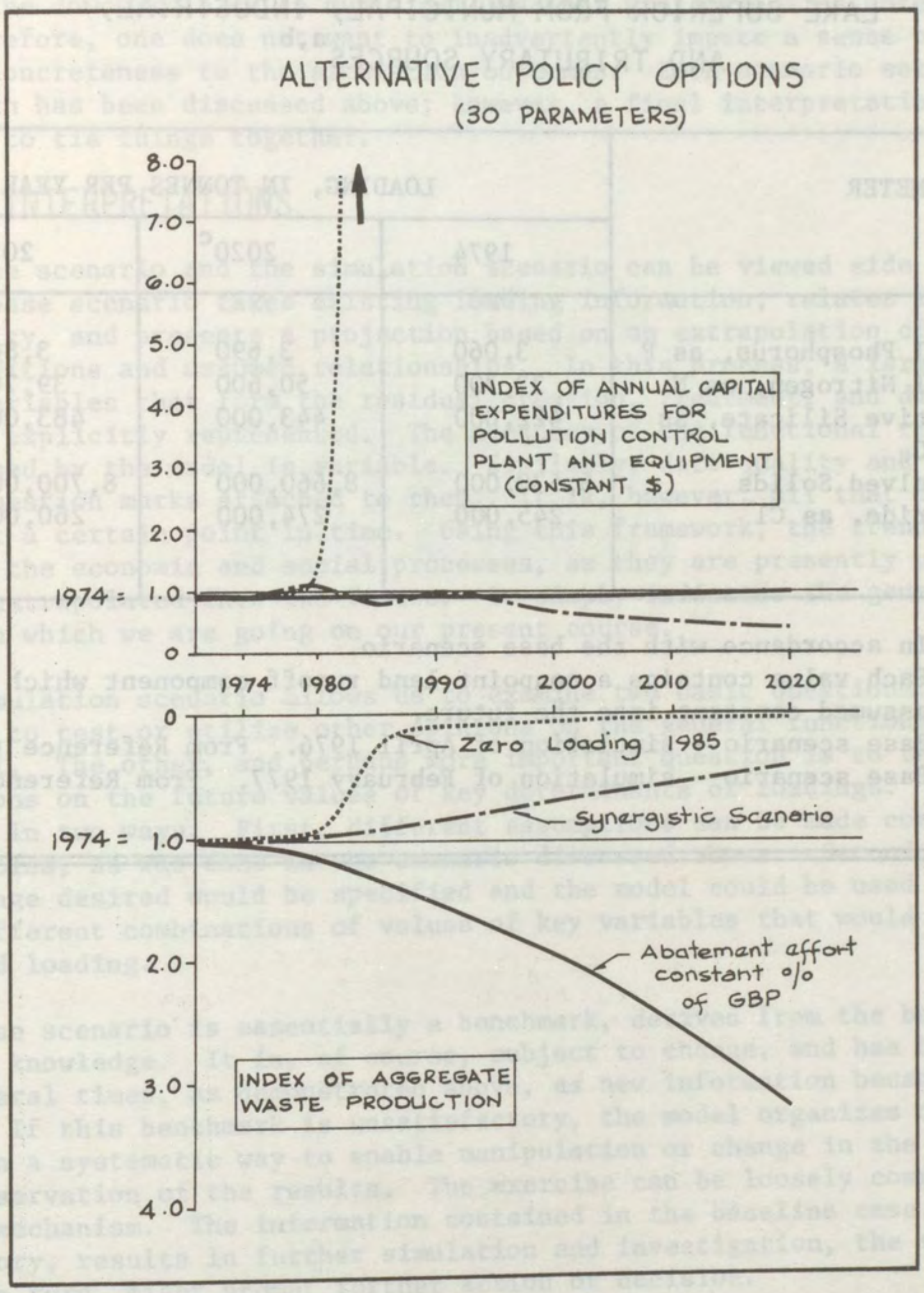


FIGURE 3.11-2.
SCHEMATIC COMPARISON OF RELATIVE CHANGE IN CAPITAL EXPENDITURES AND IN AGGREGATE WASTE PRODUCTION FOR THREE SCENARIOS.

TABLE 3.11-1

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

PARAMETER	LOADING, IN TONNES PER YEAR		
	1974	2020[c]	2020[d]
Total Phosphorus, as P	3,060	3,690	3,860
Total Nitrogen, as N	37,700	50,600	39,700
Reactive Silicate, as SiO$_2$	422,000	443,000	483,000
Dissolved Solids	6,530,000	8,660,000	8,700,000
Chloride, as Cl	245,000	274,000	260,000

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

graphy. 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.

4.0 INTRODUCTION

Chapter 4 deals with the studies of the nearshore waters of Lake Superior. 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 Superior Coastal and Embayments
4.2 Thunder Bay
4.3 Duluth-Superior Harbor
4.4 Silver Bay
4.5 Neashore-Offshore Exchange

The first four subchapters each contain a description of the limnological characteristics - physical, chemical, and biological - plus a summary of existing and developing problems. Chapter 4.5 is a commentary on the nearshore-offshore exchange of materials, leading up to the description of the open waters of Lake Superior in Chapter 5.

4.1 LAKE SUPERIOR COASTAL AND EMBAYMENTS

DESCRIPTION OF THE STUDY AREA

HYDROLOGY

Lake Superior, the largest of the St. Lawrence Great Lakes, is approximately 610 km long, 260 km wide, and 406 m maximum depth. The total surface area of the lake is 82,103 km^2, of which 28,749 km^2 is in Canada and 53,354 km^2 is in the U.S; the total volume of the lake is 11,920 km^3. About 83,916 km^2 of Canadian land drains into Lake Superior, whereas only 43,771 km^2 of U.S. land is in the drainage basin. The major river inflows on the Canadian side are the Kaministikwia River, Long Lac Diversion, Magpie River, Michipicoten River, Montreal River, Nipigon River, and White River.

The principal tributary in the Minnesota watershed is the St. Louis River, which enters the lake at Duluth. The second largest Minnesota tributary (forming the Minnesota-Ontario border) in terms of discharge is the Pigeon River. Two other rivers, representative of the many Minnesota north shore streams are the Gooseberry and Cascade Rivers.

The major Wisconsin tributaries to Lake Superior are the Bois Brule, Bad, Montreal, and Nemadji Rivers. The Michigan tributaries entering Lake Superior are the Montreal (forming the Wisconsin-Michigan border), Presque Isle, and Ontonagon Rivers.

The St. Marys River is the outlet for Lake Superior.

PHYSIOGRAPHY

Lake Superior collects water from precipitation on its surface and also from precipitation within the drainage basin. It has been suggested (1,2) that the chemical composition of Lake Superior water resembles that of rainwater since the drainage into the lake has little time to react with resistant Precambrian metamorphic rocks that underly the drainage basin. Most of the basin consists of Precambrian igneous and metamorphic rock. The topographic map of the lake bottom along the Canadian shore from the St. Marys River to Pigeon River has been constructed by Mothersill (3,4,5).

WASTE DISPOSAL AND WATER USAGE

Information regarding the usage of water for municipal and industrial consumption, recreation, fish propagation, and transportation, and for the disposal of sewage, industrial, and other wastes is documented in Chapter 1. Details about materials input to Lake Superior from municipal, industrial, and tributary sources are given in Chapter 3.

METHODS

STUDY PLAN

Investigations of water quality in the nearshore and embayment areas of Lake Superior were conducted by agencies of the three states and the province sharing its shoreline. The purpose of these studies was to undertake a systematic monitoring of the entire shoreline of the lake to determine the quality of water presently available, and to establish baselines against which future improvement or deterioration can be measured.

Information collected on physical, chemical, and biological aspects of water quality by the participating agencies is summarized in Table 4.1-1.

The Ontario Ministry of the Environment (MOE) carried out four cruises on the nearshore waters of Lake Superior between June 22 and November 9, 1973 (6). The nearshore program included stations from Whitefish Bay to Thunder Bay in a band generally ranging up to 8 km offshore (Figure 4.1-1). In addition to this, several intensive water quality surveys were undertaken in the following embayment areas: Peninsula Harbour (7), Jackfish Bay (8), Nipigon Bay (9), Black Bay (10), and Pine Bay (11). The detailed studies of Thunder Bay are discussed in Chapter 4.2.

The Minnesota shore of Lake Superior was divided into three rather distinct zones: the Duluth area dominated by the relatively polluted St. Louis River, the shore down-current (southwest) of Reserve Mining Company's taconite tailings delta at Silver Bay, and the shore up-current (northeast) of Reserve Mining (12). Water quality of Duluth-Superior Harbor is described in Chapter 4.3. Studies were conducted by the Minnesota Pollution Control Agency (PCA).

Sampling locations were selected along the Wisconsin shore of Lake Superior for the purpose of this study to document changes in water quality since the summer of 1968, when the last survey was completed (13,14). The locations were divided into groups designated as intensive, or those areas near population centres and/or sources of pollution; and non-intensive, or those areas away from population centres and/or sources of pollution. Each of the sites were sampled during June and July of 1974 by the Wisconsin Department of Natural Resources (DNR).

The Michigan shoreline was sampled to document the nearshore water quality during 1974 (15). The locations were divided into groups similar

TABLE 4.1-1

NEARSHORE STUDY PROGRAM

		Nearshore Segments										BATCHAWANA BAY	PENINSULA HAR	JACKFISH BAY	NIPIGON BAY	BLACK BAY	PINE BAY	CASCADE R MOUTH	GOOSEBERRY R MOUTH	BOIS BRULE R MOUTH	CHEQUAMEGON BAY	BAD R MOUTH	MONTREAL R MOUTH	BLACK R MOUTH	ONTONAGON	U PORTAGE ENTRY	EAGLE HR	L PORTAGE ENTRY	BIG BAY	PRESQUE ISLE	MARQUETTE	MUNISING	GRAND MARAIS	WHITEFISH POINT
		A	B	C	D	E	F	G	H	I	J																							
	AGENCY[a]	O M	O	O	N	N	N W	W	M	M	M	O	O	O	O	O	O	N	N	W	W	W	W	M	M	M	M	M	M	M	M	M	M	M
PHYSICAL LIMNOLOGY	SECCHI DISC	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	TURBIDITY	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	TEMPERATURE	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	COLOUR				*	*							*	*				*	*	*			*	*										
	SUSPENDED SOLIDS				*	*	*	*	*	*	*			*				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CHEMICAL LIMNOLOGY	NUTRIENTS																																	
	Nitrogen	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Phosphorus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Silicate	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	CHLOROPHYLL	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*					*	*	*	*	*	*	*	*	*	*	*
	DISS. OXYGEN	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	DISS. INORGANICS																																	
	Alkalinity	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Hardness				*	*	*		*	*	*							*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*
	pH			*	*	*	*	*	*	*	*							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Sulphate				*	*	*		*	*	*							*	*					*	*	*	*	*	*	*	*	*	*	*
	Chloride				*	*	*	*	*	*	*							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Conductivity	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*		*			*	*	*	*	*	*	*	*	*	*	*
	Major Ions				*	*			*	*	*							*	*					*	*	*	*	*	*	*	*	*	*	*
	ORGANICS																																	
	Pesticides				*	*		*	*	*	*							*	*		*			*	*	*	*	*	*	*	*	*	*	*
	PCB's				*	*		*	*	*	*							*	*		*			*	*	*	*	*	*	*	*	*	*	*
	Phenols	*	*	*	*	*	*	*				*	*	*	*	*	*	*	*		*													
	RADIOACTIVITY				*	*			*	*	*							*	*					*	*	*	*	*	*	*	*	*	*	*
	HEAVY METALS				*	*		*	*	*	*					*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	SEDIMENTS																																	
	Heavy Metals	*	*	*			*	*	*	*	*	*	*	*	*	*	*				*			*	*	*	*	*	*	*	*	*	*	*
	PCB's	*	*	*			*	*	*	*	*	*	*	*	*	*	*				*			*	*	*	*	*	*	*	*	*	*	*
	Pesticides	*	*	*			*	*	*	*	*	*	*	*	*	*	*				*			*	*	*	*	*	*	*	*	*	*	*
	Nutrients	*	*	*			*	*	*	*	*	*	*	*	*	*	*				*			*	*	*	*	*	*	*	*	*	*	*
	Volatile Solids	*	*	*			*	*	*	*	*	*	*	*	*	*	*				*			*	*	*	*	*	*	*	*	*	*	*
AQUATIC BIOLOGY	MICROBIOLOGY																																	
	Tot.Coliforms	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Fec.Coliforms	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Fec.Streptococci	*	*	*			*	*	*	*	*	*	*	*	*	*	*				*			*	*	*	*	*	*	*	*	*	*	*
	BENTHIC FAUNA				*	*	*	*	*	*	*					*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	PHYTOPLANKTON				*	*	*	*	*	*	*							*	*		*			*	*	*	*	*	*	*	*	*	*	*
	ZOOPLANKTON				*	*	*	*	*	*	*							*	*		*			*	*	*	*	*	*	*	*	*	*	*
	FISH CONTAMINANTS																																	
	Heavy Metals	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*		*	*	*	*	*	*	*	*	*	*	*
	PCB's	*	*				*	*	*	*	*	*	*	*	*	*	*			*	*	*		*	*	*	*	*	*	*	*	*	*	*
	Pesticides	*	*				*	*	*	*	*	*	*	*	*	*	*			*	*	*		*	*	*	*	*	*	*	*	*	*	*
	Radioactivity	*	*				*	*				*	*	*	*	*	*			*	*	*												

[a] O-Ontario Ministry of the Environment
N-Minnesota Pollution Control Agency
W-Wisconsin Department of Natural Resources
M-Michigan Department of Natural Resources

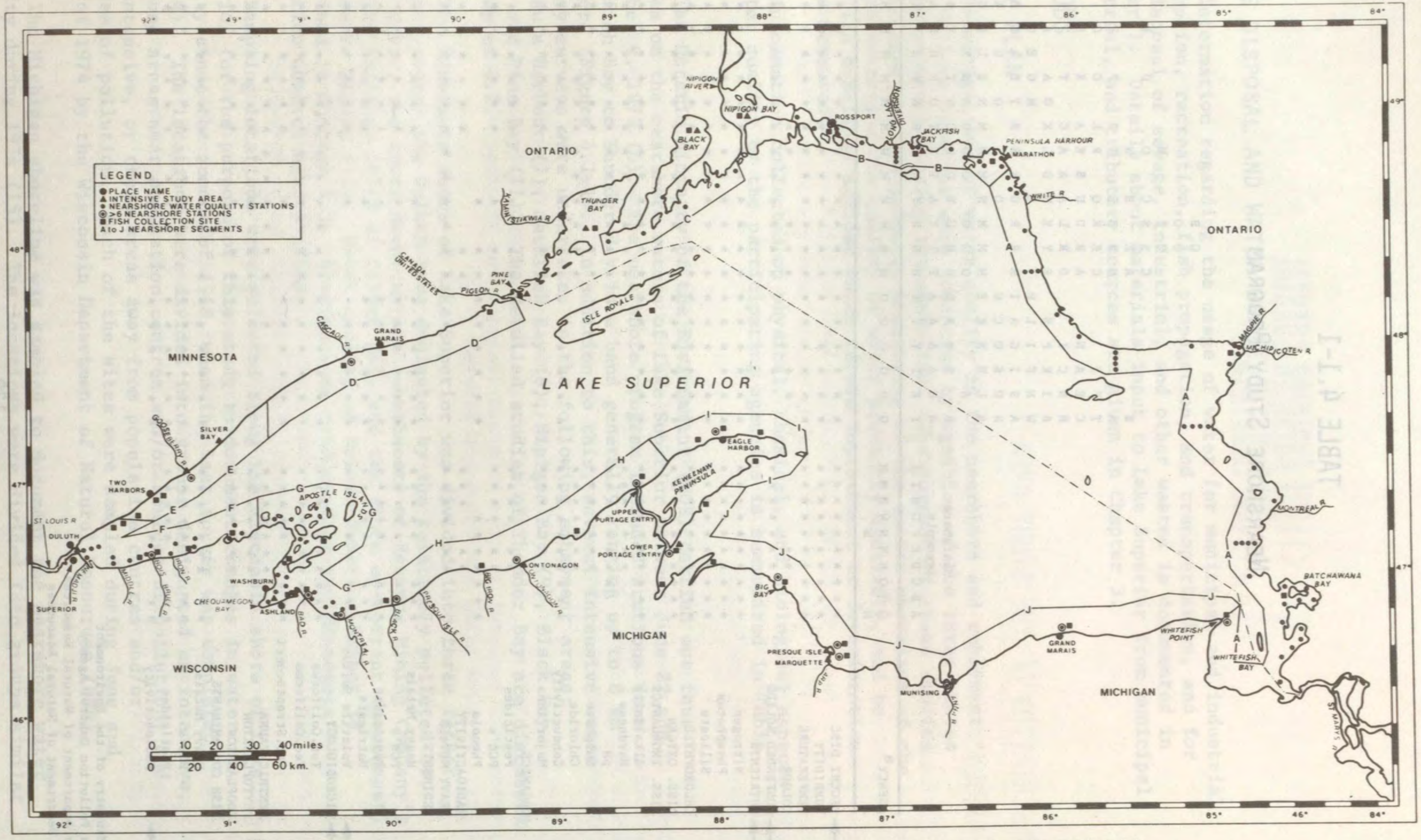


FIGURE 4.1-1 NEARSHORE SEGMENTS, STUDY AREAS, AND STATION LOCATIONS.

This nearshore zone generally extends offshore about 3 km or to a water depth of about 15 m (widths shown are not to scale).

to the Wisconsin sampling program. Each location was sampled during the spring of 1974 (June-July) and the fall of 1974 (August-September) by the Michigan Department of Natural Resources (DNR).

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 Superior into segments. The nearshore waters of Lake Superior are geographically segmented into ten segments A to J in Figure 4.1-1. Statistical summaries are shown in Figures 4.1-2 to 4.1-12 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 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, reference should be made to the individual Reference Group project reports listed in the bibliography (6-16,46,69,71) or the investigating agency contacted.

PHYSICAL LIMNOLOGY

WATER MOVEMENT

Water movements throughout the lake have important implications when considering the dispersion of dissolved and suspended materials entering the lake. Unfortunately, there has been little direct investigation of the effects currents have on the dispersion of these materials. Lake currents have been characterized by a number of investigations (16,25). Much of the available information deals with open water movements; the reader is therefore referred to the discussion about lake circulation in Chapter 5.1.

Currents in Lake Superior are primarily horizontal surface (epilimnetic) currents and vertical currents (upwellings) (Figure 5.1-5). Horizontal subsurface currents are not so significant or as well known. Horizontal epilimnetic currents are produced by wind stress on the lake surface, the Coriolis force, spatial heating differences, and the inflow of water into the lake from the drainage basin. These four factors operating within the constraints of the lake basin and lake bottom topography produce current patterns. Of the four, wind is the most important factor (23,24,26). Surface currents are generally restricted to the epilimnion and the thermocline layer of the open lake which are approximately the upper 25 m of water. The establishment of thermal stratification facilitates current development (20,27).

The overall current movement in Lake Superior is counter-clockwise around the periphery of the basin. Major cyclonic eddys occur in the extreme western end of the lake (Duluth-Silver Bay-Apostle Island triangle). In contrast to the general counter-clockwise movement is a clockwise current around Isle Royale and a weak southeasterly movement of water from the Minnesota shore near Grand Marais toward the Keweenaw Peninsula (23). Current velocities in the lake range from a few cm/s to over 50 cm/s (40 km/d) for the coastal jet current off the Keweenaw Peninsula.

The upwelling of water from the depths of the lake in the Two Harbors-Silver Bay area is caused by the prevailing winds blowing either offshore or along shore where the shoreline is to the left of the wind direction (23). An upwelling episode off Silver Bay, Minnesota was documented in October, 1972. Water from at least 150 m deep moved vertically over a 6-day period at a velocity of 30 m/d. The cause was consistent westerly winds during the period. The upwelling was measured 1.5 km from shore where the bottom drops to depths exceeding 200 m.

At the Keweenaw Peninsula, the bank of eastwardly moving, often warmer surface water narrows and apparently gains speed as it rounds the peninsula. Relatively high current velocities extend 1 to 4 km offshore from Eagle Harbor, Michigan. Surface current velocities up to 52 cm/s have been recorded (16). Although the faster currents are found in the epilimnion as expected, significant currents have also been found at depths of 60 m both at the beginning and at the end of the summer stratification period (22).

Eddy currents retard the complete mixing of materials throughout the lake. The large eddy in the triangle formed by Silver Bay, Duluth, and the Apostle Islands affects effluents from Duluth-Superior Harbor and the red clay from Wisconsin's south shore. Secchi disc readings in this part of the lake are generally lower than in the rest of the lake (18).

The effects of upwellings on dispersion is also relatively unknown. Upwellings could augment the productivity of Lake Superior by bringing up nutrients and phytoplankton from the depths into the photic zone (28).

THERMAL REGIMES

The large size, the depth, and northern location of Lake Superior are primary reasons why the entire lake does not completely thermally

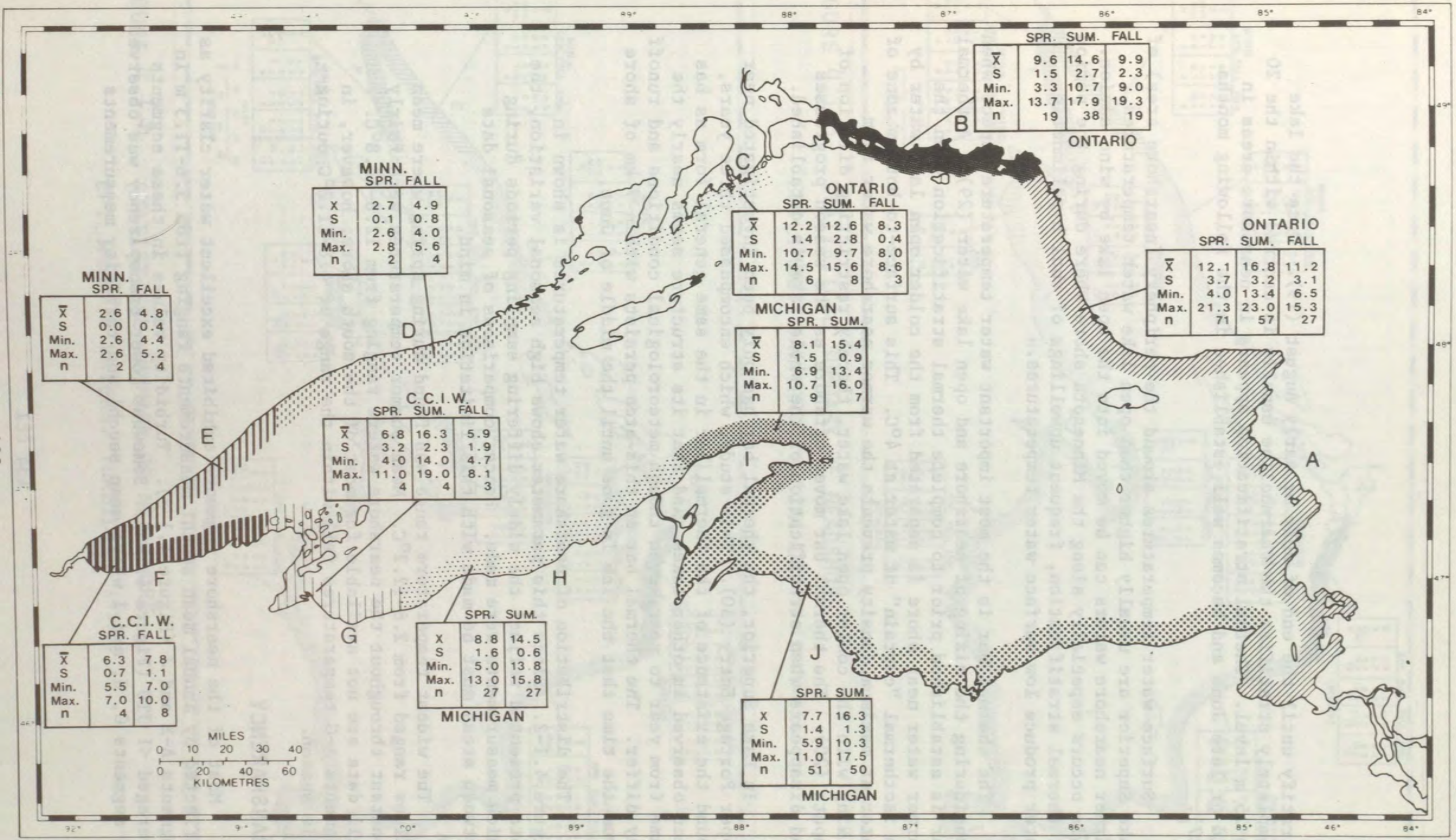


FIGURE 4.1-2 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, TEMPERATURE (°C).

stratify until the end of July or early August (19). Once the lake completely stratifies the thermocline usually is centred within the 20 to 25 m level. Thermal stratification appears in nearshore areas in mid or late June and becomes well established in the following months (27).

Surface water temperatures around the periphery (nearshore area) of Lake Superior are usually higher than open lake water temperatures. Warmer nearshore waters can be moved into the open lake by wind action. This occurs especially along the Minnesota shore where during the period of thermal stratification, frequent upwellings of cool hypolimnetic water produce low surface water temperatures.

The thermal bar is the most important water temperature aspect when considering the mixing of nearshore and open lake water (29). A thermal bar is established prior to complete thermal stratification when the warmer water near shore is separated from the colder open lake water by an isothermal "curtain" of water at 4°C. This surface-to-bottom zone of water at maximum density prevents the warmer nearshore water from mixing with the cooler open lake water, thereby restricting dilution of inputs (20). The thermal bar moves offshore as the season progresses and disappears when stratification of the whole lake is established.

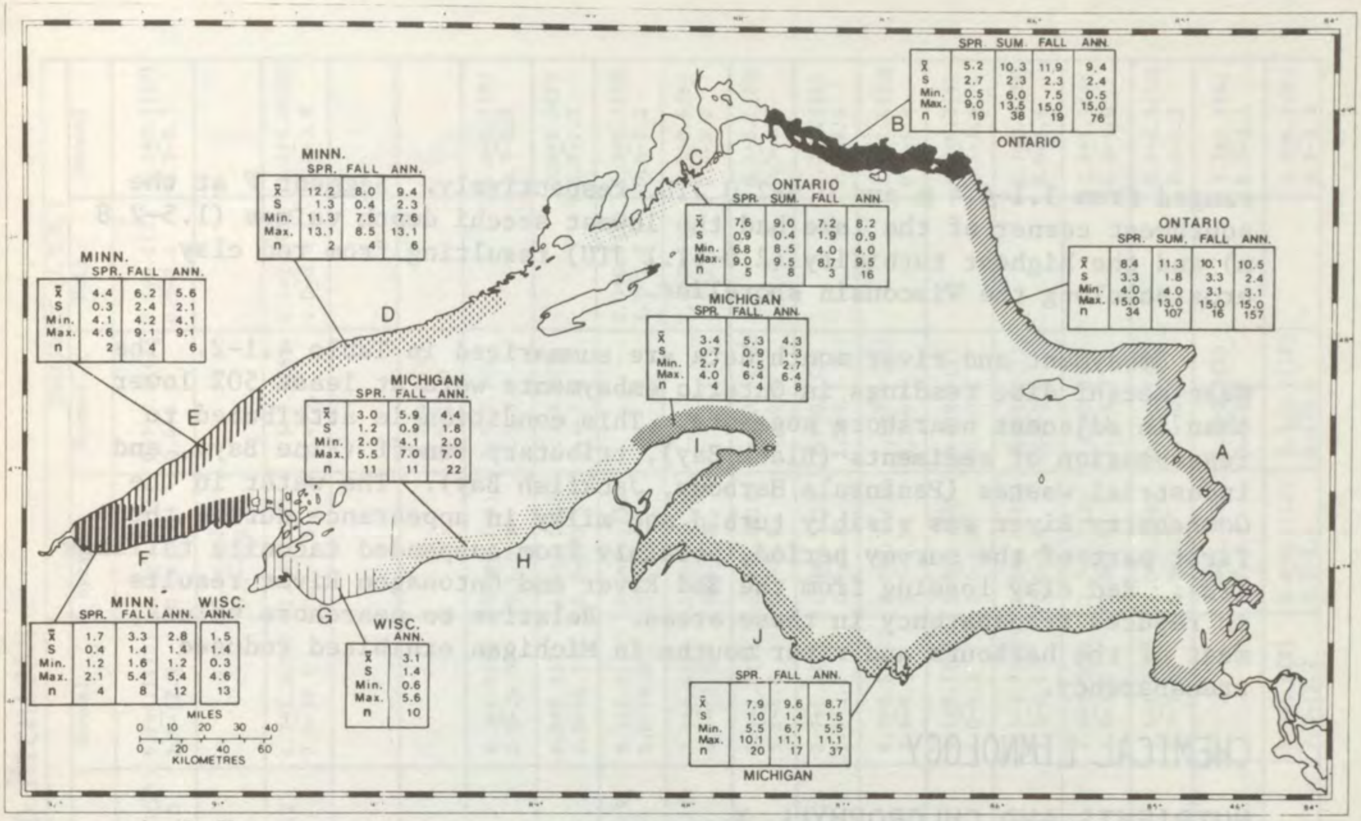
In Lake Superior, the thermal bar has only been investigated near Upper Portage Entry (30). This study, which encompassed three years, found the existence of the thermal bar in the same general form as has been observed in other lakes, and that its structure seems nearly the same from year to year, even though meteorological conditions and runoff may differ. The thermal bar in this area persists within 7 km of shore from the time that the ice is gone until the middle of June.

The distribution of nearshore water temperatures is shown in Figure 4.1-2. Since this parameter shows high seasonal variation, the data presented reflect the widely differing sampling periods during which measurements were made. Hence, comparisons of seasonal data between areas must be made with this limitation in mind.

The widest temperature range was found during spring where mean values ranged from 2.6-12.2°C. Mean summer temperatures were fairly constant throughout the nearshore waters ranging from 12.6-16.8°C. Fall data are not available for most of the south shore; however, in segments A-G temperatures fell within the range of 4.8-11.2°C during this season.

TRANSPARENCY

Most of the nearshore segments exhibited excellent water clarity as reflected by annual mean secchi measurements ranging from 5.6-11.3 m in segments A-E and J (Figure 4.1-3). Turbidity values in these segments averaged <1 JTU (Figure 4.1-4). Somewhat lower transparency was observed in segments G, H, and I where mean secchi and turbidity measurements



ONTARIO (B)

	SPR.	SUM.	FALL	ANN.
$\bar{X}$	5.2	10.3	11.9	9.4
S	2.7	2.3	2.3	2.4
Min.	0.5	6.0	7.5	0.5
Max.	9.0	13.5	15.0	15.0
n	19	38	19	76

MINN. (D)

	SPR.	FALL	ANN.
$\bar{X}$	12.2	8.0	9.4
S	1.3	0.4	2.3
Min.	11.3	7.6	7.6
Max.	13.1	8.5	13.1
n	2	4	6

ONTARIO (C)

	SPR.	SUM.	FALL	ANN.
$\bar{X}$	7.6	9.0	7.2	8.2
S	0.9	0.4	1.9	0.9
Min.	6.8	8.5	4.0	4.0
Max.	9.0	9.5	8.7	9.5
n	5	8	3	16

ONTARIO (A)

	SPR.	SUM.	FALL	ANN.
$\bar{X}$	8.4	11.3	10.1	10.5
S	3.3	1.8	3.3	2.4
Min.	4.0	4.0	3.1	3.1
Max.	15.0	13.0	15.0	15.0
n	34	107	16	157

MINN. (E)

	SPR.	FALL	ANN.
$\bar{X}$	4.4	6.2	5.6
S	0.3	2.4	2.1
Min.	4.1	4.2	4.1
Max.	4.6	9.1	9.1
n	2	4	6

MICHIGAN (I)

	SPR.	FALL	ANN.
$\bar{X}$	3.4	5.3	4.3
S	0.7	0.9	1.3
Min.	2.7	4.5	2.7
Max.	4.0	6.4	6.4
n	4	4	8

MICHIGAN (H)

	SPR.	FALL	ANN.
$\bar{X}$	3.0	5.9	4.4
S	1.2	0.9	1.8
Min.	2.0	4.1	2.0
Max.	5.5	7.0	7.0
n	11	11	22

MINN. / WISC. (F)

	MINN. SPR.	MINN. FALL	MINN. ANN.	WISC. ANN.
$\bar{X}$	1.7	3.3	2.8	1.5
S	0.4	1.4	1.4	1.4
Min.	1.2	1.6	1.2	0.3
Max.	2.1	5.4	5.4	4.6
n	4	8	12	13

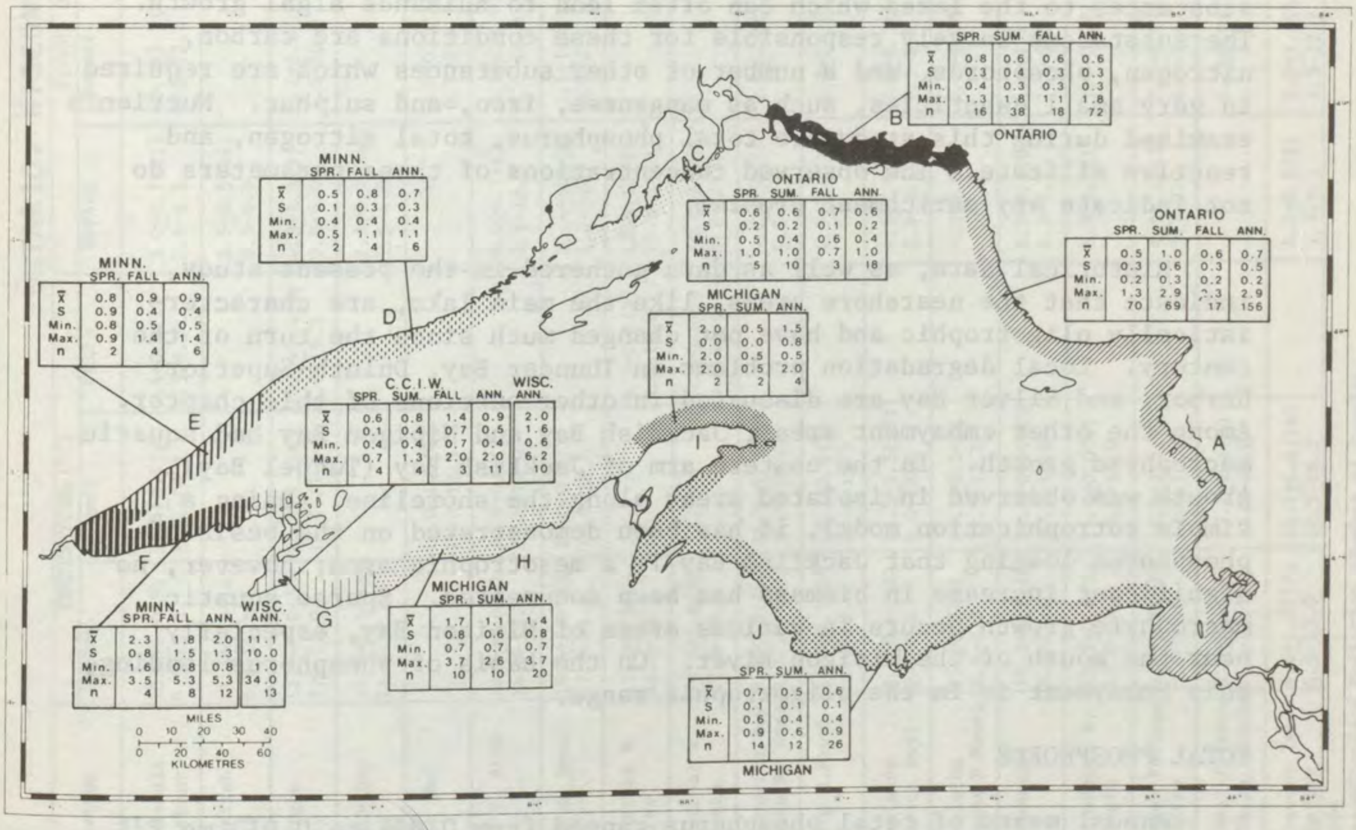
WISC. (G)

	ANN.
$\bar{X}$	3.1
S	1.4
Min.	0.6
Max.	5.6
n	10

MICHIGAN (J)

	SPR.	FALL	ANN.
$\bar{X}$	7.9	9.6	8.7
S	1.0	1.4	1.5
Min.	5.5	6.7	5.5
Max.	10.1	11.1	11.1
n	20	17	37

FIGURE 4.1-3 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, SECCHI DEPTH (metres).



ONTARIO (B)

	SPR	SUM	FALL	ANN.
$\bar{X}$	0.8	0.6	0.6	0.6
S	0.3	0.4	0.3	0.3
Min.	0.4	0.3	0.3	0.3
Max.	1.3	1.8	1.1	1.8
n	16	38	18	72

MINN. (D)

	SPR.	FALL	ANN.
$\bar{X}$	0.5	0.8	0.7
S	0.1	0.3	0.3
Min.	0.4	0.4	0.4
Max.	0.5	1.1	1.1
n	2	4	6

ONTARIO (C)

	SPR.	SUM.	FALL	ANN.
$\bar{X}$	0.6	0.6	0.7	0.6
S	0.2	0.2	0.1	0.2
Min.	0.5	0.4	0.6	0.4
Max.	1.0	1.0	0.7	1.0
n	5	10	3	18

ONTARIO (A)

	SPR.	SUM.	FALL	ANN.
$\bar{X}$	0.5	1.0	0.6	0.7
S	0.3	0.6	0.3	0.5
Min.	0.2	0.3	0.2	0.2
Max.	1.3	2.9	2.3	2.9
n	70	69	17	156

MINN. (E)

	SPR.	FALL	ANN.
$\bar{X}$	0.8	0.9	0.9
S	0.9	0.4	0.4
Min.	0.8	0.5	0.5
Max.	0.9	1.4	1.4
n	2	4	6

MICHIGAN (I)

	SPR.	SUM.	ANN.
$\bar{X}$	2.0	0.5	1.5
S	0.0	0.0	0.8
Min.	2.0	0.5	0.5
Max.	2.0	0.5	2.0
n	2	2	4

C.C.I.W. / WISC. (G)

	C.C.I.W. SPR.	C.C.I.W. SUM.	C.C.I.W. FALL	C.C.I.W. ANN.	WISC. ANN.
$\bar{X}$	0.6	0.8	1.4	0.9	2.0
S	0.1	0.4	0.7	0.5	1.6
Min.	0.4	0.4	0.7	0.4	0.6
Max.	0.7	1.3	2.0	2.0	6.2
n	4	4	3	11	10

MINN. / WISC. (F)

	MINN. SPR.	MINN. FALL	MINN. ANN.	WISC. ANN.
$\bar{X}$	2.3	1.8	2.0	11.1
S	0.8	1.5	1.3	10.0
Min.	1.6	0.8	0.8	1.0
Max.	3.5	5.3	5.3	34.0
n	4	8	12	13

MICHIGAN (H)

	SPR.	SUM.	ANN.
$\bar{X}$	1.7	1.1	1.4
S	0.8	0.6	0.8
Min.	0.7	0.7	0.7
Max.	3.7	2.6	3.7
n	10	10	20

MICHIGAN (J)

	SPR.	SUM.	ANN.
$\bar{X}$	0.7	0.5	0.6
S	0.1	0.1	0.1
Min.	0.6	0.4	0.4
Max.	0.9	0.6	0.9
n	14	12	26

FIGURE 4.1-4 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, TURBIDITY (JTU).

ranged from 3.1-4.4 m and 0.9-2.0 JTU, respectively. Segment F at the southwest corner of the lake had the lowest secchi depth values (1.5-2.8 m) and the highest turbidity (2.0-11.1 JTU) resulting from red clay erosion along the Wisconsin shoreline.

Embayment and river mouth data are summarized in Table 4.1-2. The mean secchi disc readings in Ontario embayments were at least 50% lower than in adjacent nearshore segments. This condition is attributed to resuspension of sediments (Black Bay), tributary runoff (Pine Bay), and industrial wastes (Peninsula Harbour, Jackfish Bay). The water in the Gooseberry River was visibly turbid and milky in appearance during the first part of the survey period, possibly from suspended taconite tailings (12). Red clay loading from the Bad River and Ontonagon River results in reduced transparency in these areas. Relative to nearshore values, most of the harbours and river mouths in Michigan exhibited reduced transparency.

CHEMICAL LIMNOLOGY

NUTRIENTS AND CHLOROPHYLL α

Nutrient availability is an important influence on the productivity of a lake. Man's activities accelerate the natural introduction of many substances to the lakes which can often lead to nuisance algal growth. The substances largely responsible for these conditions are carbon, nitrogen, phosphorus, and a number of other substances which are required in very small quantities, such as manganese, iron, and sulphur. Nutrients examined during this study are total phosphorus, total nitrogen, and reactive silicate. The observed concentrations of these parameters do not indicate any enrichment problem.

Historical data, as well as data gathered in the present study, indicate that the nearshore areas, like the main lake, are characteristically oligotrophic and have not changed much since the turn of the century. Local degradation problems in Thunder Bay, Duluth-Superior Harbor, and Silver Bay are discussed in other sections of this chapter. Among the other embayment areas, Jackfish Bay and Nipigon Bay had aquatic macrophyte growth. In the eastern arm of Jackfish Bay (Tunnel Bay), growth was observed in isolated areas along the shoreline. Using a simple eutrophication model, it has been demonstrated on the basis of phosphorus loading that Jackfish Bay is a mesotrophic area; however, no significant increase in biomass has been documented. Sparse aquatic macrophyte growth occurs in various areas of Nipigon Bay, especially near the mouth of the Nipigon River. On the basis of phosphorus loading, this embayment is in the oligotrophic range.

TOTAL PHOSPHORUS

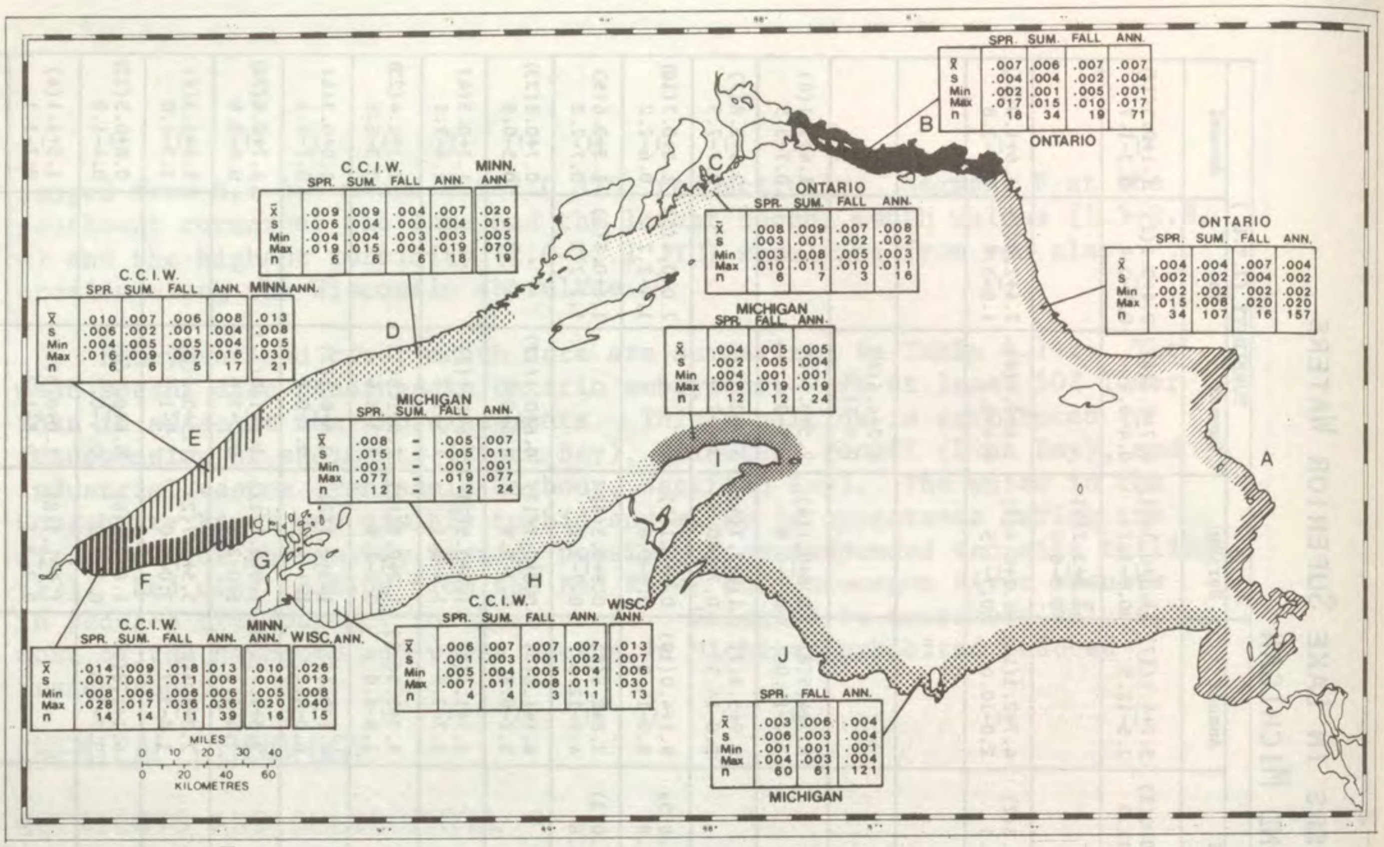
Annual means of total phosphorus ranged from 0.004 to 0.013 mg P/ℓ in the nearshore waters with the lowest mean recorded in both segments A and J and the highest annual mean occurring in segment F (Figure 4.1-5).

TABLE 4.1-2

SEASONAL VALUES FOR PHYSICAL PARAMETERS IN LAKE SUPERIOR WATERS ONTARIO, WISCONSIN AND MICHIGAN

Location	TEMPERATURE (°C)			SECCHI DISC (m)				TURBIDITY (J.T.U.)			
	Spring	Summer	Fall	Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Peninsula Harbour	10.8±1.0(9) 9.5-13.0	15.4±3.4(4) 12.4-18.7	9.4±0.1(2) 9.3-9.5	3.0±0.7(11) 2.5-4.5	10.1±3.0(4) 6.0-12.5	12.0±0.0(2) 12.0-12.0	5.7±4.1(17) 2.5-12.5	1.3±0.3(11) 0.9-1.7	0.7±0.2(4) 0.4-0.9	0.4±0.1(2) 0.3-0.4	1.1±0.5(17) 0.3-1.7
Jackfish Bay	11.5±1.0(14) 9.0-16.5			2.5±0.5(14) 0.5-6.0				2.0±2.2(9) 0.5-6.0			
Nipigon Bay	12.2±3.8(3) 7.9-15.0	14.2±3.5(6) 10.7-17.5	14.1±7.4(2) 8.8-19.3	4.3±1.5(3) 3.0-6.0	5.2±2.8(6) 2.5-10.0	3.8±2.5(2) 2.0-5.5	4.7±2.3(11) 2.0-10.0	1.1±0.4(3) 0.7-1.5	1.6±0.9(6) 0.4-3.2	2.4±2.0(2) 1.0-3.8	1.6±1.0(11) 0.4-3.8
Black Bay	19.0±0.5(48) 14.5-22.0			2.5±0.2(24) 1.5-4.0							
Pine Bay		17.0±1.0(4) 16.0-18.5			4.0±0.5(3) 0.5-9.5				4.2±4.6(4) 0.9-11.0		
Bad R. Area	16.5±0.6(4) 16.0-17.0	13.9±0.3(4) 13.5-14.0		9.2±4.7(4) 2.2-12.5	7.3±4.8(4) 3.0-14.0		8.3±4.5(8) 2.2-14.0	0.8±0.1(4) 0.7-0.9	2.5±0.9(4) 1.3-3.5		1.6±1.1(8) 0.7-3.5
Bad R. Mouth	18.5±1.7(4) 17.0-21.0	14.0±0.0(3) 14.0-14.0		10.4±4.5(4) 4.7-14.5	2.1±1.2(3) 2.0-2.2		6.9±5.5(7) 2.0-14.5	1.9±2.1(4) 0.7-5.0	5.7±2.1(3) 3.4-7.3		3.5±2.8(7) 0.7-7.3
Montreal R. Area	11.8±0.5(5) 11.0-12.0		9.7±0.5(5) 9.0-10.0	12.8±1.2(5) 11.0-14.0		5.4±0.8(5) 5.0-6.8	9.1±4.0(10) 5.0-14.0	0.6±0.1(5) 0.6-0.8		2.0±0.4(5) 1.4-2.2	1.3±0.7(10) 0.6-2.2
Montreal R. Mouth	14.5±3.9(3) 12.0-19.0		9.5±0.5(3) 9.0-10.0	10.0±2.0(3) 8.7-12.3		5.6±1.0(3) 4.9-6.8	7.8±2.8(6) 4.9-12.3	0.9±0.3(3) 0.7-1.2		1.6±0.5(3) 1.2-2.2	1.3±0.6(6) 0.7-2.2
Marquette Bay (Carp R. Area)	9.9±0.3(15) 9.3-10.4	14.9±0.3(15) 14.0-15.0		5.2±0.0(3) 5.2-5.2	8.8±0.0(1)		6.1±1.8(4) 5.2-8.8	0.8±0.1(11) 0.7-0.9	0.6±0.1(12) 0.5-0.8		0.7±0.1(23) 0.5-0.9
Carp R.Mouth	11.5±0.7(2) 11.0-12.0	15.3±0.4(2) 15.0-15.5		1.7±0.0(1)	3.7±0.0(1)		2.7±1.4(2) 1.7-3.7	1.8±0.5(2) 1.4-2.1	1.6±0.1(2) 1.5-1.7		1.7±0.3(4) 1.4-2.1
Munising (South Bay)	8.1±0.4(18) 7.0-8.8	13.5±3.5(18) 9.0-17.0		4.3±1.9(6) 2.9-7.3	8.3±0.5(6) 7.3-8.8		6.3±2.5(12) 2.9-8.8	1.2±0.7(11) 0.7-2.9	1.0±1.8(12) 0.3-6.6		1.1±1.4(23) 0.3-6.6
Munising (Anna R.Mouth)	8.1±0.1(2) 8.0-8.2	17.2±0.3(2) 17.0-17.4		4.0±0.0(1)	4.1±0.0(1)		4.1±0.1(2) 4.0-4.1	1.3±0.2(2) 1.1-1.4	0.8±0.1(2) 0.7-0.8		1.0±0.3(4) 0.7-1.4
Ontonagon	10.2±1.1(18) 8.5-12.0	14.8±0.6(18) 14.0-15.0		2.2±0.8(6) 1.5-3.7	4.8±1.4 2.4-6.1		3.5±1.7(12) 1.5-6.1	1.8±0.6(12) 1.0-3.6	1.6±1.0(12) 0.6-3.6		1.7±0.8(24) 0.6-3.6
Ontonagon R. Mouth	11.7±0.6(3) 11.0-12.0	15.0±0.0(3) 15.0-15.0		1.8±0.0(1)	3.7±0.0(1)		2.8±1.3(2) 1.8-3.7	3.5±0.7(2) 3.0-4.0	1.3±0.0(2) 1.3-1.3		2.4±1.3(4) 1.3-4.0
Lower Portage Entry	6.8±1.8(9) 5.0-11.0	14.0±2.2(9) 11.0-17.0		4.9±1.9(3) 3.7-7.0	7.3±0.1(3) 6.1-7.6		6.1±1.8(6) 3.7-7.6	1.0±0.6(6) 0.5-1.2	0.6±0.1(6) 0.4-0.7		0.8±0.5(12) 0.4-1.2
Lower Portage Entry (Mouth)	8.6±3.9(3) 6.3-13.1	13.7±2.1(3) 11.9-16.0			6.1±0.0(1)			1.9±1.7(2) 0.7-3.1	1.0±0.3(2) 0.8-1.2		1.5±1.1(4) 0.7-3.1
Presque Isle Harbor	6.6±1.7(17) 5.5-13.0	14.1±1.6(14) 10.5-16.2		8.1±0.9(3) 7.3-9.1	9.0±1.9(6) 7.3-12.2		8.7±1.6(9) 7.3-12.2	0.8±0.1(12) 0.7-1.2	0.5±0.1(12) 0.4-0.6		0.7±0.2(24) 0.4-1.2

Code
Mean±Standard Deviation (Number of Samples)
Minimum Value - Maximum Value



	C.C.I.W.				MINN.
	SPR.	SUM.	FALL	ANN.	ANN
$\bar{x}$	.009	.009	.004	.007	.020
s	.006	.004	.000	.004	.015
Min	.004	.004	.003	.003	.005
Max	.019	.015	.004	.019	.070
n	6	6	6	18	19

	C.C.I.W.				MINN.
	SPR.	SUM.	FALL	ANN.	ANN.
$\bar{x}$	.010	.007	.006	.008	.013
s	.006	.002	.001	.004	.008
Min	.004	.005	.005	.004	.005
Max	.016	.009	.007	.016	.030
n	6	6	5	17	21

MICHIGAN

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.008	-	.005	.007
s	.015	-	.005	.011
Min	.001	-	.001	.001
Max	.077	-	.019	.077
n	12	-	12	24

	C.C.I.W.				MINN.	WISC.
	SPR.	SUM.	FALL	ANN.	ANN.	ANN.
$\bar{x}$	.014	.009	.018	.013	.010	.026
s	.007	.003	.011	.008	.004	.013
Min	.008	.006	.006	.006	.005	.008
Max	.028	.017	.036	.036	.020	.040
n	14	14	11	39	16	15

	C.C.I.W.				WISC.
	SPR.	SUM.	FALL	ANN.	ANN.
$\bar{x}$	.006	.007	.007	.007	.013
s	.001	.003	.001	.002	.007
Min	.005	.004	.005	.004	.006
Max	.007	.011	.008	.011	.030
n	4	4	3	11	13

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.007	.006	.007	.007
s	.004	.004	.002	.004
Min	.002	.001	.005	.001
Max	.017	.015	.010	.017
n	18	34	19	71

ONTARIO

ONTARIO

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.008	.009	.007	.008
s	.003	.001	.002	.002
Min	.003	.008	.005	.003
Max	.010	.011	.010	.011
n	6	7	3	16

ONTARIO

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.004	.004	.007	.004
s	.002	.002	.004	.002
Min	.002	.002	.002	.002
Max	.015	.008	.020	.020
n	34	107	16	157

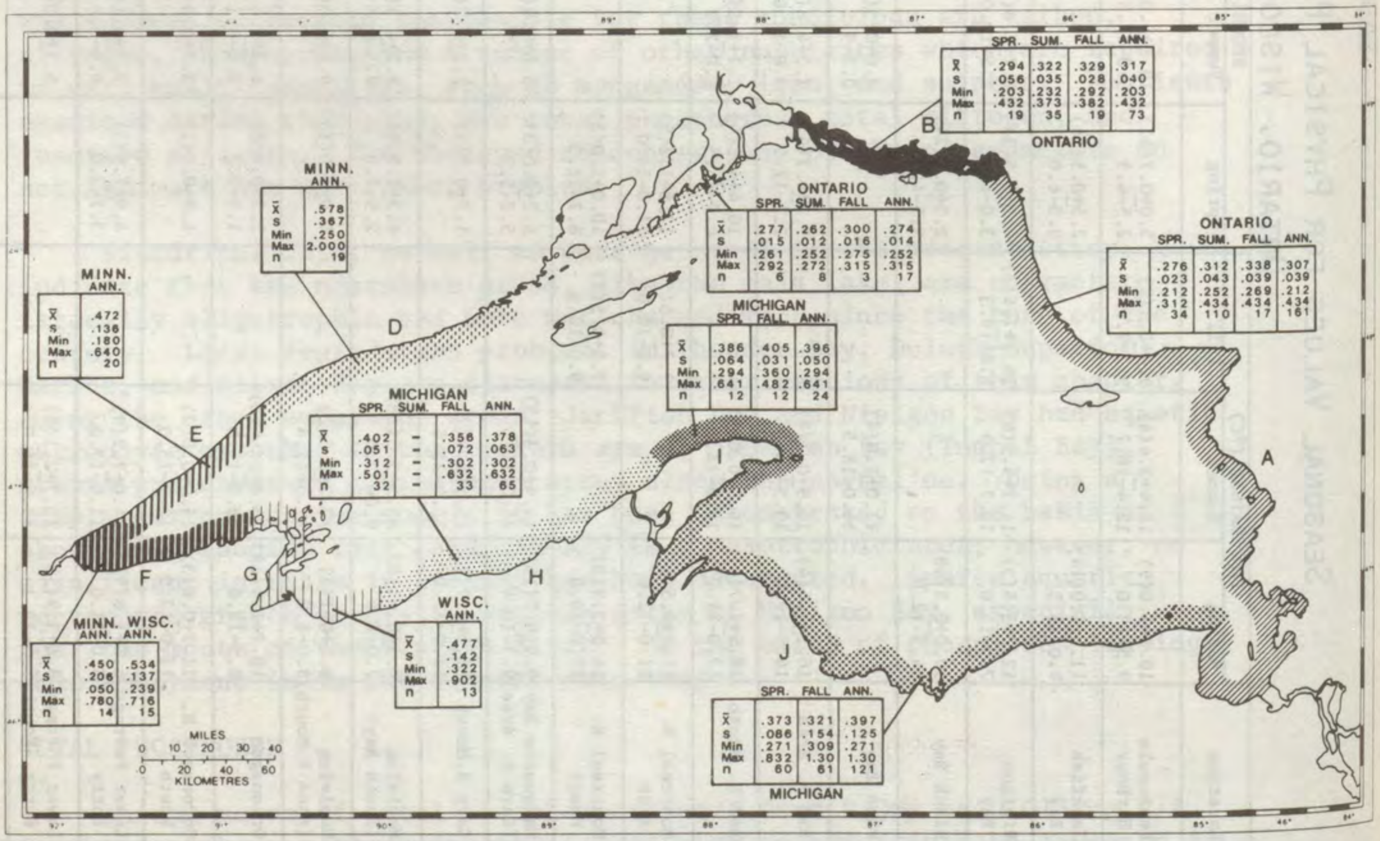
MICHIGAN

	SPR.	FALL	ANN.
$\bar{x}$	.004	.005	.005
s	.002	.005	.004
Min	.004	.001	.001
Max	.009	.019	.019
n	12	12	24

	SPR.	FALL	ANN.
$\bar{x}$	.003	.006	.004
s	.006	.003	.004
Min	.001	.001	.001
Max	.004	.003	.004
n	60	61	121

MICHIGAN

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



	MINN.
	ANN.
$\bar{x}$	.578
s	.367
Min	.250
Max	2.000
n	19

	MINN.
	ANN.
$\bar{x}$	.472
s	.136
Min	.180
Max	.640
n	20

MICHIGAN

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.402	-	.356	.378
s	.051	-	.072	.063
Min	.312	-	.302	.302
Max	.501	-	.632	.632
n	32	-	33	65

	MINN.	WISC.
	ANN.	ANN.
$\bar{x}$	.450	.534
s	.206	.137
Min	.050	.239
Max	.780	.716
n	14	15

	WISC.
	ANN.
$\bar{x}$	.477
s	.142
Min	.322
Max	.902
n	13

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.294	.322	.329	.317
s	.056	.035	.028	.040
Min	.203	.232	.292	.203
Max	.432	.373	.382	.432
n	19	35	19	73

ONTARIO

ONTARIO

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.277	.262	.300	.274
s	.015	.012	.016	.014
Min	.261	.252	.275	.252
Max	.292	.272	.315	.315
n	6	8	3	17

ONTARIO

	SPR.	SUM.	FALL	ANN.
$\bar{x}$	.276	.312	.338	.307
s	.023	.043	.039	.039
Min	.212	.252	.269	.212
Max	.312	.434	.434	.434
n	34	110	17	161

MICHIGAN

	SPR.	FALL	ANN.
$\bar{x}$	.386	.405	.396
s	.064	.031	.050
Min	.294	.360	.294
Max	.641	.482	.641
n	12	12	24

	SPR.	FALL	ANN.
$\bar{x}$	.373	.321	.397
s	.086	.154	.125
Min	.271	.309	.271
Max	.832	1.30	1.30
n	60	61	121

MICHIGAN

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

Means for the remaining nearshore segments (B-E, G-I) ranged from 0.005 to 0.008 mg/ℓ.

Exceptions to these values were reported by the Minnesota PCA for segments D and E and by Wisconsin for segments F and G. Since the station locations in Minnesota were influenced by tributary inputs, it is likely that the values reported do not truly represent baseline levels. In Wisconsin, analytical technique as well as the proximity of some stations to tributary inputs, resulted in annual means which were double the concentration reported by the Canada Centre for Inland Waters (CCIW) for segments F and G.

In the Ontario nearshore waters in the zone between Whitefish Bay and the entrance of the eastern channel of Nipigon Bay, the total phosphorus concentrations were $\leq$0.007 mg/ℓ except for a portion of Batchawana Bay where higher values were observed (6). Tributary inputs, cottage development, as well as relatively limited exchange of bay waters with open waters are factors contributing to higher phosphorus levels in this embayment. Near Rossport, the phosphorus concentration was higher than the general area, and the mouth of the western channel of Nipigon Bay exhibited still higher values. Segment C, between the western channel of Nipigon Bay and Thunder Bay Harbour, showed higher levels than segments A and B.

Minnesota studies of the Cascade and Gooseberry River mouth areas (segments D and E, respectively) indicated total phosphorus levels which fluctuated over a wide range and were generally higher than published values for the open lake and other nearshore segments. As indicated before, some anomalous values of total phosphorus were observed in Minnesota waters. The annual means of 0.007 and 0.008 mg/ℓ for segments D and E, respectively, reported by CCIW may be considered as representative of baseline levels. Water quality conditions of Ontario, Minnesota, and Wisconsin embayments and river mouths are summarized in Table 4.1-3.

The quality of Michigan waters in terms of total phosphorus is generally consistent with the northern and western sections of the lake. Segment H had a maximum value of 0.077 mg/ℓ; however, the annual mean was 0.007 mg/ℓ.

Several zones of potentially impacted water quality were identified by Michigan DNR during the 1974 sampling. These areas are all located at river inflows. The effects of watershed disturbances, agricultural activity, and municipal and industrial discharges contribute to localized water quality impairment at Ontonagon, Lower Portage Entry, Presque Isle Harbor, Carp River, and Munising. At each of these locations, the respective river mouths were sampled. A summary of water quality conditions at these river mouths is given in Table 4.1-4.

The Carp River and Munising were identified as the most impacted of the Lake Superior locations in Michigan waters. At the Carp River mouth, the total phosphorus was nine times higher than at the stations farther offshore. This level is attributed to the Marquette municipal

TABLE 4.1-3

SEASONAL VALUES FOR CHEMICAL PARAMETERS IN LAKE SUPERIOR WATERS ONTARIO, MINNESOTA AND WISCONSIN

Area	Parameter	Units	SEASONAL VALUES														
			Spring					Summer					Fall				
			n	$\bar{x}$	S	Min.	Max.	n	$\bar{x}$	S	Min.	Max.	n	$\bar{x}$	S	Min.	Max.
Peninsula Harbour	Total P (P)	mg/ℓ	9	0.006	0.002	0.004	0.010	3	0.007	0.002	0.005	0.009	2	0.009	0.002	0.007	0.010
	Total N (N)	mg/ℓ	9	0.28	0.02	0.25	0.31	3	0.36	0.06	0.32	0.43	2	0.31	0.03	0.29	0.33
	Conductivity	µS/cm	9	110	9	103	133	4	101	5	96	107	2	97	1	96	97
Jackfish Bay	Total P (P)	mg/ℓ	14	0.018	0.017	0.004	0.070										
	Total N (N)	mg/ℓ	14	0.32	0.02	0.27	0.45										
	Conductivity	µS/cm	14	153	39	94	363										
	Chlorophyll α	µg/ℓ	7	1.2	1.1	0.6	3.8										
Nipigon Bay	Total P (P)	mg/ℓ	3	0.016	0.004	0.012	0.020	5	0.008	0.003	0.005	0.011	3	0.007	0.005	0.003	0.012
	Total N (N)	mg/ℓ	3	0.28	0.03	0.24	0.31	5	0.25	0.08	0.15	0.34	3	0.34	0.05	0.29	0.38
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	3	2.3	0.2	2.0	2.4	5	2.3	0.2	2.1	2.5	3	2.6	0.1	2.5	2.6
	Conductivity	µS/cm	3	108	11	99	120	5	107	8	98	119	3	110	8	102	118
	Chlorophyll α	µg/ℓ	3	1.1	0.2	0.9	1.2	5	1.1	0.4	0.6	1.6	3	0.9	0.2	0.8	1.1
Black Bay	Total P (P)	mg/ℓ	24	0.012	0.022	0.003	0.052										
	Total N (N)	mg/ℓ	24	0.26	0.05	0.19	0.37										
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	24	2.2	0.1	2.0	2.6										
	Chlorophyll α	µg/ℓ	24	1.5	0.4	1.0	2.8										
Pine Bay	Total P (P)	mg/ℓ						4	0.033	0.026	0.015	0.070					
	Total N (N)	mg/ℓ						4	0.41	0.35	0.21	0.94					
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ						4	3.8	2.8	2.2	8.0					
	Conductivity	µS/cm						4	108	13	100	127					
	Chlorophyll α	µg/ℓ						4	1.2	0.2	0.9	1.4					
Cascade River Mouth	Total P (P)	mg/ℓ	8	0.011	0.012	0.005	0.041						15	0.022	0.011	0.010	0.040
	Total N (N)	mg/ℓ	8	0.57	0.13	0.45	0.87						15	0.57	0.41	0.27	2.00
	Chloride (Cl^-)	mg/ℓ	8	2.4	1.9	1.0	6.3						15	1.7	0.3	1.1	2.0
	Sulphate (SO_4^{2-})	mg/ℓ	8	2.7	0.3	2.4	3.2						15	3.4	0.5	2.6	4.1
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	8	2.5	0.4	2.2	3.5						15	3.2	1.6	2.0	6.9
	Conductivity	µS/cm	8	80	2	77	82						15	85	7	72	100
	Chlorophyll α	µg/ℓ	8	1.0	0.2	0.7	1.3						14	0.7	0.3	0.3	1.2
Gooseberry R. Mouth	Total P (P)	mg/ℓ	8	0.008	0.005	0.005	0.015						15	0.013	0.006	0.010	0.030
	Total N (N)	mg/ℓ	8	0.38	0.10	0.27	0.54						16	0.48	0.14	0.24	0.68
	Chloride (Cl^-)	mg/ℓ	8	4.0	1.9	1.2	7.3						16	1.5	0.3	1.0	2.0
	Sulphate (SO_4^{2-})	mg/ℓ	8	5.9	2.6	2.0	8.7						16	3.6	0.6	3.0	5.1
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	8	2.5	0.2	2.3	3.0						16	3.3	1.5	2.0	6.3
	Conductivity	µS/cm	8	79	5	70	84						15	91	8	84	110
	Chlorophyll α	mg/ℓ	8	0.9	0.2	0.7	1.1						16	0.9	0.3	0.4	1.5
Bois Brule R. Mouth	Total P (P)	mg/ℓ	8	0.036	0.005	0.030	0.040	8	0.034	0.009	0.020	0.050					
	Total N (N)	mg/ℓ	8	0.69	0.06	0.57	0.76	8	0.40	0.91	0.19	0.46					
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	8	4.7	1.5	3.7	10.4	8	4.6	4.2	2.0	11.6					
Bad R. Mouth	Total P (P)	mg/ℓ	8	0.016	0.011	0.010	0.040	7	0.019	0.002	0.015	0.020					
	Total N (N)	mg/ℓ	8	0.38	0.05	0.31	0.44	7	0.40	0.02	0.39	0.44					
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	8	3.3	2.2	2.3	8.7	7	2.4	0.02	2.2	2.8					
Montreal River Mouth	Total P (P)	mg/ℓ	8	0.019	0.021	0.003	0.070						8	0.015	0.011	0.010	0.040
	Total N (N)	mg/ℓ	7	0.45	0.12	0.32	0.69						7	0.39	0.05	0.36	0.49
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	8	2.6	1.1	1.9	5.3						8	2.1	0.5	1.7	2.3

TABLE 4.1-4

SEASONAL VALUES FOR CONTROL AND IMPACTED AREAS IN LAKE SUPERIOR MICHIGAN WATERS

AREA	PARAMETER	UNITS	SEASONAL VALUES[a,b]															
			SPRING					FALL					ANNUAL				
			n	$\overline{x}$	S	Min.	Max.	n	$\overline{x}$	S	Min.	Max.	n	$\overline{x}$	S	Min.	Max.
Isle Royale (Control)	Total P (P)	mg/ℓ	12	0.003	0.004	<0.002(4)	0.017	9	0.004	0.003	0.002	0.010	21	0.004	0.003	<0.002(4)	0.017
	Total N (N)	mg/ℓ	12	0.388	0.061	0.326	0.551	9	0.399	0.082	0.314	0.571	21	0.393	0.069	0.314	0.571
	Chloride (Cl^-)	mg/ℓ	7	1.1	0.0	1.1	1.1	6	1.2	0.1	1.1	1.4	13	1.2	0.1	1.1	1.4
	Sulphate (SO_4^{2-})	mg/ℓ	8	3.2	0.1	3.0	3.4	6	3.3	0.4	2.8	3.8	14	3.3	0.3	2.8	3.8
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	8	2.6	0.1	2.5	2.6	6	2.3	0.1	2.2	2.4	14	2.4	0.2	2.2	2.6
	Conductivity	μS/cm	9	86	1	84	88	5	87	2	84	90	14	87	2	84	90
	Chlorophyll α	μg/ℓ	4	0.83	0.05	0.76	0.89	3	2.30	0.45	2.00	2.82	7	1.46	0.83	0.76	2.82
Ontonagon	Total P (P)	mg/ℓ	3	0.005	0.002	0.003	0.008	3	0.004	0.002	0.002	0.007	6	0.004	0.002	0.002	0.008
	Total N (N)	mg/ℓ	3	0.368	0.006	0.361	0.372	3	0.365	0.020	0.342	0.382	6	0.366	0.013	0.342	0.382
	Chloride (Cl^-)	mg/ℓ	2	2.1	0.0	2.1	2.1	2	1.6	0.6	1.2	2.0	4	1.9	0.4	1.2	2.1
	Sulphate (SO_4^{2-})	mg/ℓ	2	3.3	0.2	3.1	3.4	2	3.2	0.3	3.0	3.4	4	3.2	0.2	3.0	3.4
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	2.9	0.1	2.8	3.0	2	2.2	0.1	2.1	2.2	4	2.5	0.4	2.1	3.0
	Conductivity	μS/cm	3	90	2	89	92	3	89	1	89	90	6	90	1	89	92
	Chlorophyll α	μg/ℓ	1	2.02		2.02	2.02	1	1.71		1.71	1.71	2	1.87	0.22	1.71	2.02
Lower Portage Entry	Total P (P)	mg/ℓ						2	0.004	0.0	0.004	0.004					
	Total N (N)	mg/ℓ	3	0.448	0.031	0.421	0.483	2	0.426	0.020	0.412	0.441	5	0.439	0.027	0.412	0.483
	Chloride (Cl^-)	mg/ℓ	2	1.5	0.7	1.0	2.0	2	1.5	0.2	1.3	1.6	4	1.5	0.4	1.0	2.0
	Sulphate (SO_4^{2-})	mg/ℓ	2	3.2	0.8	2.6	3.7	2	3.1	0.2	2.9	3.2	4	3.1	0.5	2.6	3.7
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	3.5	1.2	2.6	4.3	2	2.3	0.1	2.2	2.3	4	2.9	1.0	2.2	4.3
	Conductivity	μS/cm	3	85	2	83	87	3	87	2	86	89	6	86	2	83	89
	Chlorophyll α	μg/ℓ	1	1.61		1.61	1.61	1	1.95		1.95	1.95	2	1.78	0.24	1.61	1.95
Presque Isle Harbor	Total P (P)	mg/ℓ	1	0.006		0.006	0.006	2	0.005	0.001	0.004	0.006	3	0.005	0.001	0.004	0.006
	Total N (N)	mg/ℓ	2	0.358	0.034	0.334	0.383	2	0.406	0.007	0.401	0.411	4	0.382	0.034	0.334	0.411
	Chloride (Cl^-)	mg/ℓ	2	<1.0(1)		<1.0(1)	1.0	2	1.3	0.0	1.3	1.3	4	1.2	0.2	<1.0(1)	1.3
	Sulphate (SO_4^{2-})	mg/ℓ	2	2.9	0.4	2.6	3.2	2	3.1	0.1	3.0	3.2	4	3.0	0.3	2.6	3.2
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	2.9	0.6	2.5	3.3	2	2.2	0.0	2.2	2.2	4	2.6	0.5	2.2	3.3
	Conductivity	μS/cm	2	86	1	85	87	2	90	1	89	90	4	88	2	85	90
	Chlorophyll α	μg/ℓ	1	0.88		0.88	0.88										
Carp River	Total P (P)	mg/ℓ	2	0.092	0.082	0.034	0.151	2	0.104	0.007	0.099	0.110	4	0.098	0.048	0.034	0.151
	Total N (N)	mg/ℓ	2	0.550	0.165	0.433	0.667	2	0.808	0.063	0.763	0.853	4	0.679	0.180	0.433	0.853
	Chloride (Cl^-)	mg/ℓ	2	4.8	2.1	3.3	6.3	2	5.7	1.5	4.6	6.7	4	5.2	1.6	3.3	6.7
	Sulphate (SO_4^{2-})	mg/ℓ	2	6.0	2.2	4.4	7.5	2	7.5	1.4	6.5	8.5	4	6.7	1.8	4.4	8.5
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	3.5	0.8	2.9	4.0	2	3.7	0.3	3.5	3.9	4	3.6	0.5	2.9	4.0
	Conductivity	μS/cm	2	119	11	111	126	2	136	13	127	145	4	127	14	111	145
	Chlorophyll α	μg/ℓ						1	3.10		3.10	3.10					
Munising	Total P (P)	mg/ℓ	2	0.018	0.018	0.005	0.031	2	0.014	0.014	0.004	0.024	4	0.016	0.013	0.004	0.031
	Total N (N)	mg/ℓ	2	0.432	0.057	0.392	0.473	2	0.419	0.104	0.345	0.493	4	0.425	0.069	0.345	0.493
	Chloride (Cl^-)	mg/ℓ	2	2.5	0.7	2.0	3.0	2	1.5	0.4	1.2	1.7	4	2.0	0.8	1.2	3.0
	Sulphate (SO_4^{2-})	mg/ℓ	2	4.6	0.7	4.1	5.1	2	3.0	0.2	2.8	3.1	4	3.8	1.0	2.8	5.1
	Dissolved Reactive Silicate (SiO_2)	mg/ℓ	2	4.2	0.9	3.5	4.8	2	2.5	0.4	2.2	2.7	4	3.3	1.1	2.2	4.8
	Conductivity	μS/cm	2	134	5	130	137	2	95	6	90	99	4	114	6	90	137
	Chlorophyll α	μg/ℓ	1	2.12		2.12	2.12	1	1.22		1.22	1.22	2	1.67	0.64	1.22	2.12

a. less than values (<) averaged using half of detection limit.

b. the number of samples having less than values is indicated in the parentheses.

waste water treatment plant (WWTP) located approximately 0.4 km upstream from the Carp River mouth. A biological survey in 1968 indicated significant degradation in the river below the treatment plant (31). At Munising, the value of total phosphorus at the river mouth was seven-fold higher than at the offshore stations. The high values of total phosphorus (0.016 mg/ℓ) and total nitrogen (0.425 mg/ℓ) in South Bay adjacent to Munising may be due to the municipal WWTP discharge to the Anna River and discharges from the Kimberly-Clark paper mill. A biological survey conducted in 1968 indicated that these two sources adversely affected water quality (32).

TOTAL NITROGEN

The mean surface concentration of total nitrogen in the Ontario nearshore areas was 0.310 mg N/ℓ (Figure 4.1-6). The total nitrogen was lower in segment C. In respect to segments A-C, the levels were elevated in D-J. The highest values were observed in the Wisconsin waters followed by Minnesota, Michigan, and Ontario.

Values for total nitrogen were fairly constant in Minnesota nearshore waters, but were above published values for the open lake (12). Nitrogen levels were much higher in segment F at the southwest corner of the lake, again due to the municipal and industrial loadings. All three stations in Wisconsin waters showed decreased concentrations of nitrate and ammonia compared to a 1968 study (13). Total organic nitrogen had higher concentrations in 1974.

In Michigan waters, annual means of total nitrogen ranged from 0.378 - 0.397 mg/ℓ with no significant differences in concentrations found between river mouth and offshore stations.

REACTIVE SILICATE

The average concentration of reactive silicate (Figure 4.1-7) in nearshore waters of Lake Superior was characteristic of the oligotrophic nature of the lake. The surface concentration in the nearshore areas was typified by the Ontario mean of 2.2 mg SiO_2/ℓ. The major source of silicate in the lake is the geological deposits in the drainage basin. Since silicate is utilized by diatoms, lower levels are expected in the surface waters where diatoms are active. The level of reactive silicate observed in the nearshore waters compared very well with the earlier studies reported in the literature, and is not considered a cause for concern (29,33).

HISTORICAL NUTRIENT DATA

Beeton (33) compiled the chemical compositions of Lake Superior waters and presented in a tabular form the average values for several parameters, covering the period 1850 to 1963. A comparison of the mean concentrations of nutrients found in this study with those of earlier studies suggests that the average concentrations of total phosphorus observed in segments A, B, and C by MOE; in D, E, and G by CCIW; and in

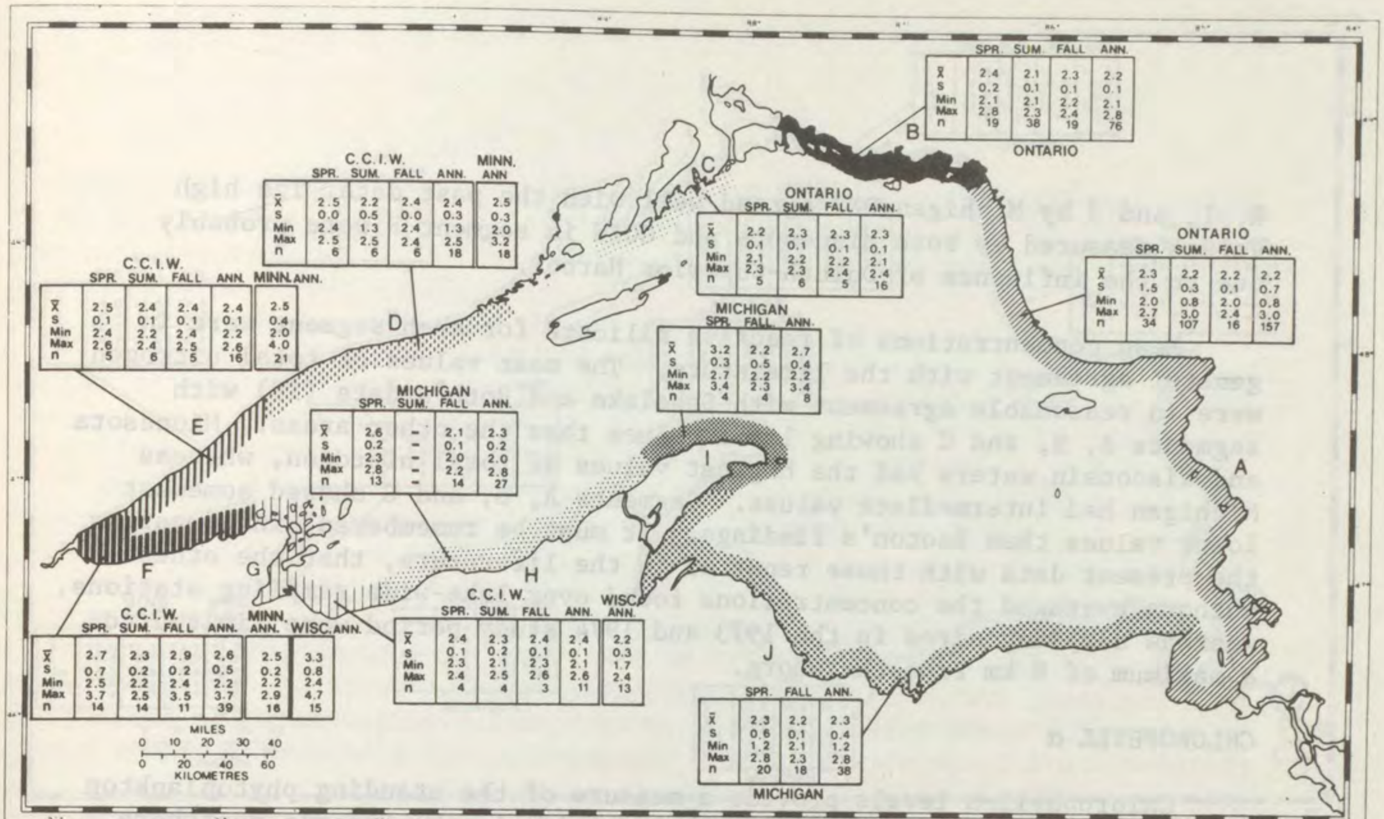


FIGURE 4.1-7 STATISTICAL SUMMARY OF NEARSHORE EPLIMNETIC WATERS, REACTIVE SILICATE (mg SiO_2/ℓ).

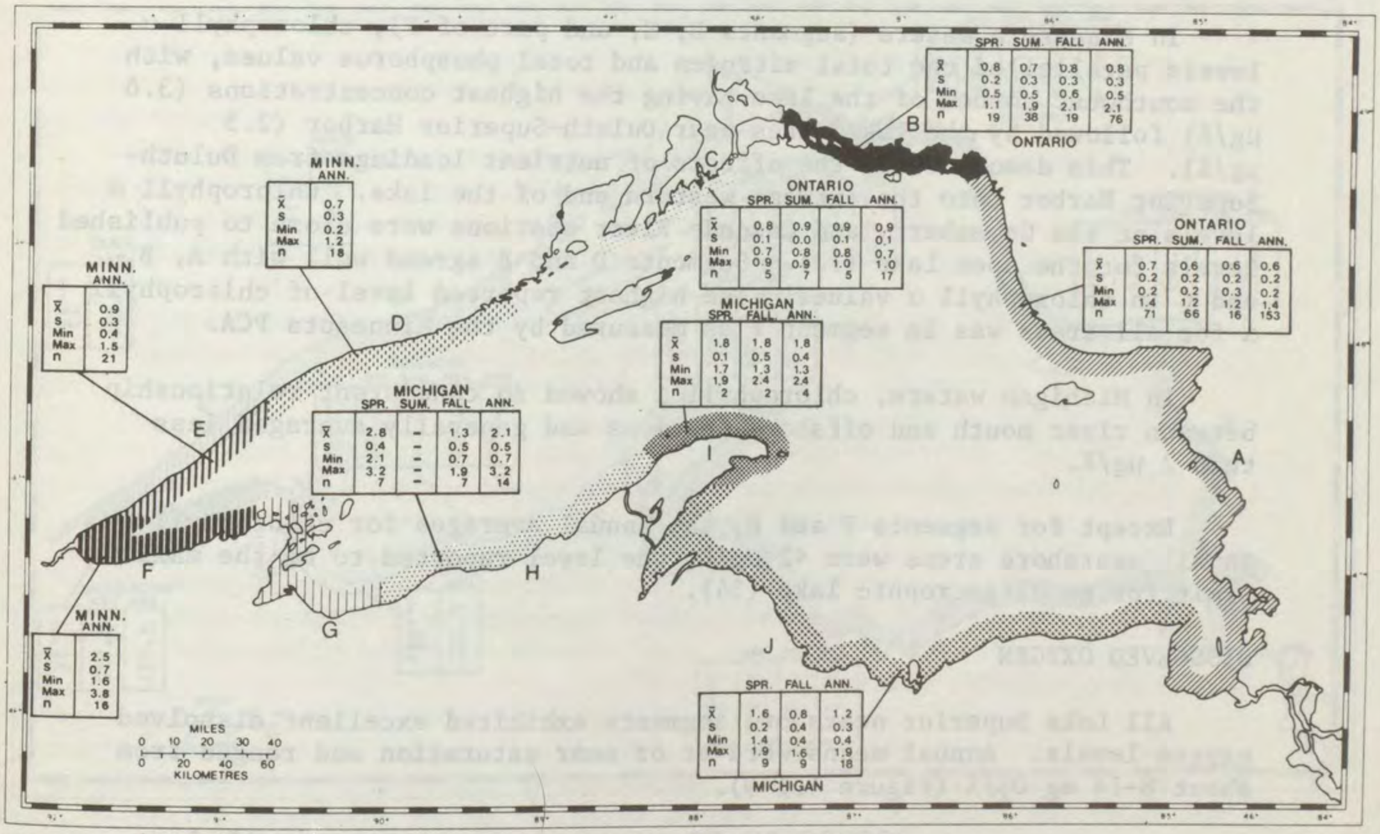


FIGURE 4.1-8 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, CHLOROPHYLL α (μg/ℓ).

H, I, and J by Michigan DNR agreed well with the past data. The high values measured by both Minnesota and CCIW in segment F were probably due to the influence of Duluth-Superior Harbor.

Mean concentrations of reactive silicate for each segment were in general agreement with the literature. The mean values of total nitrogen were in reasonable agreement with Schelske and Roth's data (29) with segments A, B, and C showing lower values than the other areas. Minnesota and Wisconsin waters had the highest values of total nitrogen, whereas Michigan had intermediate values. Segments A, B, and C showed somewhat lower values than Beeton's findings. It must be remembered, in comparing the present data with those reported in the literature, that the other authors averaged the concentrations found over lake-wide sampling stations, whereas sampling sites in the 1973 and 1974 study period were limited to a maximum of 8 km from the shore.

CHLOROPHYLL α

Chlorophyll α levels provide a measure of the standing phytoplankton crop. The average chlorophyll α concentration in the Ontario nearshore areas of Lake Superior (Figure 4.1-8) was found to be 0.8 μg/ℓ with maxima rarely exceeding 2 μg/ℓ at any location. In contrast, in the embayment areas the concentration ranged from 0.4 to 3.8 μg/ℓ.

In Minnesota waters (segments D, E, and part of F), chlorophyll α levels parallelled the total nitrogen and total phosphorus values, with the southwest corner of the lake having the highest concentrations (3.6 μg/ℓ) followed by the lake sites near Duluth-Superior Harbor (2.5 μg/ℓ). This demonstrates the effects of nutrient loadings from Duluth-Superior Harbor into the extreme western end of the lake. Chlorophyll α levels at the Gooseberry and Cascade River stations were close to published levels for the open lake (12). Segments D and E agreed well with A, B, and C in chlorophyll α values. The highest reported level of chlorophyll α for all areas was in segment F as measured by the Minnesota PCA.

In Michigan waters, chlorophyll α showed no consistent relationship between river mouth and offshore stations and generally averaged less than 2 μg/ℓ.

Except for segments F and H, the annual averages for chlorophyll α in all nearshore areas were <2 μg/ℓ, the level reported to be the maximum limit for an oligotrophic lake (34).

DISSOLVED OXYGEN

All Lake Superior nearshore segments exhibited excellent dissolved oxygen levels. Annual means were at or near saturation and ranged from about 8-14 mg O_2/ℓ (Figure 4.1-9).

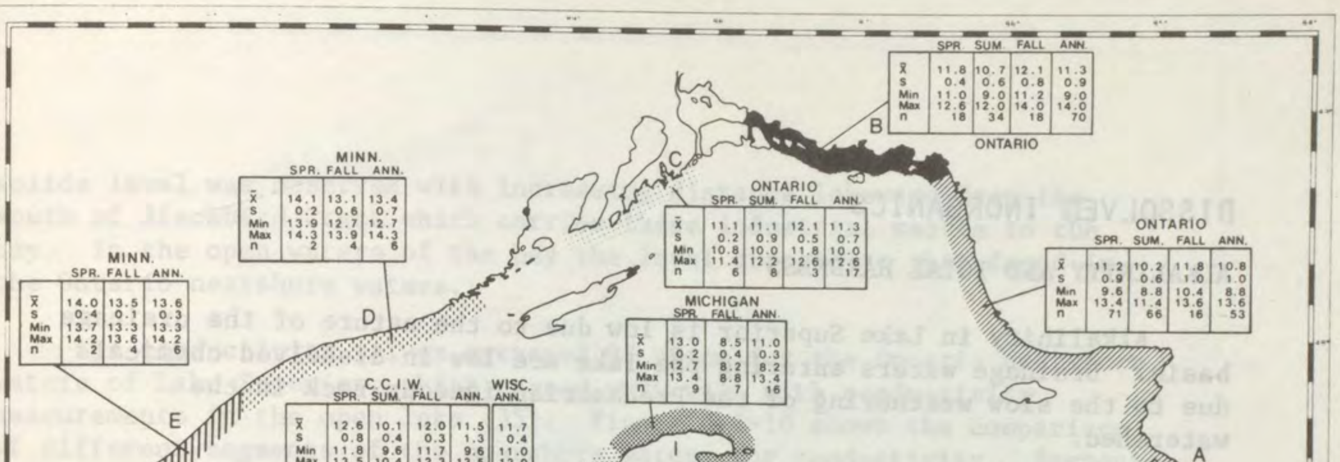


FIGURE 4.1-9 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, DISSOLVED OXYGEN (mg O_2/ℓ).

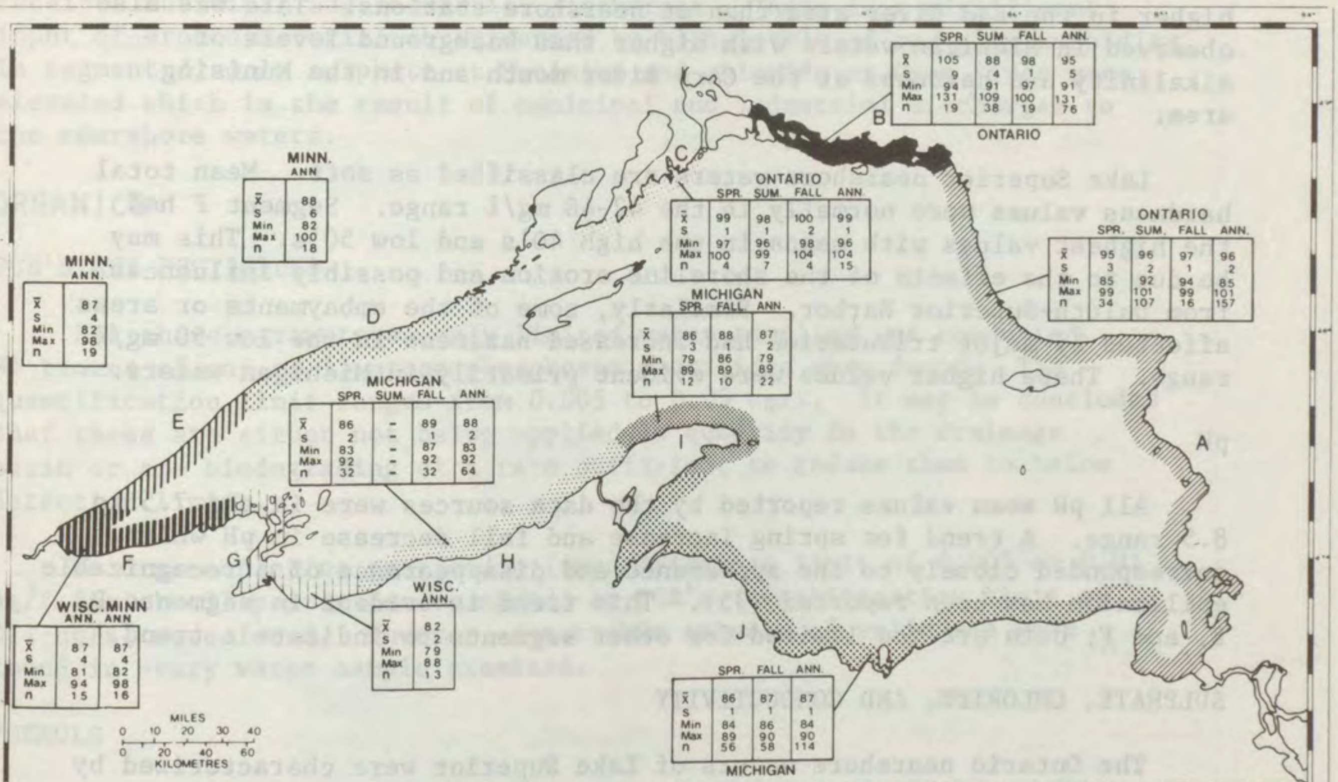


FIGURE 4.1-10 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, CONDUCTIVITY (μS/cm)

DISSOLVED INORGANICS

ALKALINITY AND TOTAL HARDNESS

Alkalinity in Lake Superior is low due to the nature of the drainage basin. Drainage waters entering the lake are low in dissolved chemicals due to the slow weathering of the Precambrian igneous rock in the watershed.

Mean values were generally in the 41 to 45 mg/ℓ range. It has been observed that alkalinity in the lake is highest in the spring and fall, prior to and after thermal stratification; this could be correlated with low water temperature and increased solubility of carbon dioxide (35). A definite rise in alkalinity was observed in the fall along the Ontario shoreline (segments A, B, and C). No other segments showed this type of fall increase, and no significant spring increase was evident. Alkalinity in embayments or in waters adjacent to tributaries varied slightly from the 41-45 mg/ℓ range with no trends discernible. In some areas, values dropped to 37 mg/ℓ (Montreal River mouth), and near the Carp River the value increased to >50 mg/ℓ.

Alkalinity values in Ontario embayment areas were variable and no trends could be defined. In Wisconsin waters, alkalinity levels were higher in the Bad River area than at nearshore stations. This was also observed in Michigan waters with higher than background levels of alkalinity and hardness at the Carp River mouth and in the Munising area.

Lake Superior nearshore waters are classified as soft. Mean total hardness values were normally in the 42-48 mg/ℓ range. Segment F had the highest values with means in the high 40's and low 50's. This may be due to the effects of the shoreline erosion and possibly influences from Duluth-Superior Harbor. Similarly, some of the embayments or areas affected by major tributaries had increased hardness in the low 50 mg/ℓ range. These higher values were evident primarily in Michigan waters.

pH

All pH mean values reported by the data sources were in the 7.5 to 8.5 range. A trend for spring increase and fall decrease in pH which corresponded closely to the appearance and disappearance of a recognizable epilimnion has been reported (35). This trend is evident in segments D, E, and F; data are too limited for other segments to indicate a trend.

SULPHATE, CHLORIDE, AND CONDUCTIVITY

The Ontario nearshore waters of Lake Superior were characterized by low "total dissolved solids" which averaged 62 mg/ℓ. Due to inputs and retention, the embayment areas showed somewhat higher dissolved solids content but did not exceed 105 mg/ℓ. The most significant levels of dissolved solids occur in Jackfish Bay which receives waste inputs from Kimberly-Clark of Canada Ltd. Considerable reduction in the dissolved solids level was observed with increasing distance lakeward from the mouth of Blackbird Creek which carries these industrial wastes to the bay. In the open waters of the bay the level dropped to that found in the Ontario nearshore waters.

The conductivity values averaged 97 µS/cm for the Ontario nearshore waters of Lake Superior, which agreed very well with conductivity measurements in the open lake (35). Figure 4.1-10 shows the comparison of different segments of the nearshore waters for conductivity. Segments F to J showed lower values ranging from 79 to 94 µS/cm, reflecting lower inputs of dissolved materials in the Wisconsin and Michigan waters.

The sulphate and chloride values for the nearshore segments are shown in Figures 4.1-11 and 4.1-12, respectively. Minnesota and Michigan measured these parameters in the nearshore waters, Wisconsin measured only chloride, and Ontario did not report any values for these two parameters. Sulphate ranged from 1.9 to 5.2 mg SO_4/ℓ whereas chloride had a range of 0-2 mg/ℓ.

In Michigan waters, river mouth values for sulphate and chloride were usually higher than nearshore segment values. The outer stations, however, usually were very near background water quality. In segment H, only chloride values at Ontonagon were higher. The Ontonagon River receives municipal and industrial discharges. There is a significant input of eroded material as evidenced by high levels of red clay turbidity. In segment J, only sulphate at Munising and chloride at Carp River were elevated which is the result of municipal and industrial discharges to the nearshore waters.

ORGANICS

PCB'S AND PESTICIDES

For these parameters, only limited water sampling was conducted. No traces of any of 15 organophosphorus pesticides were found. The quantification limit ranged from 0.005 to 0.05 µg/ℓ. It may be concluded that these are either not being applied in quantity in the drainage basin or are biodegrading at a rate sufficient to reduce them to below detection limits.

No organochlorine pesticides (quantification limit of 0.005 to 0.01 µg/ℓ for the 17 pesticides examined) or PCB's (quantification limit of 0.1 µg/ℓ) were found. However, detectable amounts of γ-lindane were found in every water sample examined.

PHENOLS

The mean level of phenolic substances in segments A to C was 3.3 µg/ℓ.

Concentrations of phenolic substances in Peninsula Harbour and Jackfish Bay waters were considerably higher than background levels of

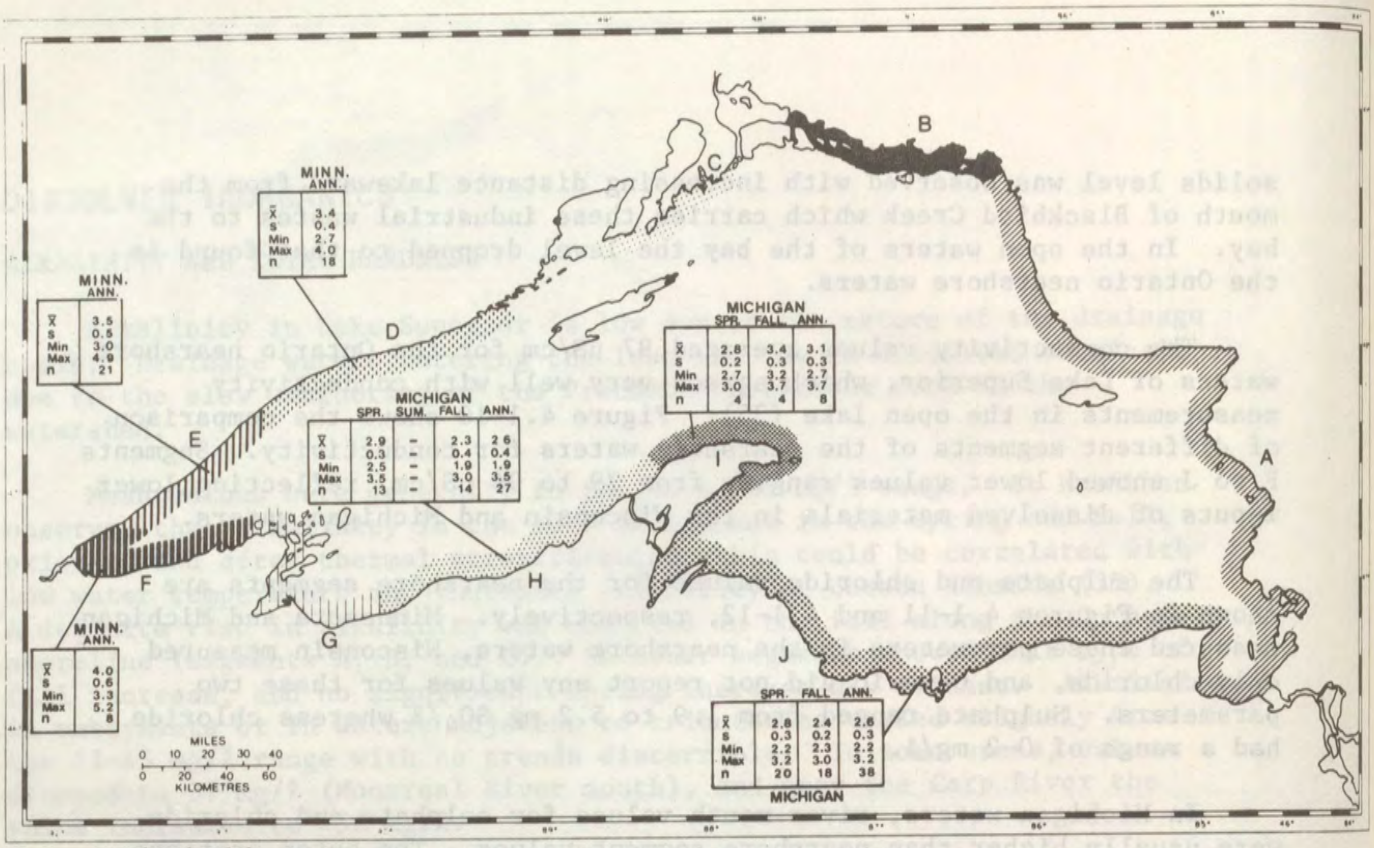


FIGURE 4.1-11 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, SULPHATE (mg SO_4/ℓ).

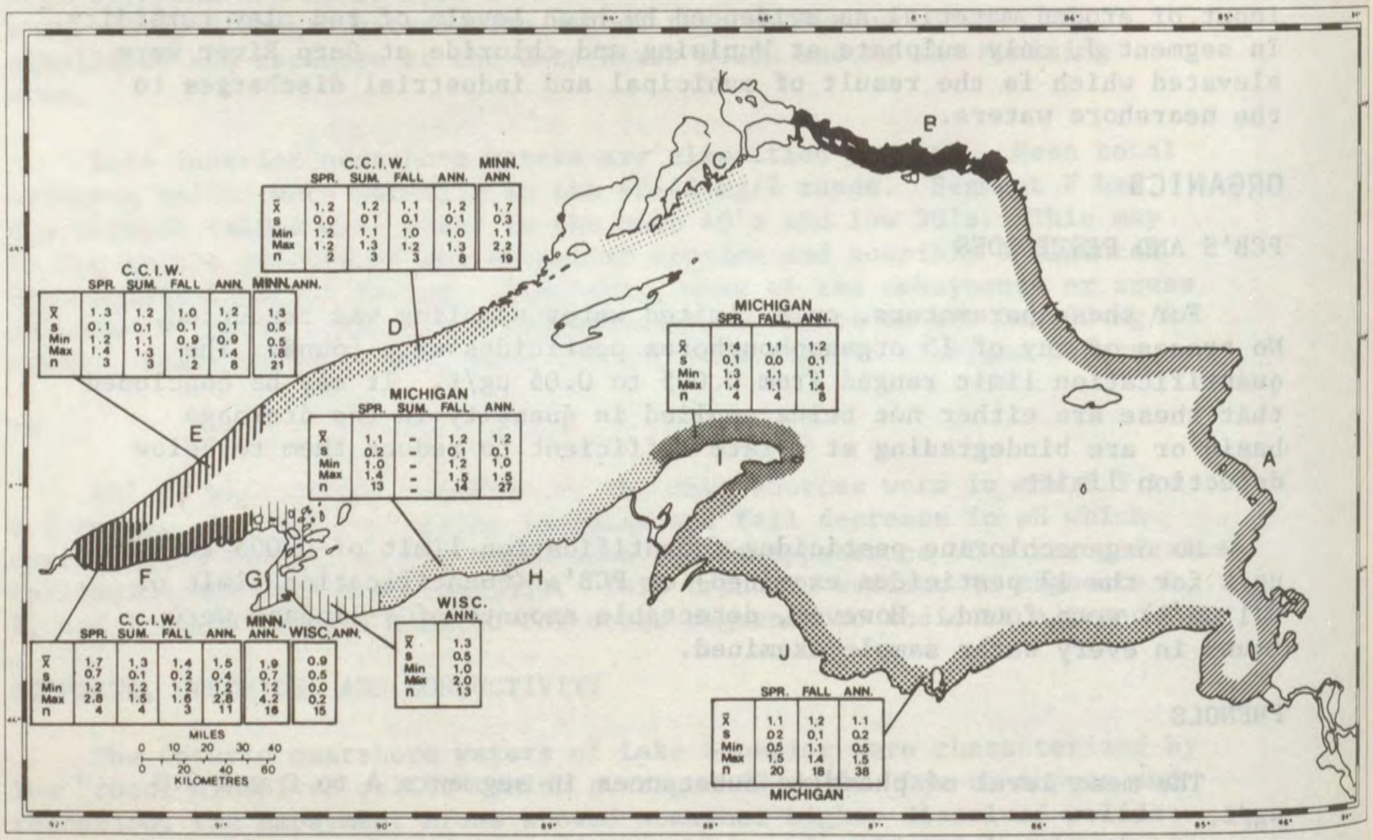


FIGURE 4.1-12 STATISTICAL SUMMARY OF NEARSHORE EPILIMNETIC WATERS, CHLORIDE (mg Cl/ℓ).

nearshore waters. Levels of phenolic substances in the waste plume of American Can of Canada Limited at Peninsula Harbour ranged from 6-80 µg/ℓ.

In Jackfish Bay, levels ranged from a mean of 60 µg/ℓ at 0.5 km from the mouth of Blackbird Creek to 4 µg/ℓ at a distance of 3.5 km from the creek mouth. This creek discharges wastes from Kimberly-Clark of Canada to Jackfish Bay. Levels of phenols in segments D to F were typically <2 µg/ℓ with a maximum value of 10 µg/ℓ reported in the Cascade River area.

HEAVY METALS

There is no heavy metal pollution in the waters of Lake Superior (Table 4.1-5). Both the open waters and the nearshore waters are devoid of harmful levels of nickel, lead, manganese, cadmium, chromium, iron, and zinc. Only iron and manganese are significantly higher in the western arm of Lake Superior (6.8 and 0.6 µg/ℓ, respectively). Nearshore and open lake levels are typically 2.0 and 0.3 µg/ℓ, respectively.

SEDIMENT CHARACTERISTICS

Mothersill (3,4,5) has summarized the surficial geology of the Canadian shoreline from the St. Marys River to Pigeon River. Nussmann (36) investigated the trace elements in the lake sediments. Grab samples of sediments taken in 1973 along the Canadian shoreline were examined for nutrients, heavy metals, percentage loss on ignition, phthalates, PCB's, and pesticides (6). Results are shown in Table 4.1-6 for heavy metals and in Table 4.1-7 for PCB's and pesticides.

Pollutants such as pesticides may be sorbed by soil aggregates and transported to lakes as sediments. However, pesticide analysis in Lake Superior sediments did not reveal the presence of lindane, heptachlor, aldrin, heptachlor epoxide, thiodan, dieldrin, or endrin. Only low levels of DDE, DDD, and DDT were found in these sediments.

During the development of a lake, algal organisms are sedimented to the bottom along with other organic and inorganic materials. Bacteria present at the bottom decompose the organic material, but a substantial portion may remain there and with the build-up of sediments over the years, they may never be exposed to the overlying waters. The quantities of organic phosphorus and nitrogen, and other chemical features, give an approximation of the productivity of the lake. The low nutrient levels found in these sediments confirm the low productivity of Lake Superior. Sediment samples collected in Jackfish Bay exhibited slightly higher levels of total nitrogen than the background levels in sediments of nearshore waters. It is, however, unlikely that a release of nutrients occurs from the sediments to the overlying waters since the bottom oxygen levels are near saturation. Accumulations of decomposing bottom deposits were found in some locations in Jackfish Bay. These deposits, consisting of wood fibres, clay, and silt, contained a maximum of 5% volatile material.

TABLE 4.1-5

HEAVY METALS IN LAKE SUPERIOR WATERS

LOCATION	SAMPLE TYPE[a]	n[b,c]	CONCENTRATION IN μg/ℓ[d]									
			As	Cd	Cr	Cu	Fe	Hg[e]	Mn	Ni	Pb	Zn
BLACK RIVER	UF	1	0.9	0.09	0.5	1.7	19	<0.02	0.6	<0.8	0.5	<2.3
	F	1	0.9	f	<0.4	0.8	0.8		0.3	<0.8	<0.2	f
ONTONAGON	UF	1	0.9	0.15	0.4	1.5	30	<0.02	0.6	<0.8	0.4	<1.6
	F	1	0.6	f	<0.3	1.0	2.0		f	<0.8	<0.2	f
U. PORTAGE ENTRY	UF	1	0.8	0.04	<0.3	1.3	43	<0.02	0.6	<0.9	0.2	<1.7
	F	1	0.7	<0.03	<0.3	0.9	0.6		0.3	<0.8	<0.2	f
L. PORTAGE ENTRY	UF	1	0.8	0.11	0.3	1.9	8.9	<0.02	0.6	<0.8	0.3	4.4
	F	1	0.7	0.11	<0.03	0.8	<1.4		f	<0.8	<0.2	f
EAGLE HARBOR	UF	2	0.8	0.11	0.3 <0.3	1.2	46	<0.02	0.8	<0.8	0.2 <0.2	<2.0 <1.5
	F	2	0.7	0.04	<0.3	0.7	0.8 <0.5		0.2	<0.8	<0.2	1.3
BIG BAY	UF	2	0.9	0.16	1.0	2.0	10.0	<0.02	0.5	<0.8	0.4	<2.7 2.6
	F	2	1.1	0.09	0.3	1.2	1.6 <0.5		0.2 <0.1	<0.8	<0.2	f
MARQUETTE HARBOR	UF	2	0.9	0.08 <0.04	0.4	1.1	20.1	<0.02	1.4	<0.8	0.4 <0.2	<2.5 <1.8
	F	2	1.2	0.11 <0.03	<0.3	<1.1 <1.0	6.6 <0.5		<0.2 0.1	<0.8	<0.2	f
CARP RIVER	UF	1	0.7	0.06	<0.3	1.3	6.0	<0.02	0.6	<0.8	0.4	<1.0
	F	1	0.7	f	<0.3	f	1.2		0.5	<0.8	<0.2	f
PRESQUE ISLE	UF	1	0.7	0.05	<0.3	0.9	7.0	<0.02	0.3	<0.8	<0.3	<1.1
	F	1	0.6	f	f	0.5	<0.5		f	<0.8	<0.2	f
MUNISING	UF	1	0.8	0.06	0.5	1.7	8.6	<0.02	0.7	<0.8	0.4	<2.1
	F	1	0.7	<0.03	<0.4	0.6	1.7		f	<0.8	<0.2	<1.0
GRAND MARAIS	UF	2	0.8(8)	0.27(8)	0.4 <0.3(8)	1.9(8)	5.2(8)	<0.03	0.4(8)	<0.8(9)	<0.6(8)	5.1 <2.7(8)
	F	2	0.7(3)	0.17(3)	<0.4 <1.0(3)	<1.6 <1.0(3)	<1.7 <0.7(3)		<0.05(3)	<0.8(3)	0.4 <0.2(3)	<4.0 <3.0(3)
WHITEFISH POINT	UF	1	0.8(5)	0.08(5)	0.4(5)	1.8(5)	10.3(5)	<0.04	0.5(5)	<0.9(5)	0.4(5)	2.4(5)
	F	1	0.7(2)	0.03(2)	<0.3(2)	<1.6(2)	1.5(2)		f	<0.8(2)	<0.2(2)	0.7(2)
CASCADE RIVER	UF+F	20	7.7 <1.0	0.05 <0.01	4.6 <0.3	1.5	12.9	0.22 <0.10	2.0 0.08	5.5 <1.0	0.4 <0.1	3.5
GOOSEBERRY RIVER	UF+F	22	3.9 <1.0	<0.05 <0.01	3.5 <0.2	1.7	91	0.17 <0.10	4.0	3.5 <1.0(21)	<0.2 <0.1	6.6
DULUTH	UF+F	24	3.1 <1.0(23)	0.22 <0.01	4.0 <0.3	1.5(23)	127	0.15 <0.10	4.6(23)	6.3 <1.0	4.5 <0.1	10.1
MINNESOTA POINT	UF	2	f	2	10	15	420	0.3	f	10	10	280
MIDDLE RIVER	UF	2	f	2	30	10	500	0.3	f	10	10	20
ASHLAND	UF	2	f	2	10	6	240	0.3	f	10	10	10
SAXON HARBOR	UF	2	f	2	20	7	120	0.3	f	10	10	10

a. UF: unfiltered; F: filtered (0.1 μm membrane); UF+F: mean includes both sample types.

b. For Michigan data, each UF sample (n) represents a composite of three individual samples.

c. If the number of sample is different from n shown, the total number of individual samples is shown in brackets after the individual result for the parameter.

d. If two values are shown, a mean could not be obtained and the range is shown.

e. Michigan Data - mercury analysis was carried out on a single unfiltered sample for each location.

f. Data not available.

TABLE 4.1-6

HEAVY METALS IN SURFICIAL SEDIMENTS OF LAKE SUPERIOR

		PARAMETERS[a,b]							
Location	Sample Size	Zinc mg/kg	Cadmium mg/kg	Lead mg/kg	Mercury mg/kg	Copper mg/kg	Chromium mg/kg	Nickel mg/kg	Iron %
SEGMENT A	10	54.3±34.4 10.2-105	1.03±0.03 1.00-1.05	24.1±13.4 6.5-47.1	0.033±0.027 0.006-0.072	26.7±17.6 2.8-55.0	26.9±15.0 3.7-45.4	21.0±11.8 2.8-36.2	1.60±0.70 0.42-2.36
SEGMENT B	8	67.2±44.5 27.0-150	<1.00-3.10	<8.0-62.2	0.204±0.388 0.026-1.160	39.7±32.3 8.3-92.0	38.1±16.7 18.9-65.9	29.8±11.9 17.1-49.6	1.77±0.84 0.94-2.10
SEGMENT C	5	84.6±21.4 53.9-109	<1.00	<8.0-30.0	0.047±0.041 0.001-0.089	37.0±11.3 23.3-54.3	45.4±13.2 30.8-65.4	41.9±6.4 34.6-51.0	2.97±0.22 2.73-3.30
PENINSULA HARBOUR	10	49.6±25.7 23.6-98.6	<1.00-3.00	<7.3-25.6	6.10±12.02 0.01-38.50		33.7±12.2 19.8-63.0		
JACKFISH BAY	6	76.6±31.7 48.6-92.6	<1.00	20.4±10.5 13.6-39.6	0.279±0.268 0.027-0.746		53.2±16.1 36.6-73.5		
NIPIGON BAY	2	68.4±44.7 36.8-100	<1.00	<8.0-27.8	0.088±0.036 0.062-0.113	50.5±13.4 41.0-60.0	51.1±17.3 38.9-63.3	45.9±8.9 39.6-52.2	2.66±0.08 2.60-2.72
BLACK BAY	3	62.9±37.9 24.2-100	<1.00-1.65	18.9±13.0 7.3-32.9	0.034±0.015 0.020-0.050	36.3±23.8 10.2-56.8	38.1±18.5 16.8-50.2	33.2±21.5 8.8-49.4	2.14±1.20 0.81-3.13
PINE BAY	4	76.0±14.0 65.6-96.6	2.19±0.51 1.93-2.96	<5.0	0.046±0.040 0.015-0.104	29.2±18.1 16.3-55.2	37.9±5.7 31.5-43.1	33.1±4.1 28.6-37.5	3.11±0.55 2.51-3.83
SEGMENT F	3	15.1±12.9 7.6-30.0	0.97±0.27 0.83-1.3	6.4±4.8 3.6-12.0	0.025±0.022 0.012-0.05	4.5±4.7 1.8-9.9	9.0±8.2 4.3-18.5	8.2±5.9 4.8-15.0	
CHEQUAMEGON BAY	1	62.0	6.0	32.0	0.16	24.0	26.0	20.0	
SEGMENT G	2	30.0±0	1.0±0	10.0±0	0.002±0	8.9±0	23.0±0	15.0±0	
BLACK RIVER	1	8.8	<0.4	3.0	<0.1	2.4	0.4	4.0	0.20
ONTONAGON	6	13.0±6.2 6.4 22.0	<0.4	<1.0-8.0	<0.1	10.6±8.0 5.4-26.0	6.1±3.0 3.2-11.0	10.0±6.2 5.0-20.0	0.34±0.21 0.26-0.62
U. PORTAGE ENTRY	3	19.0±10.1 10.0-30.0	<0.4	3.6±0.5 3.0-4.0	<0.1	154.0±109.5 82.0-280.0	10.5±8.3 4.8-20.0	20.3±15.3 10.0-38.0	0.61±0.46 0.28-1.14
L. PORTAGE ENTRY	3	8.1±1.2 6.8-9.0	<0.4	<1.0-1.0	<0.1	5.9±1.1 4.6-6.6	1.9±0.5 1.8-2.4	2.0±0.0 2.0-2.0	0.18±0.03 0.14-0.20
EAGLE HARBOR	1	14.0	<0.4	<1.0	<0.1	34.0	1.4	13.0	0.38
BIG BAY	1	22.0	<0.4	<1.0	<0.1	4.0	2.6	3.0	0.44
PRESQUE ISLE	6	21.8±13.9 10.0-48.0	<0.4	2.0±0.8 1.0-3.0	<0.1	5.9±6.4 2.6-19.0	9.4±8.4 3.8-26.0	35.5±51.7 6.0-140.0	0.43±0.21 0.30-0.84
CARP RIVER	6	11.1±3.4 6.6-17.0	<0.4	<1.0-3.0	<0.1	2.0±0.6 1.6-3.0	3.0±0.9 2.0-4.0	<1.0-5.0	0.25±0.07 0.17-0.36
MUNISING	6	134±42.5 87.0-190	<0.4	79.5±44.3 44.0-150	0.28±0.13 0.20-0.50	96.6±37.1 51.0-150.0	8.4±5.0 2.4-15.0	28.0±8.9 16.0-38.0	1.20±0.30 0.73-1.50
WHITEFISH POINT	2	16.5±3.5 14.0-19.0	<0.4	4.0±1.4 3.0-5.0	<0.1	6.8±4.5 3.6-10.0	<0.2-0.8	5.0±1.4 4.0-6.0	0.33±0.13 0.24-0.42

a. Key: Mean±Standard Deviation
Minimum Value-Maximum Value

b. If mean and standard deviation are not shown, more than 15% of the results were less than (<) values or sample size = 1.

TABLE 4.1-7

PCB's AND PESTICIDES IN SEDIMENTS FROM LAKE SUPERIOR

LOCATION	CONCENTRATION IN µg/kg[a]					
	n		PCB	DDE	DDD	DDT
Segment A	10	Min.	b	b	b	b
		Max.	<10	4.2	2.7	1.3
		Mean		1.3		
		Std.Dev.		1.5		
Segment B	8	Min.	b	b	b	b
		Max.	250	3.6	3.2	0.8
		Mean				
		Std.Dev.				
Segment C	5	Min.	b	0.2	0.4	0.5
		Max.	<10	1.0	0.5	1.0
		Mean		0.5	0.5	0.8
		Std.Dev.		0.3	0.1	0.2
Peninsula Harbour	10	Min.	10	c	c	c
		Max.	6500			
		Mean	924			
		Std.Dev.	2000			
Jackfish Bay	6	Min.	b	b	b	b
		Max.	100			
		Mean				
		Std.Dev.				
Nipigon Bay	2	Min.	b	0.9	0.7	1.0
		Max.		3.4	2.3	1.1
		Mean		2.2	1.5	1.1
		Std.Dev.		1.8	1.1	0.1
Black Bay	3	Min.	b	1.0	b	b
		Max.		11.0	4	3
		Mean		6.3		
		Std.Dev.		5.0		
Pine Bay	4	Min.	b	b	b	b
		Max.				
		Mean				
		Std.Dev.				

a. If mean and standard deviation are not shown, then less than (<) values were found for more than 15% of the samples.

b. No detectable concentration

c. No data

PCB levels were found to be extremely low. Out of 28 samples, only three had measurable levels, seven showed trace amounts below the sensitivity limit of the test, and 18 did not have any detectable PCB concentration. PCB's are very sparingly soluble in water but are extremely persistent in the environment. They can be transmitted readily through the food chain. The measurable levels occurred in the vicinity of Marathon where a maximum concentration of 250 μg/kg was found. PCB's in whitefish from this area exceeded allowable limits for human consumption. A local pulp producing industry is the probable source.

The heavy metal analyses for sediment samples collected in the nearshore waters included determinations for mercury, lead, copper, chromium, cadmium, zinc, nickel, and iron. Various workers have demonstrated a requirement of aquatic plants for these substances in low concentrations. In higher concentrations, however, they become toxic to the aquatic system. There is a lack of information on levels at which heavy metals seriously affect the biota.

From an examination of Table 4.1-6, it is evident that the sediments near localized centres of population and industrialization showed somewhat higher levels of accumulation of heavy metals than the non-industrialized areas. The heavy metal levels in the undeveloped areas reflect natural levels due to soil weathering and geochemical processes, although it is possible that they may be secondarily affected by the transport of sediment from the industrial areas.

Significant mercury contamination of sediments compared to the background levels in adjacent nearshore areas was observed in Peninsula Harbour, and is attributed to past mercury losses from a chlor-alkali plant in the area. The sediment sampling locations in this special study and concentrations of mercury are contained in a separate report (7).

In Wisconsin waters, sediment samples from four locations were analyzed for heavy metals. Samples from stations outside Duluth-Superior Harbor, the Iron River, and the Montreal River contained low concentrations of metals. Sediments from a station in Chequamegon Bay, however, contained high concentrations of metals compared to the background levels in the nearshore areas. These materials were presumably discharged by upstream industries.

During the study period, no sediment samples were taken in Minnesota waters. The sediments from the impacted locations in Michigan waters had very low levels of pesticides, PCB's, metals, nutrients and chemical oxygen demand (COD). In Munising Bay, however, all samples had elevated levels of diethylhexyl phthalate (1400 to 4100 μg/kg), hexane-extractable oils and grease (1500 to 61,000 mg/kg), and copper (7.2 to 150 mg/kg). Levels of total Kjeldahl nitrogen, COD, volatile solids, lead, and zinc at this location were above the EPA dredge spoil disposal guidelines (Appendix C). The only other location to have elevated sediment constituents was Upper Portage Entry, which had copper concentrations ranging from 82 to 280 mg/kg. These high copper levels are attributed to past copper mill tailings discharges.

AQUATIC BIOLOGY

Biological communities react measurably to subtle changes in water quality, thereby producing an assessment of water quality integrated over time. Long-term trends, as well as subtle changes in water quality, become detectable and quantifiable and thereby complement water chemistry studies.

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

MICROBIOLOGY

The bacteriological quality of Lake Superior nearshore waters has been extensively studied (6,37-40). Different analytical procedures were used which limits comparison of different nearshore regions. Selected data which characterize the waters are summarized in Tables 4.1-8, 4.1-9 and 4.1-10.

ONTARIO

Ontario data from segments A, B, and C, Peninsula Harbour, Jackfish Bay, Black Bay, Nipigon Bay, and Pine Bay indicate high bacteriological quality except in restricted localized areas (6,41).

Total coliform counts were lowest in the spring and highest in the fall (Table 4.1-8). Michipicoten Harbour in segment A and Peninsula Harbour in segment B have elevated total coliform counts which approach Agreement objectives. Batchawana Bay (segment A), during August-September, has densities ranging from 100 to 999 counts/100 mℓ. These levels may have been due to the increased recreational use of this area during this period (41). Total coliform densities throughout the study period were highest in segment B.

Fecal coliform counts at all stations, except one station near Peninsula Harbour, had geometric means <100 counts/100 mℓ (Table 4.1-9). Nearly 80% of all stations had means <1 count/100 mℓ with no seasonal or geographic trends apparent.

Fecal streptococci densities in Ontario's nearshore waters were low, except in Batchawana Bay (Segment A), where elevated counts occurred during August and September (Table 4.1-10). During this period, densities

TABLE 4.1-8

TOTAL COLIFORM DENSITIES IN THE SURFACE WATERS OF LAKE SUPERIOR, 1973 AND 1974[a]

LOCATION	PERCENT OF SAMPLES IN COUNT RANGE									
ONTARIO	JUNE - JULY 1973				AUGUST - SEPTEMBER, 1973			OCTOBER - NOVEMBER, 1973		
	≤1	2-99	100-999	≥1000	≤1	2 - 99	100 - 999	≤1	2 - 99	100 - 999
Segment A	72	21	7		54	21	25		89	11
Segment B	42	50	8		34	50	16	6	61	33
Segment C	70	30			80	20		22	78	
Jackfish Bay		14	43	43						
Peninsula Harbour	60	20	20							
Black Bay	22	45	33							
Pine Bay					25	50	25			
Nipigon Bay	50	50			67	33			70	30

MINNESOTA	SEPTEMBER - OCTOBER, 1974		
	< 2	2 - 99	100 - 999
Segment D (Cascade R.)	42	54	4
Segment E (Gooseberry R.)	39	61	

WISCONSIN	JUNE, 1974[b]			SEPTEMBER, 1974	
	<100	100 - 999	≥1000	<100	100 - 999
Segment F	27	68	5	100	
Segment G	74	26		14	86
Montreal River	76	12	12		

MICHIGAN	JUNE, 1974			AUGUST - SEPTEMBER, 1974		
	<100	100 - 999	≥1000	<100	100 - 999	≥1000
Segment H	86	14		65	21	14
Ontonagon	92	8		29	36	36
Segment I	100			100		
Segment J	100			61	39	
Lower Portage Entry	25	75		87	13	
Presque Isle	29	71		100		
Carp River	93	7		51	29	21
Munising	14	65	21	21	64	15

a. Data for Ontario (40, 41), Minnesota (12), Wisconsin (14), and Michigan (15) summarized from specific project reports. All analyses by Millipore filter method, except Minnesota (most probable number technique).

b. June percentages averaged Membrane Filter (MF) counts/100 mℓ with standard plate (SP) counts/100 mℓ.

TABLE 4.1-9

FECAL COLIFORM DENSITIES IN THE SURFACE WATERS OF LAKE SUPERIOR, 1973 AND 1974[a]

LOCATION	PERCENT OF SAMPLES IN COUNT RANGE							
ONTARIO	JUNE - JULY, 1973			AUGUST - SEPTEMBER, 1973			OCTOBER - NOVEMBER, 1973	
	≤1	2 - 99	100 - 199	≤1	2 - 99	100 - 199	≤1	2 - 99
Segment A	95	5		98	2		96	4
Segment B	89	11		81	16	3	94	6
Segment C	100			100			100	
Jackfish Bay	57	43						
Peninsula Harbour	67	17	17					
Black Bay	100							
Pine Bay				100				
Nipigon Bay	100			100			88	12

MINNESOTA	SEPTEMBER - OCTOBER, 1974
	<10
Segment D (Cascade R.)	100
Segment E (Gooseberry R.)	100

WISCONSIN	JUNE, 1974[b]		OCTOBER, 1974	
	<10	10 - 99	<10	10 - 99
Segment F	48	52		100
Segment G	92	8	100	
Montreal River	88	12	88	12

MICHIGAN	JUNE, 1974		AUGUST - SEPTEMBER, 1974			
	<10	10 - 99	<10	10 - 99	100 - 199	≥200
Segment H	93	7	93	7		
Ontonagon	100		50	36	7	7
Segment I	100		100			
Segment J	100		100			
Lower Portage Entry	100		100			
Presque Isle	100		100			
Carp River	100		79	7		14
Munising	50	50	79	21		

a. Data for Ontario (40, 41), Minnesota (12), Wisconsin (14), and Michigan (15) summarized from specific project reports. All analyses by Millipore Filter method, except Minnesota (most probable number technique).

b. June percentages averaged Membrane Filter (MF) counts/100 mℓ with standard plate (SP) counts/100 mℓ.

TABLE 4.1-10

FECAL STREPTOCOCCI DENSITIES IN SURFACE WATERS OF LAKE SUPERIOR, 1973 AND 1974[a]

PERCENT OF SAMPLES IN COUNT RANGE

LOCATION	JUNE - JULY, 1973			AUGUST - SEPTEMBER, 1973				OCTOBER - NOVEMBER, 1973	
ONTARIO	≤1	2 - 19	20 - 99	≤1	2 - 19	20 - 99	≥100	≤1	2 - 19
Segment A	85	15		75	12	3	10	85	15
Segment B	84	14	2	92	8			88	12
Segment C	90	10		100				72	28
Jackfish Bay	29	29	43						
Peninsula Harbour	50	50							
Black Bay	100								
Pine Bay				50	50				
Nipigon Bay	83	17		100				88	12

WISCONSIN	JUNE, 1974		
	<1	10 - 19	20 - 99
Segment F	40	40	20
Segment G	83	11	6

MICHIGAN	JUNE, 1974				AUGUST - SEPTEMBER, 1974		
	<10	10 - 19	20 - 99	≥100	<10	10 - 19	≥100
Segment H	71	29			93	7	
Ontonagon	83	17			86	14	
Segment I	100				100		
Segment J	100				100		
Lower Portage Entry	100				100		
Presque Isle	80	20			100		
Carp River	100				72	14	14
Munising	14	21	50	14	100		

a. Data for Ontario (40, 41), Wisconsin (14), and Michigan (15) summarized from specific project reports.

frequently exceeded 100 counts/100 mℓ with hypolimnion values higher than corresponding surface water counts.

Jackfish Bay, which receives pulp and paper mill wastes, exhibited high total coliforms, fecal coliforms, and fecal streptococci levels. Total coliform densities frequently exceeded Agreement objectives. Elevated densities were observed up to 1 km from the industrial wastewater outfall.

Industrial wastes discharged directly to Lake Superior outside Peninsula Harbour result in bacterial contamination up to 1.6 km from the outfall (7). High bacteria levels associated with the effluent plume frequently exceeded Ontario's public water supply and recreational criteria. Fecal streptococci densities also exceeded Ontario criteria (7). Although bacteria levels vary with time, all counts were high in comparison to control stations in non-industrialized areas and in that portion of the harbour receiving no wastes (7).

Except for a localized area in the western part of Nipigon Bay, populations of health indicator bacteria throughout this embayment were characteristic of Lake Superior nearshore areas. The western shore receives process wastes from pulp and paper operations combined with sanitary wastes in a single effluent stream. Bacterial populations, which were very high in the discharge channel, declined rapidly with increasing distance from the source. Within the area covered by the waste plume, total coliform counts exceeded 1,000 organisms/100 mℓ in 14% of 38 samples. Of 50 samples enumerated for fecal streptococci, 18% and 44% exceeded 50 counts/100 mℓ and 20 counts/100 mℓ, respectively. Fecal coliform densities were <200 organisms/100 mℓ for all plume samples. On a geometric mean basis, bacterial densities in the plume area did not exceed water quality objectives. However, levels of health indicator bacteria in western Nipigon Bay are certainly elevated in respect to nearshore areas as a result of waste discharges.

Black Bay, whose drainage basin is largely forested and sparsely populated with no direct waste discharges, has slightly elevated total coliform densities, but bacteriological quality is similar to other unaffected Lake Superior nearshore waters.

MINNESOTA

Geometric means for data from the nearshore area adjacent to the Gooseberry and Cascade Rivers were generally <3 MPN/100 mℓ for fecal coliform and <100 MPN/100 mℓ for total coliform. Geometric means for data from the nearshore area adjacent to Duluth-Superior Harbor were generally <17 MPN/100 mℓ for fecal coliform and <50 MPN/100 mℓ for total coliform (12).

WISCONSIN

Wisconsin nearshore segments F and G and locations at the mouth of the Brule, Bad, and Montreal Rivers had fecal coliform and fecal streptococci densities <10 counts/100 mℓ at all but four stations with little variability between surface and bottom bacterial densities (14). Slightly elevated fecal streptococci counts (20-40/100 mℓ) were observed at some stations off the Middle, Brule, Iron, and Bad Rivers. Only harbours and river mouths had fecal coliform and fecal streptococci counts exceeding the detection limits of 10 counts/100 mℓ. Two stations near the Brule River and adjacent nearshore areas suggested a localized river influence on the lake (14).

MICHIGAN

The majority of samples collected in Michigan nearshore segments H, I, and J and around Isle Royale had total coliform, fecal coliform, and fecal streptococci densities below the measurable limits (15).

Total coliform densities exceeding Agreement objectives were observed at Black River, Ontonagon, Carp River, and Munising where municipal wastewaters are discharged to rivers flowing into Lake Superior. Maximum total coliform densities recorded at the mouth of the Carp River were 1,480,000 and 1,160,000/100 mℓ. These high values decreased rapidly with distance offshore. All other locations had total coliform densities <500 counts/100 mℓ.

Fecal coliform densities were <10 counts/100 mℓ in all samples from all locations except Black River, Ontonagon, Carp River, and Munising. Fourteen percent of the Carp River samples and 7% of the Ontonagon samples had fecal coliform densities exceeding 200 counts/100 mℓ in the fall. As with total coliforms, fecal coliform densities were highest at river mouth stations. Maximum fecal coliform densities of 17,800 counts/100 mℓ were also found at the Carp River mouth.

Fecal streptococci densities for all locations were generally at or below the detection limit (10 counts/100 mℓ). However, in the spring 14% of the samples from Munising exceeded 100 counts/100 mℓ. Elevated fecal streptococci densities were recorded at Carp River with 14% of the samples having densities >100 counts/100 mℓ during fall sampling. Fecal streptococci densities from samples at the mouth of the Carp River were up to 3,710 counts/100 mℓ.

PHYTOPLANKTON

The historical information on the phytoplankton of Lake Superior is limited and usually restricted to studies reporting net plankton. Holland (42) found an oligotrophic diatom assemblage in 1964 dominated by small species of *Cyclotella (C. glomerata, C. stelligera, C. ocellata,* and *C. kutzingiana)*. Schelske *et al.* (43) reported a dominance of diatoms, especially the genus *Cyclotella,* in both nearshore and offshore waters.

Other common diatoms reported by Schelske and Roth (29) were *Asterionella*, *Tabellaria*, and *Synedra*. *Dinobryon* and *Fragilaria* have also been reported (44).

Lake Superior is classed as oligotrophic in a review by Vollenweider *et al.* (45). They found that algal populations include diatoms, chrysomonads, cryptomonads, dinoflagellates, and green and blue-green algae.

MICHIGAN

The dominant and abundant phytoplankton in Michigan nearshore waters of Lake Superior are summarized in Table 4.1-11 (15). The standing crops are relatively low; the numbers are not indicative of enriched waters, except one station near the mouth of the Carp River which had large numbers of *Stephanodiscus invisitatus*, a common eutrophic plankton.

Diatoms are more abundant than other algae and in the spring are numerically dominant. *Dinobryon spp.* increase in the fall to about a quarter and the diatoms decrease to about a third of the total numbers. The algal community in the fall was characterized by few abundant species, reduced numerical dominance of diatoms, and an increase in *Dinobryon spp.* and *Rhodomonas minuta*.

Isle Royale was different from the rest of the Michigan nearshore waters primarily in the low numbers of algae and in the different relative proportions of species. Although diatoms dominate in the spring, cryptophytes were not found and the number of *Dinobryon spp.* are minimal. In the fall, *Dinobryon spp.* increased to about half and diatoms decreased to about a third of the total population.

WISCONSIN

The phytoplankton community in Wisconsin nearshore waters (segments F and G) and at the mouths of the Brule, Bad, and Montreal Rivers was dominated by *Asterionella* and *Melosira*, while *Cyclotella* was not abundant (Table 4.1-11)(14). Lower numbers of *Cyclotella* were probably found in Wisconsin due to sampling gear differences. The diatom assemblage indicates the oligotrophic nature of Wisconsin's Lake Superior waters and agrees with observations of Davis (44).

MINNESOTA

In terms of organisms/ℓ, the phytoplankton community in Minnesota nearshore waters in the vicinity of Duluth-Superior Harbor and the Gooseberry and Cascade Rivers was dominated by two species of Cryptophyceae, *Croomonas acuta* and *Cryptomonas erosa*. In terms of cells/ℓ, the dominant algae class in the vicinity of the Gooseberry and Cascade Rivers was the Cyanophyceae while in the vicinity of Duluth-Superior Harbor, algae varied between Cyanophyceae and Bacillariophyceae. Most of the Bacillariophyceae abundance adjacent to Duluth-Superior Harbor was contributed by *Melosira islandica* and *Melosira granulata* (Table 4.1-11) (12).

TABLE 4.1-11

ABUNDANT OR DOMINANT PHYTOPLANKTON IN NEARSHORE LAKE SUPERIOR WATERS[a]

LOCATION	GROUP (PHYLUM)	GENERA OR SPECIES	COMMENTS
MICHIGAN	Diatoms (Bacillariophyta)	*Asterionella formosa, Cyclotella compta Cyclotella glomerata, Cyclotella kutzingiana, Cyclotella ocellata, Synedra tenera, Melosira granulata, Fragilaria crotonensis*	*Cyclotella* spp. was generally the dominant algae.
	Blue-greens (Cyanophyta)	*Oscillatoria prolifica*	Was abundant only in Whitefish Bay.
	Yellow-browns (Chrysophyta)	*Dinobryon* spp.	
	Cryptophyta	*Rhodomonas minuta*	Often *R. minuta* was the most abundant species.
WISCONSIN	Diatoms (Bacillariophyta)	*Asterionella, Melosira, Fragilaria, Tabellaria, Cyclotella, Synedra*	*Asterionella* or *Melosira* dominated all samples.
MINNESOTA	Diatoms (Bacillariophyta)	*Melosira islandica, Melosira granulata*	*M. pulverea* was dominant at all stations on a cell/litre basis. *C. acuta* and *C. erosa* were the most abundant species on an organism/litre basis.
	Blue-greens (Cyanophyta)	*Microcystis pulverea, Spirulina okensis*	
	Cryptophyta	*Coomonas acuta, Cryptomonas erosa, Cryptomonas marsonii*	
ONTARIO	Diatoms (Bacillariophyta)	*Tabellaria fenestrata, Asterionella formosa, Rhizsosolenia oriensis, Fragelaria crotonensis*	*F. crotonensis* was the most abundant at all locations.*T. fenestrata, A. formosa* were important during spring and early summer.
	Blue-greens (Cyanophyta)	*Aphanothece* spp., *Chroococcus* spp.	
	Yellow-browns (Chrysophyta)	*Dinobryon* spp.	
	Cryptophyta	*Cryptomoras erosa, Rhodomonas minuta*	

---

a. Data for Ontario (46), Minnesota (12), Wisconsin (14), and Michigan (15) are summarized from specific project reports.

Changes in the blue-green algae counts, primarily for *Microcystis pulverea* and *Spirulina okensis* accounted for much of the changes in total algal abundance at all sampling locations. These two algal species were more abundant in the fall than in summer.

ONTARIO

Ontario waters were sampled at Bare Point, Squaw Bay, Sturgeon Bay, Cloud Bay, Pine Bay, and Gros Cap (46). Oligotrophic planktonic species generally characterized the algal flora in Ontario's nearshore waters of Lake Superior with diatoms dominating. Blue-green algae and the chrysophyte, *Dinobryon spp.*, contributed substantially to the flora during the late summer and early fall months. Cryptophytes were rarely identified from the Gros Cap sites (46). A classifical bimodal pattern of plankton development (47) characterized the standing crop at Gros Cap, although the peaks occurred later in the growing season than they do in Lakes Ontario and Erie. The pattern was not so clearly defined in the St. Marys River, and although the data are insufficient, this pattern was also apparent at Bare Point. The predominant algal forms in Sturgeon, Squaw, Pine, and Cloud Bays were typical of forms reported previously for Lake Superior.

A special study in Nipigon Bay noted the absence of plankton in an area of 0.25 km^2 adjacent to a pulp and paper mill outfall. Experimental testing of the effluent indicated that concentrations as low as $10^{-4}\%$ have an immediate inhibitive effect on both periphyton and phytoplankton productivity by reducing photosynthetic activity. Periphyton was shown to be less sensitive to the effluent than phytoplankton.

ZOOPLANKTON

Selgeby (48) described the seasonal variation and abundance of crustacean zooplankton in Lake Superior during 1971 and 1972. He found *Cyclops bicuspidatus thomasi, Diaptomus ashlandi, D. silicis, Limnocalanus macrurus,* and *Senecella calanoides* throughout the year.

The crustacean zooplankton of Lake Superior are generally dominated by diaptomids, primarily *D. sicilis* and *D. ashlandi,* and the cyclopoid *C. bicuspidatus thomasi* (49). The most abundant cladoceran was *Bosmina longirostris.* While *Limnocalanus macrurus* should be abundant, it is often underestimated because it migrates below 50 m during daylight hours (50). The crustacean species *Senecella calanoides* and *Limnocalanus macrurus* generally indicate cold oligotrophic waters.

Nauwerck (51) recorded about 20 rotiferan taxa from summer and autumn samples with *Kellicottia longispina, Conochilus unicornis,* and *Polyarthra vulgaris* the most common species. *Gastropus stylifer, Collotheca mutabilis,* and *Conochiloides dossuarius* were also often found. Nauwerck indicated that in the Great Lakes, *Kellicottia, Conochilus,* and *Gastropus* were oligotrophic genera while *Brachionus, Filinia,* and *Keratella* were considered eutrophic or mesotrophic.

MICHIGAN

The abundant or common rotifers found in Michigan's nearshore waters are presented in Table 4.1-12 (15). Rotifers and crustaceans were most abundant at stations located closest to shore or at river mouths. They were least abundant in the Isle Royale area and most abundant at the Carp River in the spring. There is no apparent seasonal difference in abundance.

The relative proportion of calanoid copepods to cladocerans plus rotifers may be a useful ratio to assess changes in the trophic state of the Great Lakes (52). Lower Portage Entry was the only location which did not have at least a ratio of 1.0 in spring samples, which may indicate enrichment in the Lower Portage area.

The waters around Isle Royale are different from other Michigan nearshore waters. The densities of zooplankton at Isle Royale are lower and the percentage of calanoid copepods is reduced below corresponding mainland values. Excluding Isle Royale, data indicate that Michigan's nearshore Lake Superior waters are subject to enrichment during late summer. This is apparently a characteristic of nearshore waters which occurs as a result of warmer water and proximity to land and its runoff rather than a pollution problem. Schelske and Roth (29) also noted a lower ratio of calanoids to other zooplankton in Lake Superior bays than in the lake's open water.

WISCONSIN

Wisconsin waters were sampled in segments F and G and at the mouths of the Brule, Bad, and Montreal Rivers (13,14). The zooplankton populations off the Wisconsin shore are indicative of unproductive, oligotrophic waters. Generally, *Keratella* made up the greatest portion of the rotifers in Wisconsin waters. The crustacean populations were dominated by copepods which were at least twofold more abundant than the cladocerans. The only Wisconsin area where cladocerans outnumbered the copepods was 0.7 km offshore of Washburn.

MINNESOTA

Minnesota waters were sampled off the mouths of the Gooseberry and Cascade Rivers (12). The rotifers, *C. unicornis* and *K. longispina,* were found in Minnesota nearshore waters, but the populations were sparse relative to the south shore and Isle Royale. This may indicate lower productivity along the north shore.

Senecella calanoides, and oligotrophic relict species, was the most abundant crustacean zooplankton, but again the populations were sparse, indicating low productivity in this area of Lake Superior.

Gooseberry had 50% calanoid copepods while Cascade had 70% calanoid copepods. Thus, the lower number of zooplankton, fewer species, and greater dominance of calanoids indicate the Cascade area to be less

TABLE 4.1-12

ABUNDANT OR COMMON ZOOPLANKTON IN NEARSHORE LAKE SUPERIOR WATERS[a]

LOCATION	GROUP	GENERA OR SPECIES	COMMENTS
MICHIGAN	Rotifers	*Asplanchna, Keratella, Filinia, Polyarthra*	These four genera were abundant at all locations
		Kellicottia, Brachionus, Conochilus	These genera were common, but not abundant
	Crustaceans	*Bosmina longirostris, Diaptomus minutus, Diaptomus oregonensis, Cyclops bicuspidastus thomasi.*	All four species were common and abundant
		Diaptomus sicilis, Holopedium gibberum, Daphnia retrocurva, Epischura lacustris	*D. sicilis* was abundant only in spring samples. The other three species were abundant only in fall samples.
WISCONSIN	Rotifers	*Keratella*	
	Protozoans	*Cadonella*	
MINNESOTA	Rotifers	*Conochilus unicornis*	The most abundant rotifer at both locations
		Kellicottia longispina, Polyarthra	
	Crustaceans	*Senecella calanoides, Limnocalanus macrurus* *Diaptomus sicilis* *Daphnia galeata-mendotae*	*S. calanoides* was the most abundant crustacean at both locations. The other three species were abundant at both locations.

---

a. Data for Michigan (15); Wisconsin (14), and Minnesota (12) summarized from specific project reports.

enriched. However, the water quality at both locations was good.

ONTARIO

The zooplankton of Ontario nearshore waters were investigated only as part of a special study in Nipigon Bay (53). Areas of the bay, both within and beyond the influence of a paper mill plume were sampled to determine zooplankton abundance. Intensive sampling in the immediate vicinity of the discharge revealed no plankters. Results indicated that some zooplankters such as *Bosmina longirostris* are more tolerant of this type of waste discharge than others.

Similar densities of *B. longirostris* appeared in both nearshore contaminated and uncontaminated waters. Reduction in abundance of *Cyclops sp.* and *Daphnia sp.* at the shallower stations could be attributed to species specific preference for deeper water. It should be noted, however, that both species were least abundant at stations located within the plume.

Laboratory experiments were undertaken to assess the impact of the effluent on filtering rates (feeding activity) of *Daphnia retrocurva*. A significant depresssion of the filtering rates occurred in 5 and 10% effluent concentrations.

It would seem unlikely that a significant portion of the population of zooplankton in Nipigon Bay, except those very near the discharge channel, would encounter high concentrations for sustained periods of time.

BENTHOS

A limited amount of benthic literature is available for Lake Superior. Hiltunen (54), Adams and Kregear (55), and Schelske and Roth (29) found benthic faunal assemblages in the profundal zone of Lake Superior typical of deep, cold, oligotrophic lakes. Other studies of the benthos in the nearshore, harbour, and embayment areas have been conducted primarily to assess the pollutional impact of municipalities, pulp mill industries, and mining operations (39,56-61). These studies have shown that some nearshore areas have been organically enriched. However, the vast majority of the nearshore waters and the open lake exhibit oligotrophic or ultra-oligotrophic conditions.

MICHIGAN

Figure 4.1-13 shows the total density and composition of the benthic macroinvertebrate community at six control and six degraded locations in Michigan nearshore waters (15). The most prevalent taxa found in Michigan nearshore waters were the oligotrophic indicator species, *Pontoporeia affinis*, *Heterotrissocladius spp.*, and *Paracladopelma spp.*, all of which occurred at every location.

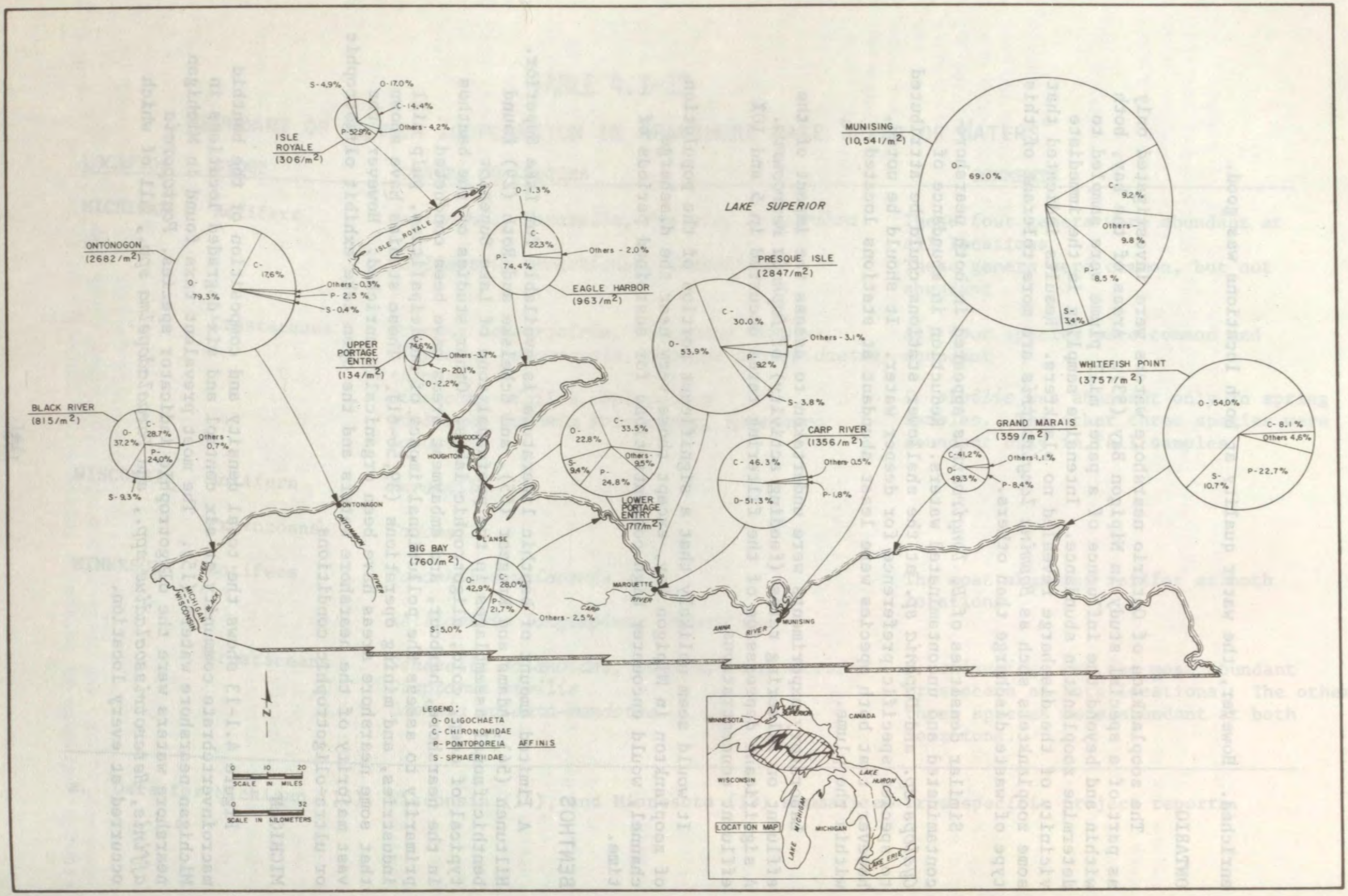


FIGURE 4.1-13 COMPOSITION AND DENSITY OF BENTHIC FAUNAL COMMUNITIES IN MICHIGAN NEARSHORE WATERS OF LAKE SUPERIOR, 1974. Information from Reference (15).

The control locations, with the exception of Whitefish Point, generally had total populations <1,000 organisms/m^2 (Table 4.1-13); a dominance of intolerant amphipod, oligochaete, and chironomid forms; and a low diversity of species.

The benthic community of Whitefish Point is different from the communities at the other control locations. The total population at Whitefish Point was approximately four times greater than the total population at the next highest control location and was dominated by the pollution tolerant oligochaete, *Peloscolex ferox*. This indicates the area is organically enriched; the source is unknown since the area is virtually undeveloped.

The six impacted locations consisted of Ontonagon, Upper Portage Entry, Lower Portage Entry, Presque Isle, Carp River, and Munising. Upper Portage Entry is affected by copper mill stamp sand waste discharges and the other five by municipal and/or industrial discharges.

Although *P. affinis* comprised a substantial portion of the population, the total benthic population at Upper Portage Entry was substantially lower than any of the control locations, supporting a previous report (61) that copper toxicity has reduced the benthic community.

The five locations affected by nutrient enrichment had benthic communities differing from the control locations primarily in greater densities of organisms; greater over-all species diversity; rich assemblages of tubificids; the presence, but not necessarily the dominance, of pollution tolerant forms; and the reduced abundance of intolerant forms. These differences indicate that although these areas are enriched, the sediments have not been degraded to the extent that intolerant forms are eliminated. However, there are indications that the impacted areas are becoming more enriched based on historical data. At the impacted locations, the percentage of *P. affinis* was reduced while the percentage of oligochaetes increased. Except for Lower Portage Entry, *P. affinis* formed <10% of the total population while oligochaetes comprised >50%. The percentages of chironomids, sphaeriids, and other taxa were not substantially different from the control locations.

Lower Portage Entry does not show the *Pontoporeia* - oligochaete shift and is dominated by the oligotrophic indicator forms, *P. affinis* and *Heterotrissocladius spp.* The remaining four impacted locations are dominated by oligochaete assemblages which are diverse and highly variable between locations. Both pollution-tolerant and intolerant forms are represented with no clear dominance of either group. Maximum densities of oligochaetes were found at Munising near the mouth of the Anna River (56,000/m^2).

Based on 1968 data (39) the total number of organisms/m^2 at Ontonagon, Presque Isle Harbor, Carp River, and Munising have increased by 5.6, 1.9, 1.7, and 2.3 fold, respectively, from 1968 to 1974. In addition, there were shifts of the percentages of the major groups at three of the

TABLE 4.1-13

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

LOCATIONS	# of Stations	Mean Density (org/m^2)	Standard Deviation	Range	Mean No. *Pontoporeia affinis*/m^2	Mean No. Oligochaete/m^2	Mean No. Chironomid/m^2	Mean No. Sphaeriid/m^2	Mean No. Other taxa/m^2	No. of Taxa
MICHIGAN										
Black River	1	815			196	303	234	76	6	11
Eagle Harbor	1	963			716	13	215	0	19	8
Isle Royale	3	306	± 100	214 - 412	181	52	44	15	13	12
Big Bay	2	760	± 773	213 - 1,306	165	326	213	38	19	27
Grand Marais	3	359	± 216	157 - 587	30	177	148	0	4	25
Whitefish Point	3	3,757	± 1,827	1,727 - 5,269	853	2,028	304	401	171	46
Ontonagon	12	2,682	± 2,511	88 - 8,008	67	2,126	472	10	7	67
Lower Portage Entry	4	1,717	± 490	1,158 - 2,278	426	392	575	161	163	42
Presque Isle	7	2,847	± 2,751	525 - 8,832	261	1,535	853	109	89	84
Carp River	7	1,356	± 1,405	562 - 4,475	25	695	628	0	7	48
Munising	13	10,541	± 14,719	1,462 - 56,652	900	7,275	974	357	1,036	98
Upper Portage Entry	4	134	± 87	113 - 247	29	3	100	0	5	18
WISCONSIN										
Middle River	1	420			0	227	193	0	0	4
Brule River	1	679			0	41	68	149	421	5
Iron River	1	108			22	0	86	0	0	4
Point Detour	1	689			97	475	96	0	21	5
Hermit Island	1	2,098			1,112	336	105	545	0	6
Bayfield	3	3,816	± 4,852	839 - 9,415	2,597	857	168	190	4	11
Chequamegon Bay	3	4,286	± 3,268	581 - 6,757	1,715	1,457	857	86	171	13
Bad River	2	1,560	± 289	1,365 - 1,765	47	62	1,435	0	16	13
Saxon Harbor	1	2,023			344	538	1,141	0	0	5
MINNESOTA										
Gooseberry River	7	2,528	± 3,112	140 - 8,868	126	1,492	885	0	25	44
Cascade River	2	1,599	± 1,598	520 - 2,695	160	1,167	256	0	16	25
ONTARIO										
Black Bay	9	843	± 469	344 - 1,700	506	0	76	93	160	10

a. Data for Ontario (10), Minnesota (12), Wisconsin (13, 14), and Michigan (15) summarized from specific project reports.

locations. The percentages of oligochaetes at Ontonagon, Carp River, and Munising increased by 28, 29, and 15%, respectively, with corresponding decreases in *P. affinis*, chironomids, and sphaeriids, indicating a trend of increasing enrichment. Comparing 1957 and 1968 data, the density of benthic organisms was about the same at Munising (56), but oligochaetes, which comprised only 23% of the total population during 1957, had increased to 55% in 1968 and to 69% in 1974 indicating increasing enrichment.

WISCONSIN

Wisconsin nearshore locations west of the Apostle Islands were characterized by total populations <700 organisms/m^2 and the dominance of intolerant forms, reflecting unenriched oligotrophic conditions (Figure 4.1-14)(14). The Apostle Islands locations had mean total populations between 2,000 and 4,000 organisms/m^2 and were dominated by *P. affinis* which reached maximum densities of >6,000/m^2. Although this area was impacted by domestic waste inputs, the benthic community was completely dominated by oligotrophic indicator benthic forms. The influence of the waste loadings is evident only in the increased standing crops. A similar benthic community was present in 1965 (54).

The total benthic community in Chequamegon Bay exceeded 4,000 organisms/m^2 and, although *P. affinis* was present in substantial numbers, pollution-tolerant forms were predominant, indicating the enriched condition of the bay. A similar benthic community was present in 1967 and 1968 (54,62) indicating little change over this time period. A 1968 survey found a severely degraded benthic community in the area of Ashland and a benthic community indicative of enriched conditions in the rest of the bay.

The locations east of the Apostle Islands had total populations between 1500 and 2000 organisms/m^2 and pollution-tolerant chironomids dominated the benthic community, indicating organic enrichment.

MINNESOTA

The benthic populations in Minnesota are dominated by intolerant oligotrophic indicator organisms (Figure 4.1-14). The total numbers of organisms/m^2 at the Minnesota locations were substantially higher than most other control areas (Table 4.1-13); however, both locations were dominated by intolerant forms indicating high water quality.

ONTARIO

Benthic studies in Ontario at Peninsula Harbour (63), Jackfish Bay (59), and Nipigon Bay (58), conducted to assess the effects of municipal and industrial discharges on the aquatic environment, found aquatic organisms completely absent in the vicinity of the discharges. Beyond the discharges, large numbers of oligochaetes were found, indicating organic enrichment associated with these discharges. At varying distances, up to 3 km from the discharge, the benthic community returned to normal,

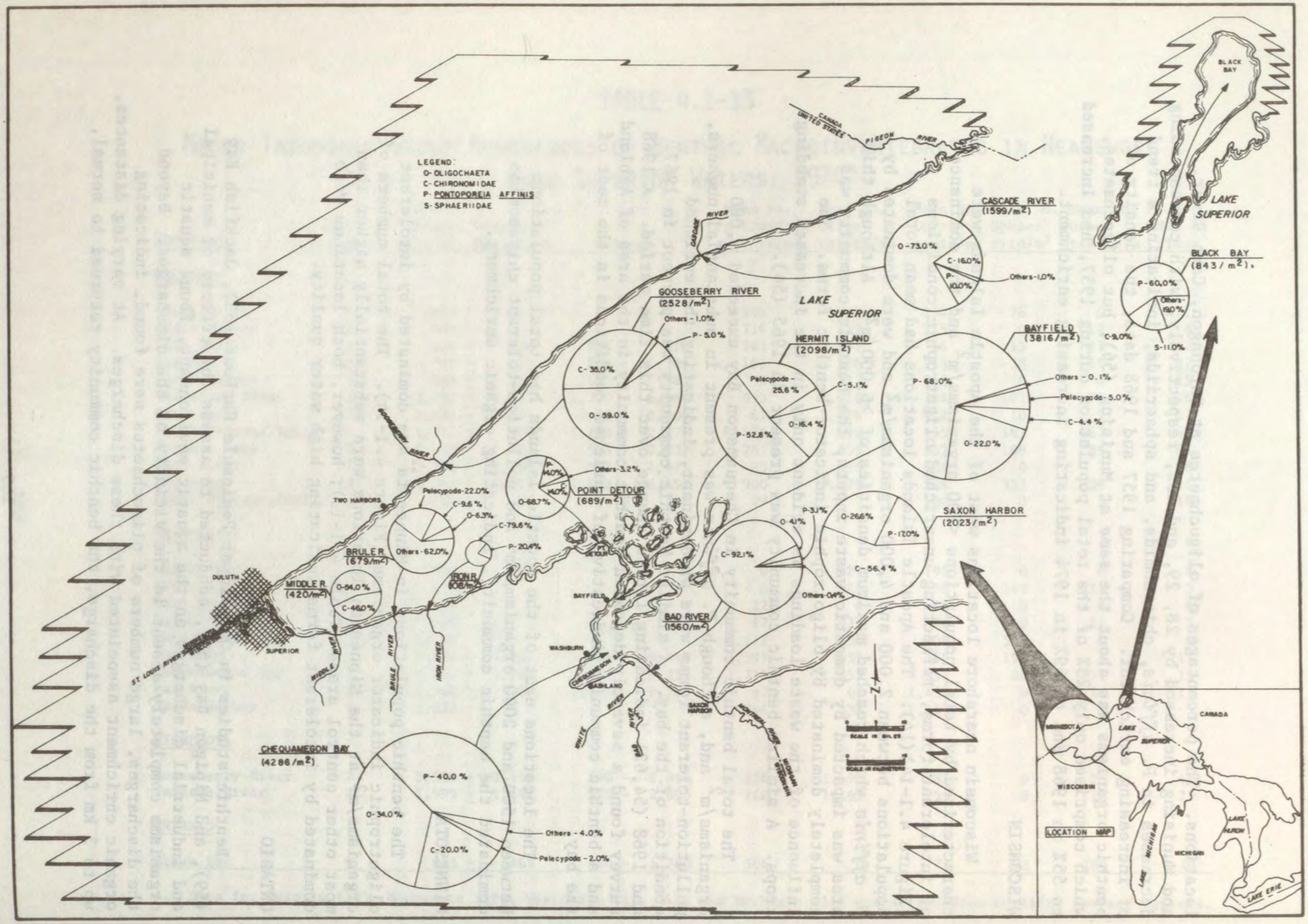


FIGURE 4.1-14 COMPOSITION AND DENSITY OF BENTHIC FAUNAL COMMUNITIES IN WISCONSIN, MINNESOTA, AND ONTARIO NEARSHORE WATERS OF LAKE SUPERIOR, 1974 . Information from References (14), (12), and (10), respectively.

being dominated by *P. affinis* and other intolerant forms. Studies at Black Bay, an unenriched location, showed that *P. affinis* is the dominant organism and oligochaetes are completely absent (10).

METALS AND ORGANIC CONTAMINANTS IN FISH

Excessive levels of certain metals and organic contaminants have been found in Great Lakes fishes. Discovery of elevated mercury levels in Lake St. Clair fish led to a ban of commercial fishing in this lake. High PCB's, DDT, and dieldrin in lake trout, coho salmon, and chubs have resulted in seizures of interstate shipments of these species from Lake Michigan. High levels of DDT and PCB's have been implicated as the cause of reduced reproductive success of fish, fish-eating birds, and animals.

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.

Previous studies of heavy metal contamination of Great Lakes fishes, including Lake Superior, have been reported by Lucas *et al.* (64), Uthe and Bligh (65), Beal (66), and Thommes *et al.* (67). Mercury in burbot and lake trout from Lake Superior were found to exceed the 0.5 mg/kg FDA guideline. PCB's, DDT, dieldrin, and mercury have been reported by the Great Lakes Environmental Contaminant Survey (68). Levels of PCB's and mercury in this survey occasionally exceeded tolerance levels.

SAMPLING AND ANALYSIS CONSIDERATIONS

Locations of fish collections and the species analyzed are given in Tables 4.1-14 and 4.1-15. Analyses of fish from Michigan nearshore waters were made on skinless fillets, except the sculpins which were eviscerated and composited. All samples were analyzed for at least DDT, dieldrin, PCB's, mercury, and up to 17 additional contaminants (Table 4.1-16)(15).

Skinless fillets of fish from Wisconsin nearshore waters were analyzed for 20 trace contaminants (Table 4.1-16)(69). Analyses of fish from Minnesota's nearshore waters were conducted on whole fish, eviscerated fish, and skinless fillets. Samples were analyzed for 23 trace contaminants (Table 4.1-16)(70). Fish samples from Ontario nearshore water consisted of 50 mature fish of a similar size for each of three species. The fillets were composited into 10 groups of 5 fish for a given species and analyses were conducted for 21 contaminants (Table 4.1-16)(71).

MICHIGAN

Chlordane, methoxychlor, benzenehexachloride, hexachlorobenzene,

TABLE 4.1 - 14

CONCENTRATIONS (MG/KG WET WEIGHT BASIS) OF SELECTED TRACE CONTAMINANTS IN FISH COLLECTED FROM NEARSHORE LAKE SUPERIOR WATERS, 1974 MICHIGAN AND WISCONSIN[a]

LOCATION	SPECIES	DDT	PCB	DIELDRIN	MERCURY	COPPER	ZINC	LEAD	CADMIUM
MICHIGAN Detection Limit		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Whitefish Point	Lake Trout	0.74	0.98	0.03	0.30	0.54	3.80	0.39	0.02
	Fat Lake Trout	1.82	3.18	0.05	0.50	0.35	2.87	0.45	0.02
	Mottled Sculpin	0.23	0.44	0.02	0.04	0.82	11.90	1.50	0.09
Grand Marais	Lake Trout	1.03	1.61	0.02	0.39				
	Mottled Sculpin	0.10	0.29	b	0.03	0.66	11.70	1.40	0.07
Munising	Herring	0.17	0.22	0.01	0.18				
	Lake Trout	3.31	3.31	0.04	0.44				
	Fat Lake Trout	3.46	5.10	0.04	0.71				
	Mottled Sculpin	0.03	0.09	b	0.07				
	Whitefish	0.19	0.27	0.19	0.04				
Marquette	Lake Trout	1.35	1.95	0.02	0.32				
	Fat Lake Trout	3.89	5.05	0.08	0.64				
	Mottled Sculpin	0.06	0.15	b	0.02				
	Whitefish	0.29	0.31	0.02	0.07				
Presque Isle	Mottled Sculpin	0.03	b	b	0.04				
Big Bay	Lake Trout	0.85	1.13	b	0.26				
	Mottled Sculpin	0.09	0.15	0.01	0.05	0.95	12.30	1.20	0.12
Hutch Bay	Mottled Sculpin	b	b	b	0.05	0.75	12.15	1.30	0.10
L'Anse	Mottled Sculpin	b	b	b	0.02	0.66	11.78	1.40	0.08
Lower Portage Entry	Herring	1.18	1.03		0.12				
	Lake Trout	1.35	b	0.02	0.21	0.36	3.11	0.26	0.09
	Mottled Sculpin	0.09	0.04	b	0.02	0.72	11.86	1.20	0.10
Grand Traverse Bay	Mottled Sculpin	0.02	b	b	0.02				
Bete Grise	Whitefish	0.69	0.89	0.08	0.16				
Copper Harbor	Lake Trout	2.44	2.99	0.02	0.36				
	Mottled Sculpin	0.04	0.09	b	0.03	0.90	11.92	1.30	0.11
Eagle Harbor	Mottled Sculpin	0.10	0.15	b	0.02				
Eagle River	Mottled Sculpin	0.43	0.46	0.03	0.04				
Upper Portage Entry	Lake Trout	0.98	1.17	0.02	0.45	0.35	3.34	0.30	0.02
	Mottled Sculpin	b	b	b	0.05	1.22	12.45	1.50	0.13
Carver's Bay	Mottled Sculpin	0.45	0.37	0.03	0.03	0.83	11.81	1.20	0.11
Big Iron River	Mottled Sculpin	0.05	0.09	b	0.03	0.90	12.13	1.40	0.11
Black River	Lake Trout	1.51	2.09	0.03	0.33	0.40	3.44	0.36	0.02
	Fat Lake Trout	5.11	8.37	0.07	0.58	0.29	3.12	0.28	0.04
	Mottled Sculpin	0.62	b	b	0.03				
Isle Royale	Fat Lake Trout	2.10	2.33	b	0.58				
	Mottled Sculpin				0.06	1.30	34.80	0.15	<0.05
Little Girls Point	Lake Trout	0.47	1.25	0.03	0.22	0.56	6.16	0.25	0.02
	Herring				0.61	1.10	22.45	0.39	0.22
	Whitefish				0.06	0.82	8.00	0.23	0.09
WISCONSIN Detection Limit		0.001	0.001	0.001	0.01	0.01	0.01	0.02	0.05
Mouth of Bad River	Bullhead	0.011	0.050	<1	0.11	1.10	18.00	<0.02	<0.05
	Northern Pike	0.008	0.020	<1	0.29	0.20	7.00	0.03	<0.05
	Walleye	0.023	0.200	0.004	0.02	0.58	13.00	<0.02	0.06
	White Sucker	0.058	0.024	<1	0.23	0.34	12.00	<0.02	0.08
Kakagon Slough	Bullhead	0.018	0.017	0.002	0.09	0.57	15.00	0.03	0.06
	Northern Pike	0.015	0.030	<1	0.22	0.34	39.00	<0.02	<0.05
	Yellow Perch	0.030	0.050	<1	0.02	0.32	17.00	<0.02	0.05
Chequamegon Bay	Herring	0.057	0.097	<1	0.05	0.29	12.00	0.05	0.05
	Northern Pike	0.025	0.026	<1	0.03	0.24	30.00	<0.02	<0.05
	Smelt	0.173	0.202	0.004	0.08	0.46	21.00	0.02	0.07
	Walleye	0.034	0.110	<1	0.12	0.25	12.00	0.04	<0.05
	Whitefish	0.129	0.202	0.019	0.08	0.40	14.50	0.04	0.07
	Yellow Perch	0.045	0.046	0.003	0.03	0.30	16.60	0.15	0.05
Onion River	Mottled Sculpin				0.04	1.67	28.10	0.07	<0.05
Stockton Island	Mottled Sculpin				0.03	1.23	21.93	0.25	0.05
	Spoonhead Sculpin	0.045	0.300	0.057	0.11	1.28	22.90	0.38	0.09
Bayfield	Lake Trout				0.37	0.73	6.90	<0.05	0.06
Bark Bay	Brook Trout				0.06	0.69	3.80	<0.05	<0.05
Port Wing	Burbot				0.48	0.76	7.13	0.07	<0.05
	Cisco				0.11	0.73	10.20	0.08	<0.05
	Lake Trout				0.15	1.20	12.40	0.09	<0.05
	Long Nose Sucker				0.12	1.40	15.20	0.13	0.09
	Rainbow Trout				0.13	1.05	4.50	0.26	<0.05
	Smelt				0.10	0.69	23.00		
	Sea Lamprey				1.32	2.80	34.90	<0.05	0.05
Mouth of Brule River	Brown Trout	0.193	0.145	0.006	0.12	0.49	6.20	0.04	<0.05
	Rainbow Trout	0.110	0.065	0.002	0.11	1.85	6.10	0.07	<0.05
	Walleye	0.074	0.080	0.005	0.20	0.59	11.03	0.05	0.10
West of Brule River	Rainbow Trout	0.070	0.110	<0.001	0.10	0.36	5.80	0.03	0.02
	Smelt	0.200	0.263	0.007	0.93	0.38	24.30	0.04	0.07
	Walleye	0.229	0.218	0.003	0.38	0.30	8.18	0.03	0.05

a. information from references (68 and 69).
b. not detected.

hexachlorobutadiene, dibutyl-n-phthalate, diethylhexylphthalate, and polybrominated biphenyl were below the level of detection in fish from the nearshore waters of Michigan. Total DDT was present in all samples, ranging from a low of 0.17 mg/kg in herring from Munising to a maximum of 5.1 ± 2.78 mg/kg in fat lake trout from Black River Harbor.

Species differences were evident; whitefish and herring had a mean of 0.50 ± 0.45 mg/kg total DDT while lean lake trout had a mean of 2.03 ± 1.35 mg/kg total DDT. The total DDT concentration for fat lake trout at Black River Harbor, Lower Portage Entry, Copper Harbor, Marquette, and Munising exceeded the 5.0 mg/kg FDA guideline. The highest measured value was 26.02 mg/kg in a lake trout captured near Munising.

PCB levels were highly variable, ranging from 0.22 mg/kg in herring from Munising to 8.37 mg/kg in fat lake trout from Black River. Mean PCB levels in fat lake trout at Munising (5.10 mg/kg), Marquette (5.05 mg/kg), and Black River (8.37 mg/kg) exceeded the FDA 5.0 mg/kg guideline. Lean lake trout from the corresponding locations averaged 2.53 mg/kg PCB's; whitefish and herring were lower than lake trout, averaging 0.54 mg/kg.

Only total DDT, dieldrin, and PCB's were identified in sculpins. Total DDT residues ranged up to 0.32 mg/kg, which is less than 10% of the current FDA guideline. Carver's Bay and Whitefish Bay were the only locations with DDT levels over 0.15 mg/kg. Sculpins from these locations also contained measurable dieldrin. PCB levels in mottled sculpin were low, ranging up to 0.75 mg/kg.

Heavy metals concentrations in fish from Michigan's Lake Superior waters were low, with only mercury approaching or exceeding present guidelines for fish flesh. Mean location mercury levels were variable, ranging from 0.04 mg/kg in whitefish from Munising to 0.73 mg/kg in fat lake trout from the Marquette area.

All location mean mercury values for fat lake trout exceeded the FDA guideline of 0.5 mg/kg. No other species had mean mercury values above the guideline. Lake trout generally had mercury values two to three times the values found in whitefish. Mercury levels in sculpins ranged from 0.01 to 0.07 mg/kg with no geographic differences.

WISCONSIN

Total DDT concentrations were generally low in all species analyzed within Wisconsin nearshore waters. Carp appeared to have approximately two times more DDT residues than the other fish sampled. Carp also had higher PCB levels than the other species. The observed levels of PCB's and DDT were much below the FDA guidelines of 5.0 mg/kg for PCB's and for DDT. All samples contained less than 10% of the guideline for dieldrin. No samples contained detectable amounts of benzenehexachloride or methoxychlor.

TABLE 4.1 - 15

CONCENTRATIONS (MG/KG WET WEIGHT BASIS) OF SELECTED TRACE CONTAMINANTS IN FISH COLLECTED FROM NEARSHORE LAKE SUPERIOR WATERS, 1974

MINNESOTA AND ONTARIO[a]

LOCATION	SPECIES	DDT	PCB	DIELDRIN	MERCURY	COPPER	ZINC	LEAD	CADMIUM
MINNESOTA									
Detection Limit					0.001	0.01	0.01	0.05	0.05
Lester River	Sculpin	0.213	0.600	0.028					
French River	Sculpin	0.163	0.300	0.022	0.165	1.14	26.80	0.13	0.09
Stony Cove	Burbot				0.118	0.68	23.60	<0.05	<0.05
	Herring				0.260	1.67	18.50	0.20	0.17
Knife River	Sculpin	0.094	0.050	0.011	0.440	1.18	27.50	0.21	<0.05
Two Harbors	Sculpin	0.051	0.200	0.008	0.041	1.26	34.30	0.43	<0.05
Stewart River	Sculpin	0.036	0.300	0.009	0.061	0.71	43.00	0.09	<0.05
Gooseberry River	Sculpin	0.027	0.200	0.005					
Split Rock River	Sculpin	0.051	0.300	0.012					
Cross River	Burbot				0.046	0.46	15.40	0.09	<0.05
	Sculpin	0.027	0.200	<0.015	0.110	0.99	24.15	0.88	<0.05
Cascade River	Sculpin	0.065	0.300	0.013	0.105	1.11	24.10	0.23	0.07
Grand Marais	Brook Trout				0.097	0.28	12.80	<0.05	<0.05
	Sculpin	0.100	0.035	0.006	0.190	0.79	18.75	0.17	<0.05
Grand Portage	Cisco				0.340	0.74	11.10	0.09	0.05
	Herring				0.220	0.77	12.40	0.25	0.07
ONTARIO									
Detection Limit		0.001	0.001	0.001	0.01	0.01	0.01	0.5	0.2
Pine Bay	Lake Trout	0.283	0.512	0.012	0.39	0.69	3.57	<0.5	<0.2
	Walleye	0.104	0.243	0.003	0.60	0.61	3.51	<0.5	<0.2
	Whitefish	0.258	0.279	0.012	0.18	0.63	4.84	<0.5	<0.2
Black Bay	Herring	0.581	0.632	0.014	0.19	0.39	5.19	<0.5	<0.2
	Lake Trout	0.940	1.796	0.048	0.63	0.53	3.21	0.7	0.4
	Whitefish	0.468	0.537	0.043	0.04	0.90	4.01	0.8	<0.2
Nipigon Bay	Herring	0.329	0.757	0.022	0.14	0.59	5.46	<0.5	<0.2
	Lake Trout	0.661	0.765	0.029	0.57	0.20	6.00	<0.5	<0.2
	Whitefish	0.229	0.891	0.012	0.10	0.83	5.68	<0.5	<0.2
Rossport Point	Lake Trout	0.654	0.894	0.016	0.35	0.64	3.58	0.5	<0.2
	Menominee	0.163	0.205	b	0.08	0.51	5.27	0.7	<0.2
	Whitefish	0.303	0.395	0.015	0.20	0.52	3.93	0.5	<0.2
Jackfish Bay	Herring	0.231	0.193	0.008	0.16	0.99	5.39	<0.5	<0.2
	Lake Trout	0.683	0.698	0.036	0.46	0.67	3.63	<0.5	<0.2
	Whitefish	0.084	0.125	0.006	0.06	0.61	4.07	<0.5	<0.2
Marathon	Lake Trout	0.170	0.690	0.011	0.67	0.71	3.39	<0.5	<0.2
	Whitefish	0.382	3.635	0.017	0.76	0.62	4.08	<0.5	<0.2
Michipicoten Bay	Herring	0.480	0.297	0.014	0.25	0.62	5.00	<0.5	<0.2
	Lake Trout	0.383	0.439	0.016	0.47	0.62	3.50	<0.5	<0.2
	Whitefish	0.262	0.240	0.015	0.17	0.61	3.48	<0.5	<0.2
Batchawana Bay	Herring	0.207	0.193	0.010	0.17	0.75	7.02	<0.5	<0.2
	Lake Trout	0.705	0.387	0.023	0.42	0.62	3.49	<0.5	<0.2
	Whitefish	0.229	0.152	0.009	0.13	0.48	3.43	<0.5	<0.2

a. information from references (68 and 71).
b. not detected.

Only mercury in fish from Wisconsin's nearshore waters occasionally approached or exceeded the established guidelines. The highest mercury levels occurred in walleye, with mean location concentrations ranging from 0.02 mg/kg at the mouth of the Bad River to 0.38 mg/kg 5 km west of the Brule River. The highest concentration of mercury was 0.54 mg/kg found in a walleye captured west of the Brule River. The only other location where mercury levels in walleyes were above 0.12 mg/kg was the Brule River mouth (0.20 mg/kg). Zinc concentrations vary by species but not by geographic location. Northern pike and smelt had the highest levels (25.30 mg/kg). Other metals showed no consistent location or species variation. Nickel and lead were not detected (<0.1 mg/kg and <0.02 mg/kg, respectively).

MINNESOTA

PCB's in Minnesota's nearshore waters of western Lake Superior ranged from less than detection limits in burbot to high values (8.4 mg/kg) in siscowet (fat) lake trout. Consistently low levels were generally found in burbot, chinook salmon, coho salmon, American smelt, brook trout, walleye, and whitefish, while intermediate values (1.1 to 1.5 mg/kg) were noted in common suckers and long-nose suckers.

Total DDT and its residues varied throughout a range of 0.023 mg/kg in burbot to 11.7 mg/kg in whole siscowet lake trout. p,p-DDE generally was the dominant form with o,p-DDT and p,p-DDT in the mid-range, while p,p-DDD was the lowest of the DDT residues. Dieldrin values were observed, ranging from a low of 0.003 mg/kg in walleye to a high of 0.062 mg/kg in whitefish.

Mirex and lindane were not measured in the fish sampled. Methoxychlor was observed above detection thresholds at 2.1 mg/kg in American smelt and eggs of burbot.

Hexachlorobenzene mean values per species were generally low. Means ranged from less than detection limits to 0.04 mg/kg in siscowet lake trout. Hexachlorobutadiene was generally less than detection levels, except in lake trout, 2.18 mg/kg, and 7.7 mg/kg in skinless fillets of long-nose suckers.

Three phthalate esters were studied. Diethyl phthalate was measured in whitefish, skinless fillets of siscowet lake trout, and skinless fillets of brook trout, (2.4 mg/kg, 1.3 mg/kg, and 0.1 mg/kg, respectively). Dibutylphthalates were found in rainbow trout (5.4 mg/kg) and long-nose suckers (8.1 mg/kg). The highest level of diethylhexylphthalate was observed in skinless fillets of whitefish (2.2 mg/kg). However, it was generally found at detectable levels except in common suckers, walleye, and siscowet lake trout.

The data for sculpin can be used as indicative of localized contamination. Generally, the PCB values for sculpin were in a range of 0.2 to 0.3 mg/kg although there were a few exceptions. Lester River sculpins had a mean value of 0.6 mg/kg, although other areas on the north shore of

TABLE 4.1-16

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

	Michigan	Wisconsin	Minnesota	Ontario
Benzene hexachloride		*	*	
Heptachlor-heptachlor epoxide			*	*
Dieldrin	*	*	*	*
Endrin			*	
Aldrin				*
Lindane	*	*	*	*
DDT	*	*	*	*
DDD	*	*	*	*
DDE	*	*	*	*
Chlordane	*	*	*	*
Methoxychlor	*	*		
Mirex			*	
Polychlorinated biphenyl (PCB)	*	*	*	*
Polybrominated biphenyl	*			
Hexachlorobutadiene	*		*	
Hexachlorobenzene	*		*	
Dibutylphthalate	*			
Diethylphthalate			*	
Diethylhexylphthalate	*			
Copper	*	*	*	*
Nickel	*	*	*	*
Lead	*	*	*	*
Zinc	*	*	*	*
Cadmium	*	*	*	*
Manganese				*
Arsenic	*	*	*	*
Chromium	*	*	*	*
Selenium		*	*	*
Mercury	*	*	*	*
Gross α		*		*
Gross β		*		*
Fillet	*	*	*	*
Whole fish	*		*	

---

a. Information from References (68-71).

Minnesota were very low. Levels of total DDT were generally low, ranging from 0.015 to 0.213 mg/kg. Again, Lester River sculpin had the highest mean value while Knife River had the second highest, 0.163 mg/kg. From this point to the northeast along the Minnesota north shore, values decreased dramatically. Lester River area sculpin had the only elevated dieldrin (0.028 mg/kg) relative to the other sculpin data from Minnesota. From these data, it is apparent that outside of the Duluth vicinity, persistent organic compounds were not entering Lake Superior from Minnesota.

The levels of metals in sculpins captured in Minnesota's nearshore Lake Superior waters were generally low with no location differences noted except for mercury. Mercury levels in sculpins ranged from 0.041 mg/kg at Agate Beach to 0.784 mg/kg at the Knife River. Except at Knife River, all mercury levels in sculpins were <0.2 mg/kg. Mean location levels of mercury exceeded 0.2 mg/kg in 4 species of fish at 5 of 15 locations: cisco at Grand Portage (0.372 mg/kg); herring at Stony Point (0.207 mg/kg); burbot at Port Wing (0.478 mg/kg); lake trout at Bayfield, Wisconsin (0.368 mg/kg); and herring at Little Girls Point, Michigan (0.610 mg/kg).

Skinned herring, cisco, and burbot had higher levels of mercury than the corresponding whole fish (approximately 2, 2, and 4 times higher, respectively). Lake trout had similar levels whether skinned or whole (0.385 and 0.350 mg/kg, respectively). Conversely, zinc levels in whole lake trout were three to four times the level in the skinless fillets. Thus, the method of sample preparation determined in part the level of metal observed in a given species. No significant location differences were noted for any of the metals analyzed.

ONTARIO

The organic contaminants in fish from Ontario's nearshore waters of Lake Superior varied widely between species and locations. PCB levels ranged from 0.125 mg/kg in whitefish from Jackfish Bay to 3.635 mg/kg in whitefish from Marathon. All location mean values were less than the guideline of 5.0 mg/kg, but individual whitefish samples at Marathon did exceed 5.0 mg/kg. Many samples exceeded the proposed Agreement objective of 0.1 mg/kg. The highest mean concentration of total DDT (0.940 mg/kg) was found in lake trout from Black Bay. The lowest mean concentration (0.084 mg/kg) was found in whitefish from Jackfish Bay. Total DDT concentrations for all areas were less than guidelines.

Dieldrin or endrin concentrations did not exceed the 0.3 mg/kg guideline; concentrations were generally <15% of the guidelines. Heptachlor epoxide levels were also very low and showed little variation between species or areas sampled. Lindane, heptachlor, and aldrin were not detected in any of the samples.

Other than mercury, none of the metals in fish from Ontario's nearshore waters exceeded 10% of the guideline in any sample. Lake trout from Black Bay and Marathon had mean concentrations of mercury which exceeded the guideline (0.63 mg/kg and 0.67 mg/kg, respectively).

Ten composite samples of walleye from Pine Bay and four composite samples of whitefish from Marathon had mean values of 0.60 and 0.76 mg/kg, respectively, for mercury, which exceed the 0.5 mg/kg guideline. Overall, there is little inter-species variation in concentration between whitefish, lake trout, and lake herring.

All fish samples from Ontario waters had a gross α <1.0 pCi/g. Samples analyzed for gross β radioactivity had a range of mean values from 2.39 pCi/g in herring from Nipigon Bay to 3.83 pCi/g in menominee at Rossport Point. However, there was little variation in radioactivity levels between species or areas surveyed.

Fish toxicity studies (72) conducted on the pulp and paper mill discharges to Nipigon Bay indicated that the final effluent was acutely toxic to fish. Impairment of the growth rate of fish and the production of unnatural flavour of fish flesh resulted from exposure to a concentration of 6% of the final effluent. Under normal mill operating conditions it is unlikely that effluent concentrations approach lethal levels in Nipigon Bay beyond the immediate area of the outfall.

SUMMARY OF EXISTING AND DEVELOPING PROBLEMS

From an examination of the sources and loading characteristics of materials discharged into Lake Superior by municipalities, industries, and tributaries, the local effects on water quality in the immediate receiving waters were evaluated with respect to water use. For the protection of intensive use of the nearshore waters, it is necessary to control all pollution sources. Water quality investigations indicated that unsatisfactory conditions existed in certain embayments but not in nearshore areas.

EXISTING PROBLEMS

ENRICHMENT

There are no major inputs of nutrients to the Ontario nearshore areas of Lake Superior from any sources. The unproductive nature of these waters is reflected by low algal populations and low levels of nutrients, which are characteristic of oligotrophic lake waters.

At five impacted U.S. locations (Ontonagon, Lower Portage Entry, Presque Isle, Carp River, and Munising) and at one control location (Whitefish Point) the data indicate existing or developing enrichment problems; however, no specific Agreement water quality objectives were violated.

Calculated nutrient loadings for the five impacted locations accounted for 79% of the total phosphorus and 16% of the total nitrogen discharged to Lake Superior from the Michigan portion of the drainage basin. The most enriched areas included Ontonagon, Carp River, and Munising. Nutrient concentrations were elevated at the last two locations while the nearshore currents quickly dispersed the nutrient loading at Ontonagon. Historical benthic data suggest that enrichment at these three locations has increased since the late 1950's.

All impacted locations had benthic communities indicative of enrichment. The control location at Whitefish Point also had a benthic community which indicated enrichment; however, no nutrient sources were found in this area.

Phosphorus removal at the wastewater treatment plants for Ontonagon, Marquette, and Munising are to be operational by 1978, 1979, and 1976, respectively.

In the enrichment section, Chapter 6.1, a discussion of the future enrichment trends in local embayments of Lake Superior utilizes the waste load simulation model presented in Chapter 3.11. Based on the application of best practicable technology available today, 85% of phosphorus removal from the industrial effluent to Jackfish Bay would result in an estimated chlorophyll α level of 1.0 µg/ℓ in the year 2020. Without phosphorus removal, the level of chlorophyll α in the year 2020 is expected to be 3.7 µg/ℓ, which is in the mesotrophic range.

In Nipigon Bay, without phosphorus removal from controllable sources, the estimated chlorophyll α concentration in the year 2020 is 2.6 µg/ℓ. If 85% phosphorus removal is applied, the 1974 chlorophyll α level of 1.5 µg/ℓ is expected to remain essentially unchanged for the next 45 years.

BACTERIAL CONTAMINATION

Results indicate excellent microbial quality in nearshore areas of Lake Superior. No existing problems were apparent. However, the inadequate operation of municipal waste treatment plants resulted in elevated total and fecal coliform counts at Black River, Ontonagon, Carp River, and Munising. The highest counts were recorded at the river mouth stations. Most of the problems are with the disinfection facilities.

Localized impairment also exists in a number of Ontario embayments. In Batchawana Bay, although indicator bacteria were virtually absent in spring, populations during the September survey showed a marked increase of total coliforms and fecal streptococci. Tributary monitoring data indicate that both human and animal wastes from three influent streams (Batchawana River, Harmony River, Stockley Creek) are probable sources of bacterial contamination. An additional input may originate from the numerous cottages along the shoreline of this embayment.

The Peninsula Harbour area receives industrial and sanitary wastes originating from the main mill sewer of American Can of Canada Limited, as well as the primary treated sewage from the Township of Marathon. By far the largest source of wastes is the mill which discharges directly to Lake Superior. As a result, bacterial contamination is restricted to a localized area of Lake Superior around the outfall as opposed to inside the harbour. High bacterial levels, which frequently exceeded Ontario criteria for public water supplies and recreational uses, are associated with the effluent waste plume and are subject to highly variable dispersion mechanisms. Although bacterial densities showed a wide variation between respective sampling days, all counts were very high in comparison to control stations in non-industrialized nearshore areas of Lake Superior. Contamination was noted at distances up to 1.6 km from the outfall of American Can of Canada Ltd. Bacterial populations within Peninsula Harbour, which receives no sewage inputs, did not exhibit significant increases over nearshore areas.

Jackfish Bay serves as the receiving body for pulp and paper wastes originating from the Kimberly-Clark of Canada Limited mill at Terrace Bay. These wastes enter Jackfish Bay via Blackbird Creek. A marked increase in levels of total coliforms, fecal coliforms, and fecal streptococci over nearshore areas was found in Jackfish Bay. Although fecal coliform densities were below criteria, the total coliform and fecal streptococci densities exceeded Ontario criteria for recreational uses. Water quality degradation resulting from bacterial levels was evident for a distance of 1 km from the mouth of Blackbird Creek.

Except for a localized area in the western part of Nipigon Bay, populations of health indicator bacteria throughout this embayment were characteristic of Lake Superior nearshore areas. The western shoreline receives industrial and sanitary wastes from Domtar Packaging Limited located in the Improvement District of Red Rock. Although individual samples occasionally exceeded 1,000 total coliforms/100 mℓ and frequently exceeded 20 fecal streptococci/100 mℓ, the geometric mean of samples collected in the plume area did not exceed Agreement water quality objectives.

METALS CONTAMINATION

Heavy metal concentrations in the sediments of undeveloped nearshore areas of Lake Superior reflect natural levels due to soil weathering and geochemical processes. Mercury in sediments of Peninsula Harbour and Jackfish Bay, copper and zinc at Upper Portage Entry, and a variety of parameters at Ontonagon and Munising were the only accumulations observed in the study.

Significant mercury contamination of sediments has occurred in Peninsula Harbour (Marathon) as a result of past mercury losses from the chlor-alkali plant of the American Can of Canada Limited. Present discharges of this metal generally meet the Canadian Chlor-Alkali Regulations (73). The greatest contamination was found in the Jellicoe Cove area of Peninsula Harbour near the main mill sump overflow. Mercury concentrations of 38.8 mg/kg and 31.9 mg/kg were detected at distances from the outfall of 200 m and 500 m, respectively. Since background levels were not reached in the 1973 sampling grid, the areal extent of mercury contamination cannot be determined, but at a single station 4 km from the point source, the level of mercury was 1.16 mg/kg.

In Jackfish Bay, two stations out of six had concentrations of 0.75 and 0.42 mg/kg. Mercury-contaminated sediments were not present in other embayments on the Ontario side.

Severely degraded sediments occurred at Ontonagon and Munising. Ontonagon sediments violated U.S. EPA dredge spoil guidelines for chemical oxygen demand (COD) and total Kjeldahl nitrogen (TKN), while Munising sediments violated U.S. EPA criteria for COD, TKN, zinc, lead, and total volatile solids. The enrichment of the sediments at these two harbours has resulted in a degraded benthic community. Inadequate sewage treatment is the source of these contaminated sediments.

Upper Portage Entry sediments contained high concentrations of copper and zinc from past mining activities. Copper toxicity has reduced the benthic populations in the area. Copper concentrations were also high in the water at both Upper and Lower Portage Entry.

Fish captured in the vicinity of Marathon contained unacceptable levels of mercury in their flesh. The Canadian Food and Drug Act recommends that for the protection of human consumers of fish, the level of mercury in fish flesh be <0.5 mg/kg. Whitefish and lake trout exceeded the guideline. In Jackfish Bay, lake trout samples also exceeded the guideline.

Although mercury-contaminated sediments were not present in other areas, unacceptable levels were found in fish from Michipicoten Harbour, Black Bay, Nipigon Bay, and Pine Bay. Mean location values for mercury exceeded the guidelines in all fat lake trout at Munising, Marquette, and Whitefish Point.

ORGANIC CONTAMINANTS

Organic substances like PCB's, pesticides, and phenolic compounds are potent environmental contaminants which can seriously affect the aquatic biota.

PCB levels in the nearshore sediments were found to be extremely low. Of 27 Ontario nearshore stations, only two locations near Marathon had measurable levels (12 and 250 µg/kg). Seven nearshore sediment samples showed trace amounts below the sensitivity limit of the test (10 µg/kg) and the remaining 18 samples did not have any detectable PCB concentration.

An intensive study revealed serious contamination of sediments by PCB's in Peninsula Harbour (Marathon) where all nine stations contained measurable levels ranging from 10 to 6500 µg/kg. Jackfish Bay sediments contained PCB levels ranging from trace (<10 µg/kg) to 142 µg/kg near the mouth of Blackbird Creek. Evidence indicates that the PCB's originate from the industrial waste discharges. The sediments of Nipigon Bay in the area receiving similar industrial wastes were not analyzed for PCB's. In Black Bay and Pine Bay, PCB's in sediments were not detected.

Whitefish in Peninsula Harbour showed PCB-contaminated samples exceeding the Canadian Food and Drug Directorate guideline of 2 mg/kg set for fish.

Whitefish collected from Nipigon Bay exceeded the guidelines in one of ten composite samples. In Black Bay, PCB's in sediments were not detected; however, three of 10 composite lake trout samples from this embayment contained >2 mg/kg.

Organic contaminants and metals were low in fish captured in U.S. nearshore Lake Superior waters except in lake trout. Levels of DDT and PCB's were high in both the lean and fat varieties of lake trout. Fat lake trout at Black River Harbor, Munising, and Marquette exceeded the 5.0 mg/kg guideline for PCB's. Average location values for lean lake trout did not exceed this guideline.

Low levels of DDD, DDE, and DDT were found in Lake Superior sediments. The total DDT concentration in individual fat lake trout at Black River Harbor, Lower Portage Entry, Copper Harbor, Marquette, and Munising exceeded the 5.0 mg/kg FDA guideline; however, the mean DDT concentration exceeded the guideline only at Black River Harbor.

Phenolic substances in Peninsula Harbour and Jackfish Bay waters were considerably higher than background levels of Lake Superior. Levels of phenolic substances in the waste plume of American Can of Canada Limited at Peninsula Harbour ranged from 6-80 μg/ℓ. The substances should be absent according to the desirable Ontario criterion for public water supplies.

In Jackfish Bay, levels ranged from a mean of 60 μg/ℓ at 0.5 km from the mouth of Blackbird Creek to 4 μg/ℓ at a distance of 3.5 km from the creek mouth. Although examination of fish tainting has not been conducted in these areas, kraft mill effluents are known to contribute to tainting of fish flesh.

DEVELOPING PROBLEMS

The overall quality of nearshore waters of Lake Superior is excellent. No developing water quality impairment has been identified in nearshore regions. Localized impairment exists in Peninsula Harbour, Jackfish Bay, Munising, Ontonagon, Black River, and Marquette.

Although the Kimberly-Clark mill at Terrace Bay is expanding its operations, no additional impact to Jackfish Bay is expected since in-plant waste treatment facilities are also being installed.

An area which may be of environmental concern in the future is Pine Bay. Great Lakes Nickel Ltd. has partially completed construction of mining, milling, and smelting facilities for copper and nickel ores in Pardee Township. For economic reasons, construction has been stopped. Should this mine ever become operational, Pine Bay will serve as the terminal basin for mine wastes.

4.2 THUNDER BAY

DESCRIPTION OF STUDY AREA

Thunder Bay is the largest Canadian city on Lake Superior and due to the concentration of population and industry it is a potential contributor to the pollution of Lake Superior. A general view of the Thunder Bay area is shown in Figure 4.2-1. The area can be divided into two sections: the Inner Harbour (inside the breakwater) and the Outer Harbour (outside the breakwater). An extensive study of the water quality in the Thunder Bay area was carried out in 1970 (4). It was concluded that the surface waters in Thunder Bay Inner Harbour and the adjacent section of the Outer Harbour were being contaminated by local industrial and municipal waste water discharges. Recommendations were made to alleviate the pollution pressure in Thunder Bay. Intensive water quality sampling surveys in Thunder Bay were made in 1973 and 1974. This section summarizes the findings and recommendations of the 1970 survey and presents the 1973 and 1974 findings. The water quality surveys are compared to evaluate the changes in the nearshore and offshore waters.

WATER USES

The waters of the Thunder Bay area must meet a variety of needs some of which are in conflict with each other. The predominant existing uses are domestic and industrial water supply, waste disposal, thermal power generation, and commercial shipping. To a lesser extent portions of Thunder Bay are used for boating, angling, and swimming. Each of these uses is discussed in the section which follows.

WATER SUPPLY

MUNICIPAL

The City of Thunder Bay is supplied by two waterworks: the Thunder Bay North Plant and the Thunder Bay South Plant. The first is capable of pumping 50,000 m^3/d and withdraws water from Thunder Bay through an intake located at Bare Point. The second is rated at 55,000 m^3/d and withdraws water from Loch Lomond located about 8 km southwest of the mouth of Mission River. Both plants utilize screening and chlorination. The average annual pumpages for the years 1972 to 1974 from the north and south plants were 31,000 m^3/d and 37,300 m^3/d, respectively. The

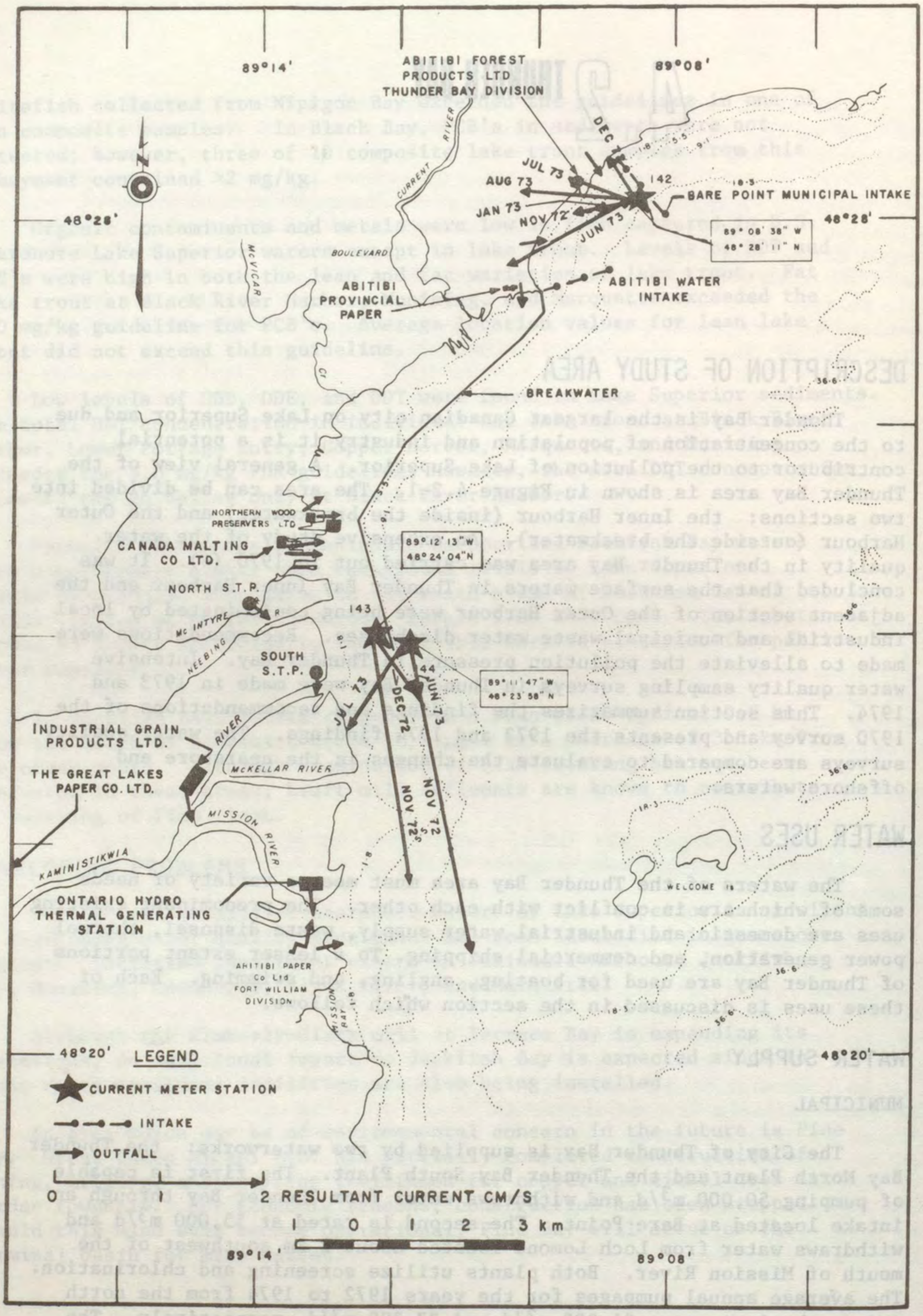


FIGURE 4.2-1 : RESULTANT CURRENTS

treated water distribution systems are being partially integrated to provide more flexible operation and reliability of the supply.

INDUSTRIAL

The largest individual industrial user of water in Thunder Bay is the Ontario Hydro Thermal Generating Station which, when operating, utilizes for once-through cooling, approximately 540,000 m^3/d of water taken from the mouth of Mission River. However, this station only operates when the load on Ontario Hydro's east-west grid increases. In 1975, the station operated a total of three months.

The pulp and paper industry is another large water user. Of the four major mills in the area, three - Abitibi Paper Company Ltd. (Fort William Division), Abitibi Forest Products Ltd. (Provincial Paper Division), and Abitibi Forest Products Ltd. (Thunder Bay Division) - withdraw 30,900, 75,900, and 52,700 m^3/d, respectively, of water for cooling and process purposes (1974 averages). The fourth, owned and operated by The Great Lakes Paper Co. Ltd., is located on and withdraws 151,000 m^3/d of water from the Kaministikwia River.

Several small industries withdraw part of their water supply directly from the bay with the rest obtained from the city. Northern Wood Preservers Ltd. takes approximately 160 m^3/d from the inner harbour. Canada Malting Co. Ltd. draws, in the mean, about 2200 m^3/d (or 65% of its need) from the lake.

WASTE WATER DISPOSAL

Some of the watercourses in the Thunder Bay area are used for disposal of treated and untreated wastes from industrial and municipal sources. The major industrial discharges originate from the pulp and paper mills in the area. The City of Thunder Bay is served by two primary sewage treatment plants with one discharging into the McIntyre River and the other into the Kaministikwia River. The city has a combined sewer system with numerous outfalls to the nearest watercourse. These outfalls will be combined by mid-1977 and directed to the sewage treatment plant.

ELECTRIC POWER PRODUCTION

There are two hydro-electric power generating stations on the Kaministikwia River upstream from Thunder Bay. Flow regulations for these stations are provided by two dams. An arrangement has been made to discharge at least 17 m^3/s to provide additional dilution water in the lower Kaministikwia River.

COMMERCIAL AND RECREATIONAL FISHING

Commercial fishing, which seriously declined in 1970 to 1972, has made a comeback in Thunder Bay. In 1974 the restriction imposed as a result of high mercury levels on lake trout was lifted. Fish species in order of value of fish commercially caught in Thunder Bay are: whitefish, suckers, lake trout, smelt, menominee, perch, northern pike, and burbot. The value of the 1975 catch exceeded $300,000. In 1974 angling became important to the southwest section of Thunder Bay and in 1975 to the northern section. Anglers experienced more and better fishing than in the past twenty years.

RECREATION

Thunder Bay area has been increasingly developed for recreational uses. On the north shore outside the city there is considerable cottage development and several public beaches. Most of the east shore lies within the boundaries of Sibley Provincial Park. Other small recreational areas are located south of the City of Thunder Bay.

Pleasure boating is developing extensively in the area. Two marinas are located in the Inner Harbour area while the two yacht clubs and a rowing club are located on the Kaministikwia Channel of the Kaministikwia River.

Swimming in Thunder Bay has never developed extensively because of the cold water.

COMMERCIAL SHIPPING

Thunder Bay is Canada's western terminus of the St. Lawrence Seaway. Ships are able to navigate up the Kaministikwia River to the Westfort turning basin and operate behind the eight kilometre breakwall that forms Thunder Bay Inner Harbour. Wheat and grain products, iron ore, bulk cargo, paper and wood products, oil, and coal are the major commodities handled at Thunder Bay. In 1974, total cargo was 18.5 million tonnes.

DREDGING DISPOSAL

Sections of the lower Kaministikwia and Mission Rivers are dredged to allow commercial shipping up to Westfort turning basin. In the past approximately 140,000 m^3 of sediment, dredged each year from the Kaministikwia River, were disposed of by the Canada Department of Public Works in Thunder Bay near the Welcome Islands. Presently, uncontaminated material dredged from the river is being disposed of well offshore in the lake at a Ministry of the Environment (MOE) approved site. Some contaminated material was deposited into a semi-enclosed basin in 1975 (see also Chapter 3.8).

WATER QUALITY

In the 1972 report (4) on Thunder Bay it was concluded that the surface waters in the bay are being contaminated by local industrial and municipal waste water discharges. Industrial waste water discharges accounted for approximately 95% of the BOD inputs. The most seriously affected area was the lower Kaministikwia River and the area around its mouth. The impairment of the Thunder Bay Inner Harbour was restricted to the extreme north and south sections, which receive the major waste inputs. The main changes are a decrease in dissolved oxygen levels, increase in nutrient levels, and increase in bacterial contamination in excess of accepted criteria for swimming and bathing(11)(see Appendix C). The Outer Harbour problems included bacterial contamination and aesthetic impairment, particularly in the vicinity of outfalls. However, at the time of the 1970 study water quality degradation due to the discharges of oxygen-consuming wastes and nutrients was not serious.

LIMNOLOGY

To be able to determine the changes of Lake Superior in the Thunder Bay area, to widen general knowledge of the lake, and to have baseline data for the future studies, a variety of physical, chemical, and biological parameters were measured (4-6) and are reviewed below.

PHYSICAL LIMNOLOGY

WATER MOVEMENTS AND DISPERSION

Recording current meters were operated at three locations in Thunder Bay (Figure 4.2-1) between November 1972 and August 1973, in order to determine the nearshore water dynamics and estimate dispersion characteristics (6). Monthly records of current meter data were processed by the usual statistical and time series methods (see for example (7)). Results indicate slower and more variable currents at the northern location (142) compared to the southern locations (143 and 144). The southern currents were generally along the shore and toward the south with relatively large persistence. Those at the northern location were variable and with resultants generally toward the shore. In addition, long periods of stagnation (no measurable currents) were observed, particularly in the winter. This reflects the effect of ice cover shielding the water from wind-induced motions. Results indicate that the bay is flushed from the northeast.

Periods related to fundamental Lake Superior oscillations (8) were absent. Thus, the bay is quite isolated from the lake and the predominant factors controlling the bay currents are the local shore geometry and the variation of water levels in the bay. Dispersion coefficients indicate that pollutant dispersion is relatively slower at all locations in Thunder Bay than in Lakes Erie and Ontario (6). Residence time in the nearshore region computed on the basis of water chemistry is approximately 22 days.

TEMPERATURE

Monthly average temperatures, standard deviations, and minimum and maximum values are given in Table 4.2-1. The data were divided into the surface values (down to 1.5 m from the surface) and bottom values (below

TABLE 4.2-1

WATER TEMPERATURE, ^{0}C[a]

Month		July	August	October
1973 Surface Layer	Mean	17.10	17.53	7.65
	Standard Deviation	0.62	1.24	0.90
	Number of Samples	4	86	48
1973 Bottom Layer	Mean	14.45	14.57	7.50
	Standard Deviation	1.23	4.16	0.64
	Minimum	–	6.80	6.50
	Maximum	–	18.00	8.20
	Number of Samples	4	48	45
1974 Surface Layer	Mean	16.37	–	6.44
	Standard Deviation	1.34	–	0.42
	Minimum	11.20	–	5.80
	Maximum	17.70	–	7.80
	Number of Samples	26	–	27
1974 Bottom Layer	Mean	11.25	–	6.34
	Standard Deviation	2.99	–	0.29
	Minimum	6.40	–	5.20
	Maximum	17.40	–	6.70
	Number of Samples	50	–	84

[a] All data collected down to a depth of 1.5 m below the surface are included in the surface means, all other values are included in the bottom means.

1.5 m from the surface). July, August, and October are presented as representative of events. Thermal stratification existed in July and August. The mean surface layer temperatures in July and August were from 16.4 to 17.5°C with the mean bottom layer values of 11.6 to 14.6°C. In October the whole water column was practically homogenous in temperature with the mean values of 7.6°C in 1973 and 6.4°C in 1974, respectively.

CHEMICAL LIMNOLOGY

WATER CHEMISTRY SURVEYS

Samples of the water in Thunder Bay were collected from July to October 1973 and May to October 1974 several times a month. The sampling locations are shown in Figure 4.2-2. There was generally no significant difference in the chemistry parameters measured at different depths. Surveys were designed to remove bias caused by wind. Water samples were analyzed for specific conductance, ammonia, total Kjeldahl nitrogen, nitrite, nitrate, total phosphorus, filtered reactive phosphate, chloride, sulphate, total and fecal coliform, bacteria, chlorophyll *a*, dissolved oxygen, and enterococci. The analytical methods are outlined in (9). The summary of data is given in the project report on Thunder Bay water quality (5).

CHANGES IN WATER QUALITY BETWEEN 1970 AND 1974

To better understand pollutant exchange and to be able to compare the change in water quality of the harbour area, the harbour and the adjacent area were divided into 24 cells with four zones (A,B,C,D) parallel to the shore and six zones (1,2,3,4,5,6) perpendicular to the shore (Figure 4.2-2). The segmentation was based partly on the bottom morphology and partly on the location of the sampling stations.

There are from one to four sampling stations in each cell. It was assumed that the concentration is homogeneous in each grid; either the concentration of the sampling station or the mean concentration of all the stations in the cell was used. This grid system was used to calculate the change of concentration in the individual zones and to show graphically how the concentration has changed over the years. Some physical characteristics such as volume, depth, and surface area for the four zones (A,B,C,D) parallel to the shore are given in Table 4.2-2.

The changes in key chemical parameters are discussed below.

DISSOLVED SOLIDS

To be able to compare 1970 data for dissolved solids with 1973 and 1974 data, dissolved solids for 1973 and 1974 were estimated from specific conductance data using a conversion factor of 0.65 (9). The changes in the dissolved solids can be seen from Figure 4.2-2. There is little change between the years with apparent decrease of the concentrations in the nearshore zones (A and B) in 1974. However, the calculation of the

TABLE 4.2-2

THUNDER BAY, NEARSHORE AREA PARAMETERS

ZONE[a]		A			B			C			D			A+B+C+D		
Volume $m^3 x 10^6$			81.9			207.7			287.6			580.0			1157	
Mean Depth m			4.55			9.15			15.8			19.4			13.0	
Surface Area km^2			18.0			22.7			18.2			29.9			88.8	
YEAR		-1970-	-1973-	-1974-	-1970-	-1973-	-1974-	-1970-	-1973-	-1974-	-1970-	-1973-	-1974-	-1970-	-1973-	-1974-
Dissolved Solids	mg/ℓ	70.7	73.8	68.8	65.5	66.6	66.3	65.0	64.7	64.7	62.3	64.5	64.3	64.1	65.6	65.1
	t	5790	6050	5640	13600	12800	13800	18700	18600	18600	36200	37500	37400	74300	76000	75400
Total Phosphorus	mg/ℓ	0.0252	0.0400	0.0548	0.0093	0.0164	0.0338	0.0069	0.0135	0.0200	0.0074	0.0121	0.0298	0.0089	0.0152	0.0299
	t	2.06	3.28	4.48	1.94	3.40	7.02	1.98	3.88	5.87	4.28	7.04	17.32	10.27	17.60	34.59
Total Nitrogen	mg/ℓ	0.387	0.455	0.324	0.313	0.339	0.269	0.309	0.377	0.195	0.298	0.367	0.187	0.310	0.310	0.213
	t	31.7	37.3	26.5	65.1	70.5	55.9	88.9	108.6	56.2	173.3	213.4	108.6	359	430	247
Ratio Total N: Total P		15.4	11.4	5.9	33.6	20.7	8.0	44.8	27.9	9.8	40.3	30.3	6.3	34.8	24.4	7.12
Total Coliforms per 100 mℓ, Geom. Means		3219	-	1640	1406	-	438	672	46	108	451	40	31	1486	-	450
Chlorophyll *a*	μg/ℓ	-	1.53	-	-	1.31	-	-	1.08	-	-	1.06	-	-	1.24	-

a. Individual zones are shown in Figure 4.2-2.

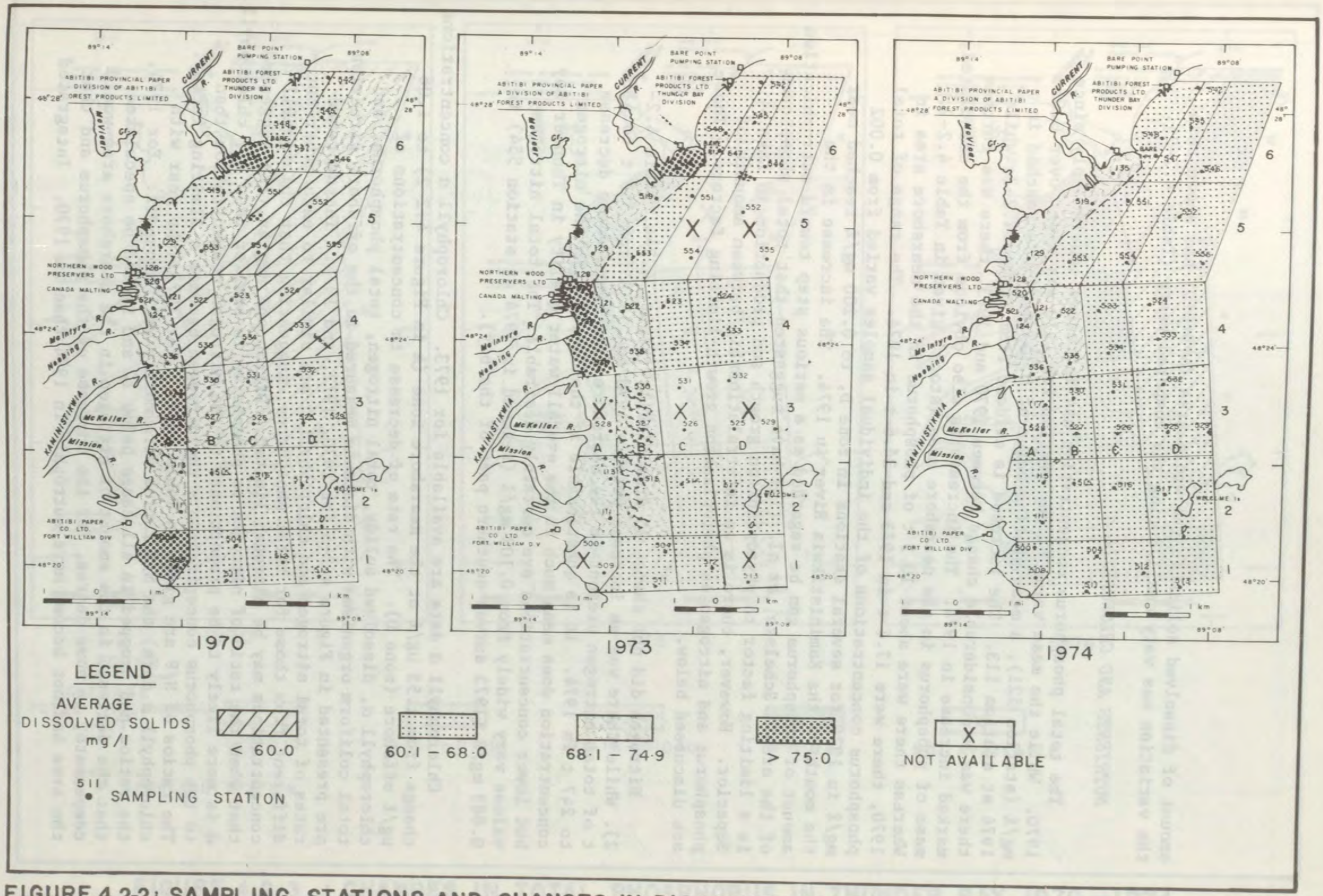


FIGURE 4.2-2: SAMPLING STATIONS AND CHANGES IN DISSOLVED SOLIDS IN THUNDER BAY 1970 — 1974

amount of dissolved solids in the whole area (A+B+C+D) has shown that the variation was very small during the compared years (Table 4.2-2).

NUTRIENTS AND CHLOROPHYLL a

The total phosphorus concentration has increased considerably since 1970. While the mean value at any station for 1970 was never over 0.053 mg/ℓ (station 521), a mean station value of 0.111 mg/ℓ was reached in 1974 at station 113. The increase is evident from Figure 4.2-3; while there was a considerable change between 1970 and 1973, there was further marked increase in 1974. The increase is also obvious from the calculated mass of phosphorus in the nearshore area (stock) given in Table 4.2-2. Whereas there were about 10.3 t of phosphorus in the nearshore area in 1970, there were 17.6 t in 1973 and 34.6 t in 1974. The range of total phosphorus concentrations of the individual samples varied from 0.002 mg/ℓ in 1970 for several stations in zone D, to 0.200 mg/ℓ reached near the mouth of the Kaministikwia River in 1974. The increase in the amount of phosphorus can be regarded as a serious step toward eutrophication of the area. Schelske, *et al.* (10) have suggested that total phosphorus is a limiting factor to phytoplankton growth and production in Lake Superior. However, there is an interrelationship between amounts of phosphorus and nitrogen as phytoplankton growth-limiting factors. These are discussed below.

Nitrogen did not change so dramatically (Figure 4.2-4, Table 4.2-2). While there was an increase between 1970 and 1973 from 359 t to 430 t of total nitrogen present in the nearshore area there was a decrease to 247 t in 1974. It is questionable if the decrease in the nitrogen concentration does mean much in the overall water quality in Thunder Bay but lower concentrations are certainly desirable. The total nitrogen values vary widely from 0.109 mg/ℓ (reached in 1974 at station 554) to 0.883 mg/ℓ (1973 survey southern part of the bay).

Chlorophyll *a* data are available for 1973. Chlorophyll *a* concentrations change from 1.53 μg/ℓ at the nearshore zone (A in Figure 4.2-2) to 1.06 μg/ℓ offshore (zone D). The rate of decrease in concentrations of chlorophyll *a*, dissolved solids, total nitrogen, total phosphorus, and total coliform organisms with distance measured in the offshore direction are presented in Figure 4.2-5 for 1970, 1972, and 1974. The decrease rates of total nitrogen and chlorophyll *a* are similar to each other but different from those for total phosphorus, suggesting that chlorophyll *a* concentrations may be nitrogen limited. Dillon and Rigler (12) suggested that when the ratio of nitrogen to phosphorus is smaller than 12, chlorophyll *a* is more likely to be proportional to the nitrogen concentration than to the phosphorus concentration - the nitrogen becomes a limiting factor. The ratios of N/P are given in Table 4.2-2. For 1973 (the year with chlorophyll *a* data) the N/P ratios were mostly well above 12. For 1974, the ratios had dropped in all cases below 12 and it can be speculated that the decrease in the amount of nitrogen in the nearshore area would compensate, to some degree, for the increase of the phosphorus and that the area had not become more eutrophic in 1974 than in 1970. Integrated

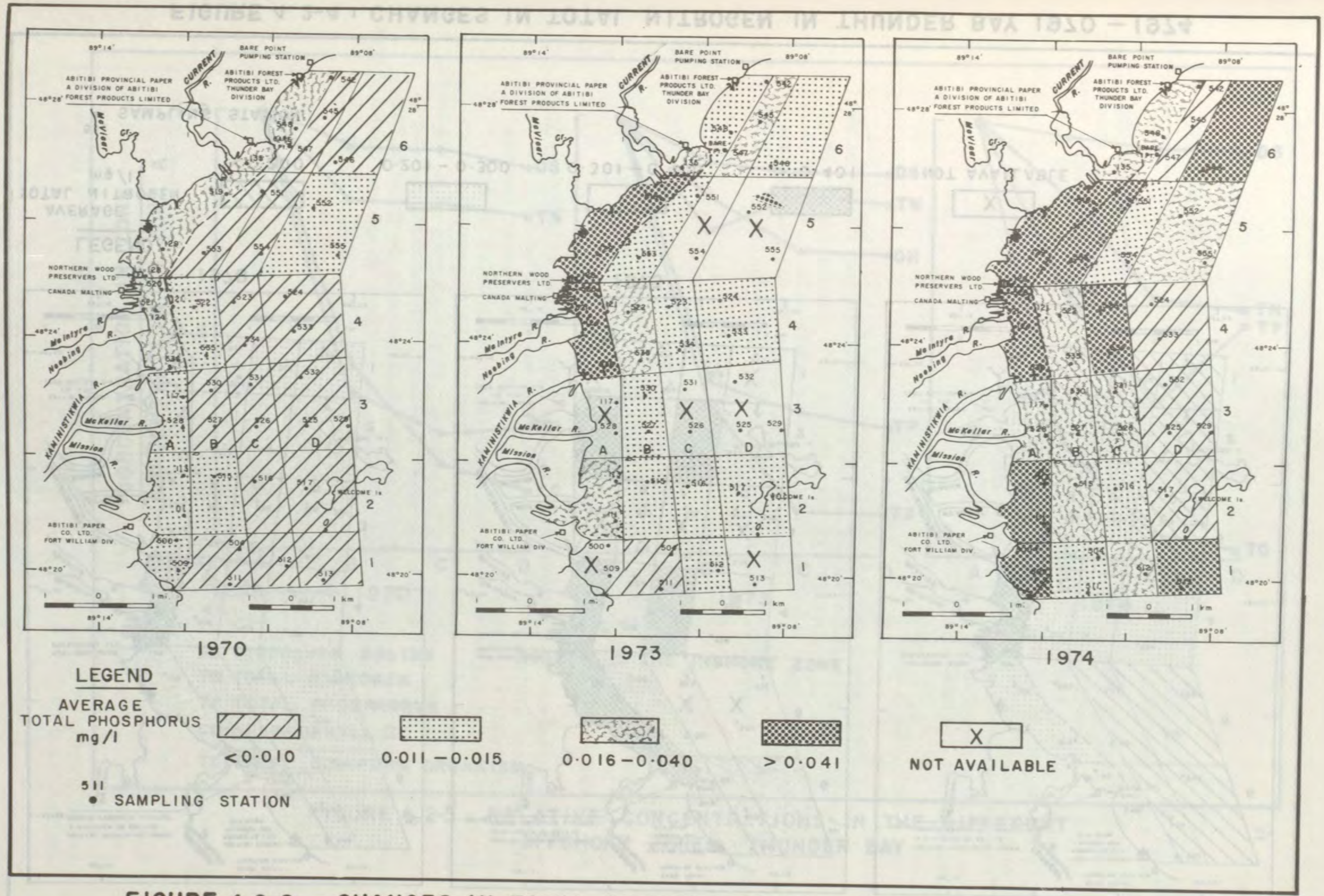


FIGURE 4.2-3 : CHANGES IN TOTAL PHOSPHORUS IN THUNDER BAY 1970 —1974

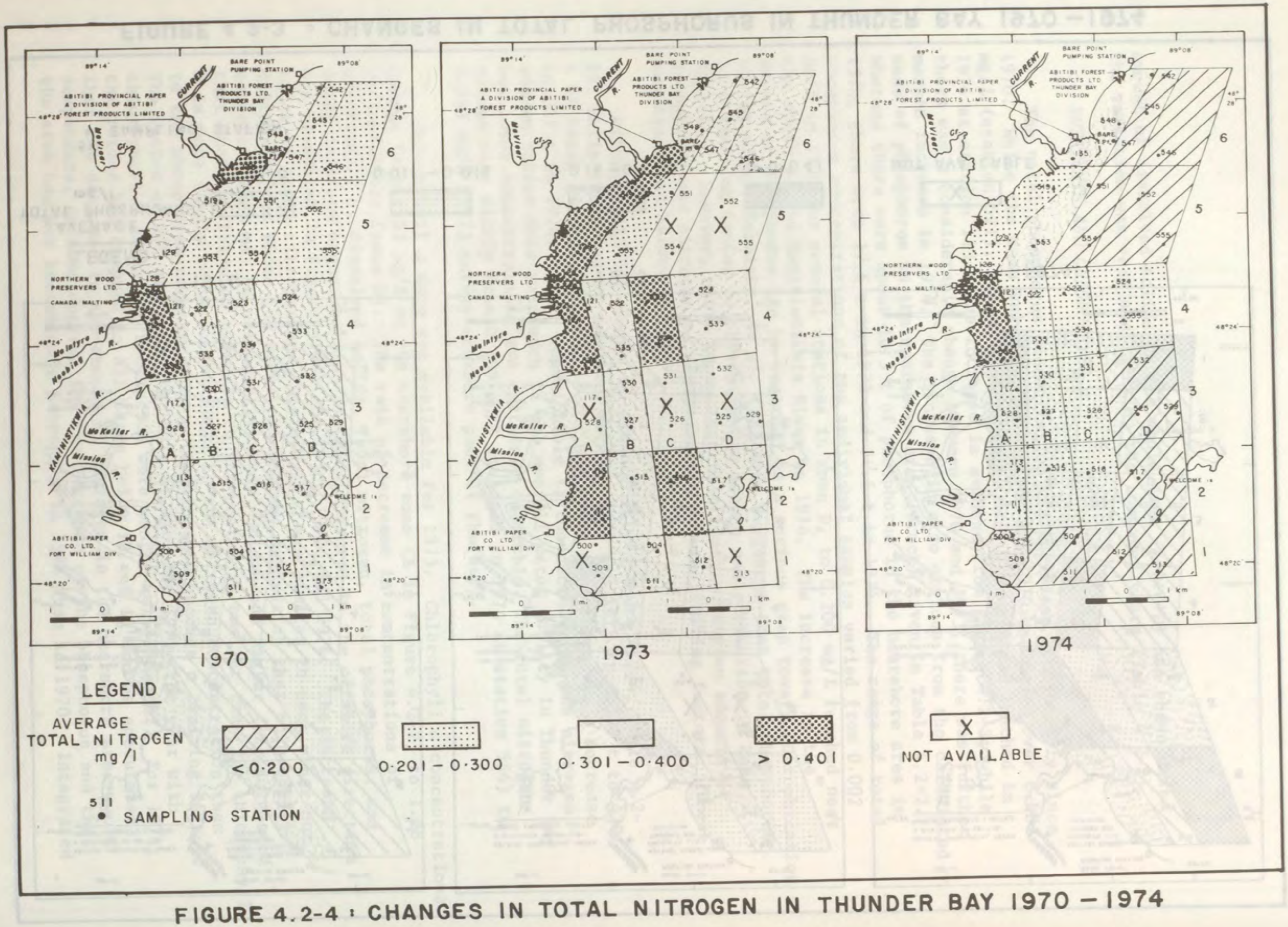


FIGURE 4.2-4 : CHANGES IN TOTAL NITROGEN IN THUNDER BAY 1970 – 1974

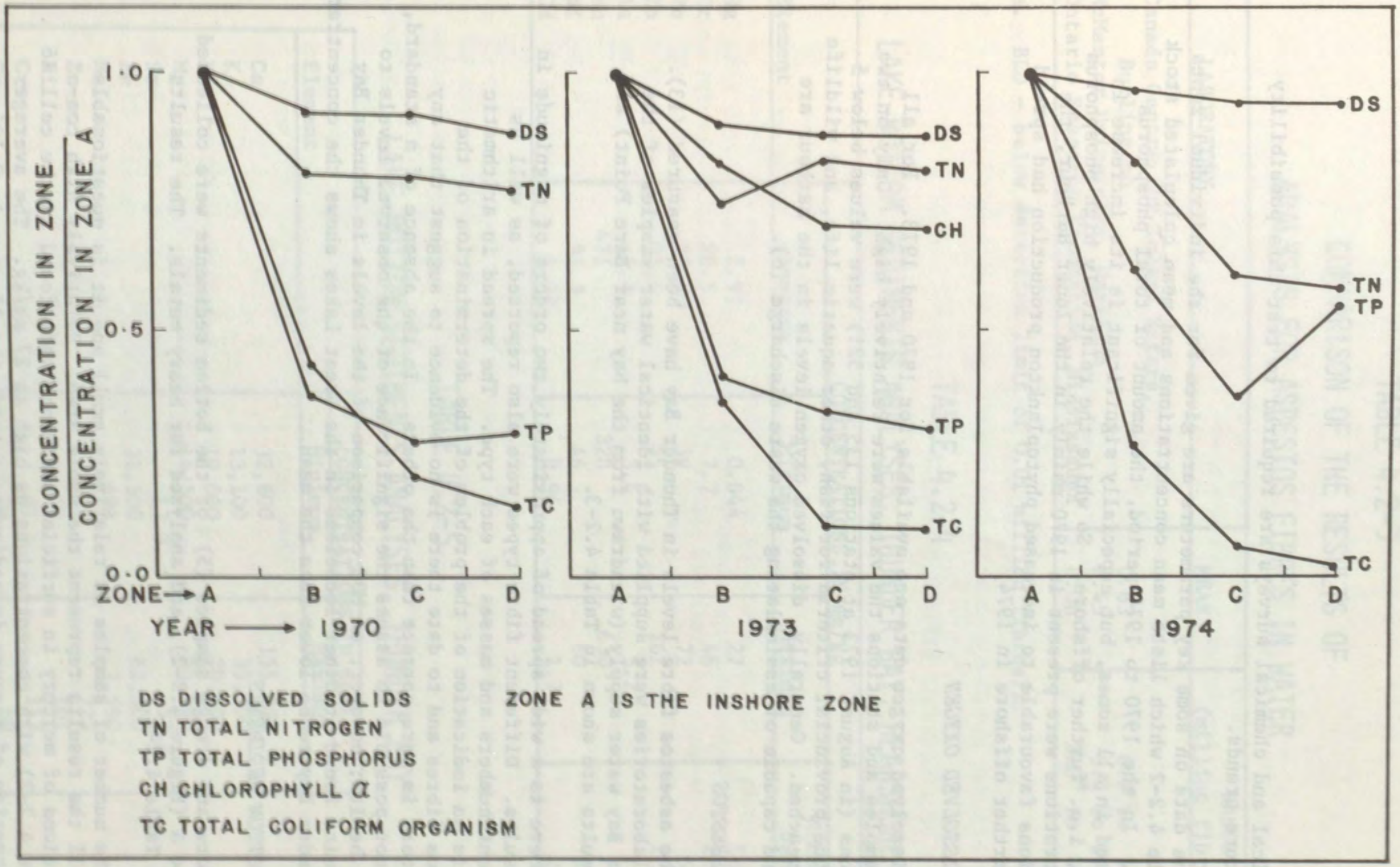


FIGURE 4.2-5 · RELATIVE CONCENTRATIONS IN THE DIFFERENT OFFSHORE ZONES, THUNDER BAY

biological and chemical surveys are required to test this possibility and future trends.

The data on some key parameters are given for the individual zones in Table 4.2-2 which lists mean concentrations and mean calculated stock values. In the 1970 to 1974 period, the amount of total phosphorus increased in all zones, but especially significant is its increase in zone D, i.e. further offshore. So while the relatively high phosphorus concentrations were present in 1970 mainly in the Inner Harbour, the conditions favourable to increased phytoplankton production had spread much farther offshore in 1974.

DISSOLVED OXYGEN

Dissolved oxygen data are available for 1970 and 1973. For all 1973 samples and stations the values were relatively high. Only on two occasions (in August 1973 at stations 135 and 521) were values below 5 mg/ℓ (the provincial criteria for fish, other aquatic life, and wildlife (11)) reached. Generally, dissolved oxygen levels in the harbour are high and capable of assimilating the waste discharge (6).

ASBESTOS

The asbestos fibre levels in Thunder Bay have been measured (13). Three laboratories were supplied with identical water samples of the Thunder Bay water supply (withdrawn from the bay near Bare Point) and the results are shown in Table 4.2-3.

There is a wide spread of approximately two orders of magnitude in the results. Different fibre types were also reported, as well as different numbers and masses of each type. The spread in arithmetic means is an indication of the problem of the determination of the asbestos fibres and to date there is no evidence to suggest that any laboratory is more correct than the others. In the absence of a standard, it is not possible to assess the significance of the observed levels to public health; however, an MOE comparison of the levels in Thunder Bay to results found at other locations in the Great Lakes shows the concentration at Thunder Bay to be lower than the mean.

BOTTOM SEDIMENTS

Core and dredge samples (5) of the bottom sediments were collected in zone A (Figure 4.2-2), and analyzed for heavy metals. The results are in Table 4.2-4.

The number of samples is relatively small and it is questionable how well the results represent the whole area. Relatively high concentrations of mercury in surficial sediments were found in the cell A6 (Figure 4.2-2) with concentrations as high as 27 mg/kg. The average concentration of mercury in sediments outside the A6 area is 0.106 mg/kg.

TABLE 4.2-3

COMPARISON OF THE RESULTS OF ANALYSIS FOR ASBESTOS FIBRES IN WATER

LABORATORY	MEAN	RANGE (million fibres/ℓ)
Canada Centre for Inland Waters, Burlington	0.63	0.2 to 1.0
McMaster University, Hamilton	8.45	3.4 to 29
Ontario Research Foundation, Mississauga	0.06	BLD[a] to 0.16

[a] BLD - below detection limit of 0.01 million fibres/ℓ.

TABLE 4.2-4

LAKE-BOTTOM SEDIMENTS ANALYSES, THUNDER BAY, NEARSHORE

Element	CONCENTRATIONS IN mg/kg			
	Average	Minimum	Maximum	Number of Samples
Hg	2.97	0.044	27	13
Cr	26.5	7.7	46	12
Pb	53.6	39	72	5
Zn	95.5	55	161	12
As	4.4	3.6	5.2	2
Mn	475	320	630	2
Ni	51.3	46	60	3
Cd	1.33	0.96	1.7	2

TABLE 4.2-5

LAKE-BOTTOM SEDIMENTS ANALYSES, THUNDER BAY

Element	CONCENTRATIONS IN mg/kg	
	Minimum	Maximum
Ca	32,600	155,000
K	13,100	35,000
Na	10,000	20,600
Mg	14,500	55,600
Sr	17.3	52.8
Fe	31,500	62,300
Mn	498	7,590
Zn	70	723
Ni	50	101
Cr	81	117
Co	34	60
Cu	27	103
P	386	1,627

Lake-bottom sediments at 201 stations (14) were collected in 1974. The sample collection area coincides with the area shown in Figure 4.2-1. Metals and phosphorus results are given in Table 4.2-5.

There were some general trends in the spatial distribution of the various elements. Iron, nickel, and chromium were irregularly distributed throughout the area. Zinc, cobalt, copper, and phosphorus increased in deeper water zones. Sodium, magnesium, and strontium concentrations were highest in the north-central section of the bay. The highest concentrations of calcium were found within the breakwater and at the northern section near the breakwater while the highest potassium concentrations were within the breakwater and in the eastern part of the study area.

EXCHANGE OF POLLUTANTS BETWEEN NEARSHORE AND OFFSHORE WATERS

Palmer's method (15) was used to estimate the exchange between the nearshore and offshore waters.

The method assumes steady state conditions (constant flows, constant loadings, constant and homogenous concentrations of the cells) and no precipitation in the nearshore zone. These assumptions are never strictly maintained as both concentrations and flows do change with time and certain amounts of water and chemicals are brought in with precipitation. By averaging the results over a long period of time (year) the flow and concentration variations are averaged out. However, the results should be taken as an approximation only. For evaluation and comparison of the nearshore-offshore estimation methods see Chapter 4.5.

The calculated values of the residence time, number of flushings per year (defined as the ratio of the total volume of water passing through the inshore zone and the total volume of this zone), and predicted excess or deficit values for phosphorus and nitrogen are given in Table 4.2-6. Results are sensitive to many factors including the loading values and background concentrations in the offshore areas. For this analysis the background concentrations were based on the lowest values found in zone D as well as on information from Schelske and Roth (2), Schelske, *et al.* (10), and Beeton (1). The loadings used for calculation of exchanges for 1973 and 1974 are shown in Table 4.2-7 and are based on the loading data summarized in Chapter 3. The loadings for 1970 were taken from the 1972 report (4).

The calculated flushing times change from 80 days for 1970 to 23 and 21 days for 1973 and 1974 respectively. The results for 1970 are not reliable as the values of loadings are based on limited data. For example, the loading flows for 1970 were one-third of 1973 data. This changes the results by a factor of three. It is believed that the 1973 and 1974 data are more reliable.

There are some inferences that can be made in the predicted excess of 65% in 1970 and deficit of 19% in 1974. The positive values indicate that more phosphorus is being brought into the area than is taken out

TABLE 4.2-6

MASS EXCHANGE IN THE NEARSHORE AREA

	1970	1973	1974
Calculated number of flushings/year	4.55	16.8	16.2
Residence Time (days)	80.2[a]	21.7	22.6
Predicted Excess (+) or Deficit (-) in nearshore zone percent of input			
- Phosphorus	64.6	44.6	-24.8
- Nitrogen	-59.0	-43.9	47.4

a. Unrealistically low available loading data, resulting value is too high.

TABLE 4.2-7

ESTIMATED MUNICIPAL, INDUSTRIAL AND TRIBUTARY LOADINGS TO THUNDER BAY[a]

SOURCE	MEAN CONCENTRATION, mg/ℓ				MEAN LOADINGS, t/a		
	Mean Flow $m^3 x10^6/a$	Dissolved Solids	Total P	Total N	Dissolved Solids	Total P	Total N
Kaministikwia R.	2634.0	170.0	0.065	0.718	447000	172.00	1890.0
Current R.	240.0	69.6	0.018	0.562	16700	4.34	135.0
Neebing R.	76.8	241.0	0.073	0.967	18500	5.61	74.3
McIntyre R.	72.7	239.0	1.036	6.094	17400	75.30	443.0
McVicar Bank	18.1	222.0	0.064	0.702	4020	1.16	12.7
Thunder Bay STP-South	10.0	345.0	3.08	21.9	3450	30.80	219.0
Thunder Bay STP-North[b]	10.8	347.0	3.48	23.0	3745	37.60	248.0
Abitibi Paper Co. Fort William Div.	11.1	1620.0	0.343	1.840	18000	3.81	20.4
Great Lakes Paper Co.[b]	63.9	2500.0	0.355	1.910	160000	22.70	122.0
Dow Chemical Co.[b]	3.5	136	0.000	0.008	467	0.00	0.3
Industrial Grain Prod.[b]	0.5	4560	53.0	178.0	2280	26.50	89.1
Canada Malting Co.	1.3	792	9.80	33.8	1030	12.70	44.0
Northern Wood Pres.	0.008	250	21.0	25.0	2	0.17	0.2
Abitibi Forest Prod. Provincial Paper Co.	26.5	1450	0.256	2.76	38500	6.79	73.2
Abitibi Forest Prod. Thunder Bay Div.	19.6	1430	0.447	2.16	28100	8.77	42.4
Sum of loadings or mean concentrations	3111[c]	191	0.112	0.977	595000[c]	348[c]	3040[c]

a. Averages based on 1973, 1974 and 1975 data.
b. Not included in the sum as they are already included in the tributary streams.
c. These sums do not include sources noted under b.

with the water moving through the zones. This can be explained as a result of excess phosphorus being removed by sedimentation, probably after part of it is first used by phytoplankton and/or by an increase in phosphorus concentration in the area by the end of the period. The negative 1974 value indicates that less phosphorus was brought into the area than was carried out. This could result either from release of phosphorus from the sediments or from a decrease in the phosphorus concentration in the area by the end of 1974. The latter possibility, based on this simple model, would be supported if the 1975 data show a decline in phosphorus concentrations.

For nitrogen, negative values were obtained for 1970 and 1973 data. While no conclusion can be made from rates between 1970 and 1973 as there are no data available for 1971 and 1972, it is interesting to note that, actually, the amount of nitrogen in the area in 1974 has declined in comparison with 1973. The positive value for 1974 suggested that more nitrogen was being brought into the area than was carried away and that an increase can be expected in 1975. The values of the residence times are different from that of Palmer (15) (40 days) which may be attributed to different loading and concentration data.

AQUATIC BIOLOGY

MICROBIOLOGY

Total and fecal coliform counts were determined in 1970, 1973, and 1974 (4,5). In 1973, numerous bacti samples could not be counted as inadequate dilutions were used in the laboratory. These samples are not used in computing statistical values and comparisons with other years for these data are not made. The geometric mean total coliform values in the individual zones are given in Table 4.2-2 and also shown in Figure 4.2-6. The mean values decreased between 1970 and 1974. No data are available for the northern part of the area in 1974. There is an apparent improvement in the total coliform counts in the southern area. The Ontario criteria (11) for body contact (1000 coliforms/100 mℓ) were exceeded in zone A in 1970 and 1974 while in zone B only 1970 data are over the limit. Ontario surface water criteria (5000 coliforms/100 mℓ) were not exceeded in this area.

FISH

A fish sampling program (16) was carried out to determine baseline levels of selected contaminants in sport and commercially valuable fish species collected in Thunder Bay. The results are shown in Table 4.2-8.

PCB AND PESTICIDES

Presently there are no Canadian regulations governing levels of pesticides in edible portions of fresh water fish. The proposed Agreement objective for total PCB's in whole fish on a wet weight basis is 0.1 μg/g for the protection of fish-consuming birds and animals (17). As

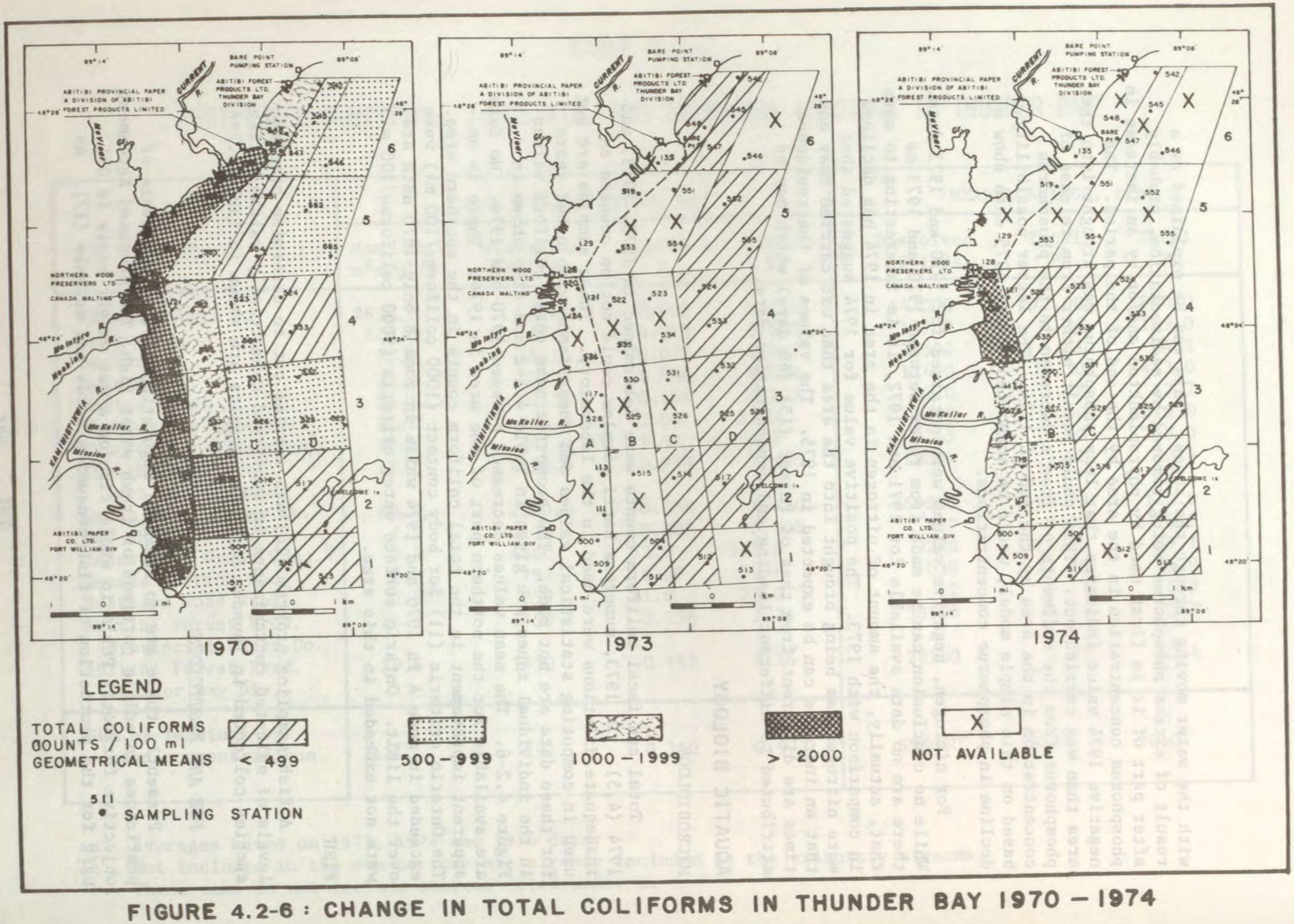


FIGURE 4.2-6 : CHANGE IN TOTAL COLIFORMS IN THUNDER BAY 1970 – 1974

TABLE 4.2-8

THUNDER BAY FISH ANALYSES

Parameter	Whitefish[a,b]		Lake Trout[a,b]		Lake Herring[a,b]	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Dieldrin	25.1	11.7	43.6	11.6	19.6	2.7
PCB	799	184	1720	315	706	205
pp 'DDE	235	82	513	95	284	59
pp 'DDD	35.5	7.8	45.9	11.5	30.9	7.3
pp 'DDT	162	42	103	47	172	53
op 'DDT	67.9	14.3	102	22	64.5	13.9
ΣDDT + Metabolites	501	-	865	-	552	-
Cu	0.51	0.38	0.49	0.26	0.49	0.13
Ni	0.22	0.32	<0.02-0.25	-	<0.02	-
Pb	1.21	1.60	<0.2-4.98	-	<0.02	-
Zn	4.09	0.62	3.39	0.67	6.21	1.92
Cd	0.08	0.03	0.28	0.44	0.06	0.02
Mn	0.15	0.07	0.15	0.12	0.20	0.06
As	<0.01-0.11	-	<0.01-0.30	-	0.13	0.03
Cr	1.01	0.58	0.60	0.56	0.18	0.09
Se	0.11	0.04	0.15	0.08	0.16	0.03
Hg	0.12	0.03	0.70[c]	0.06	0.17	0.02
Gross α pCi/g	<1.0	-	<1.0	-	<1.0	-
Gross β pCi/g	2.59	0.63	1.88	1.38	3.80	0.36

a. Means calculated from 10 samples, each consisting of a composite of flesh from five fish.
Pesticide and PCB results in μg/kg.
Heavy metal results in mg/kg.

b. If more than 15% of the results are less than (<) values, the range is shown.

c. Mean exceeds Canada Health Protection Guideline for the protection of consumers of fish and aquatic life (see also Appendix C).

the proposed objective is for whole fish samples while most of the analyses were done for flesh samples, comparison of the two sampling methods was carried out for slimy sculpins. PCB and pesticide analysis of whole fish showed reduced levels of organic compounds when compared to the results derived from flesh samples. Notwithstanding this limitation, PCB levels in fish did not meet the proposed Agreement objective but were within the Canadian guideline of 2 μg/g. All other pesticide levels indicated low levels of contamination and met all existing Agreement objectives or Canadian guidelines.

No relationship could be developed between the mean extractible oil content of fish and levels of PCB's and DDT. Lake trout samples consistently had higher levels of PCB's and pesticide residues. A predator species such as lake trout tends to further accumulate the body burden carried by lower trophic levels.

HEAVY METALS

Table 4.2-8 also presents the data for heavy metal concentrations along with allowable limits, where applicable. Heavy metal contamination of fish was minimal with the exception of mercury. Mercury was the only metal found to approach or exceed the present guideline level of 0.5 μg/g as recommended in the Food and Drug Act and Regulations (18) and this occurred in large, fatty lake trout.

RADIOACTIVITY

Presently there are no maximum levels established for radioactivity other than the recommendation that radioactivity be kept at the lowest practicable level to prevent harmful effects on health.

All samples analyzed had a gross α level of less than 1.0 pCi/g based on the wet weight of sample (Table 4.2-8). Samples analyzed for gross β radioactivity had a range of mean values from a maximum of 3.80 pCi/g in herring samples to a minimum mean value of 1.88 pCi/g in lake trout samples. As there are no current acceptable levels for radioactivity the data presented are difficult to interpret but do provide baseline levels for comparison with future surveys.

SUMMARY OF EXISTING AND DEVELOPING PROBLEMS

The nearshore waters in Thunder Bay are being impaired by local, industrial, and municipal waste water discharges (see (4) and also Table 4.2-7). Even though this report is limited to the years 1970 to 1974, some of the parameters are showing distinctive changes. Indications are that the dissolved oxygen is quite high. Nutrients have changed since 1970. While nitrogen was slightly lower in 1974 than in 1970, total phosphorus has increased significantly. There are not enough data on phytoplankton production to make any conclusions on the significance of the high nutrient levels. Dissolved solids have remained nearly constant while total coliform counts have declined. Water movements in the area are predominantly from north to south with the currents generally slower for the north part of the bay. This is important for determination of the fate of pollutants in the region.

Thunder Bay is a rapidly growing community. Both the industrial development and population are expected to increase in the near future. At present, expansion programs are underway on the Ontario Hydro Thermal Generating Station and Great Lakes Paper Company, a new coal handling terminal is being constructed, and other smaller developments are progressing. The importance of Thunder Bay as a port is increasing, with expected rises in the amounts of grain, lumber, ore, chemicals, and other commodities shipped. All these expansions will result in population growth and will have direct or indirect impact on water use and pollution and/or degradation in the area.

The municipal water supply with a total capacity of 105,000 m^3/d is expected to be able to meet the projected demands for the next 20 years. The expansion of the municipal primary sewage treatment plant capacity from 27,000 m^3/d to 110,000 m^3/d will, when finished in 1977, have adequate capacity to handle the municipal sewage. This construction program will essentially remove all untreated sewage discharges to watercourses in and around Thunder Bay. No nutrient removal program is planned at this time. The need for nutrient removal program should be reassessed, as the documented rapid increase of phosphorus concentrations in the area could lead to a serious degradation of the nearshore waters. Of the total phosphorus loadings into the Bay, the municipal and industrial sources account for about 43%. Of this, 23% are industrial while 20% are the municipal discharges. Municipal and industrial sources of total nitrogen account for only 28% of the total with 13% for the industrial and 15% for the municipal discharges. The percentage of the uncontrollable sources of the nutrients (mainly land drainage) is quite high; therefore, a point source nutrient removal program would be only partially effective.

There is a small amount of asbestos fibres in the municipal water supply in Thunder Bay. No conclusion on the possible health effects can be made at the present time, as neither the analytical methods are reliable nor any satisfactory standard for asbestos fibres in drinking water is available.

Mercury is still a problem in Thunder Bay. Lake trout samples from 1973 and 1974 had a mercury content above the recommended safe concentration for human consumption while the samples of whitefish and herring had concentrations below the maximum safe level. The situation should be improving since the closure of the Dow Chemical Company's chlor-alkali plant on the Kaministikwia River in 1973. Dredged materials are tested for mercury content and only uncontaminated material is disposed of in the lake.

Several additional remedial measures are being carried out by the local industries, including sulphite mill expansion and conversion toward the load reduction with the complete recycle of kraft mill by the Great Lakes Paper Company Ltd.

Bacterial contamination is not serious except in the Inner Harbour where the criteria for body contact are frequently exceeded. Due to its population and industrialization, Thunder Bay is one of the "areas of concern" on Lake Superior. Because historical data are scarce and incomplete, the trends in water quality can not be established with much confidence yet, even though some water quality degradation is apparent. The baseline data are now available and future changes can be detected.

4.3 DULUTH-SUPERIOR HARBOR

DESCRIPTION OF THE STUDY AREA

GEOLOGY AND TOPOGRAPHY

The Duluth-Superior Harbor (Figure 4.3-1) is located at the southwestern tip of Lake Superior. The harbour serves as the economic base for the cities of Duluth, Minnesota and Superior, Wisconsin which combined have a metropolitan population of approximately 138,000 people.

The harbour consists of two major bays - St. Louis Bay to the west and Superior Bay to the east. St. Louis Bay has a surface area of 9.7 km^2. Superior Bay has a surface area of 14.3 km^2 (3,4). The St. Louis River, which flows into St. Louis Bay, has an average flow of 64.3 m^3/s and a flow range of 2.27 to 1,070 m^3/s (5).

Minnesota and Wisconsin Points are largely deposits of sand washed up by waves aided by shore currents set up by the prevailing northeasterly wind. Originally, the only outlet of the harbour was at what is now the Superior Ship Canal, but in 1870 work began on the Duluth Ship Canal which was completed in 1871. The natural depth of the harbour and of what is now the Superior Ship Canal was between 2.4 - 2.7 m but dredging, which is necessary to continue commercial shipping, maintains the depth at 9.8 m at breakwaters, 8.5 m at pierheads, and 8.2 - 8.5 m in main channels (1).

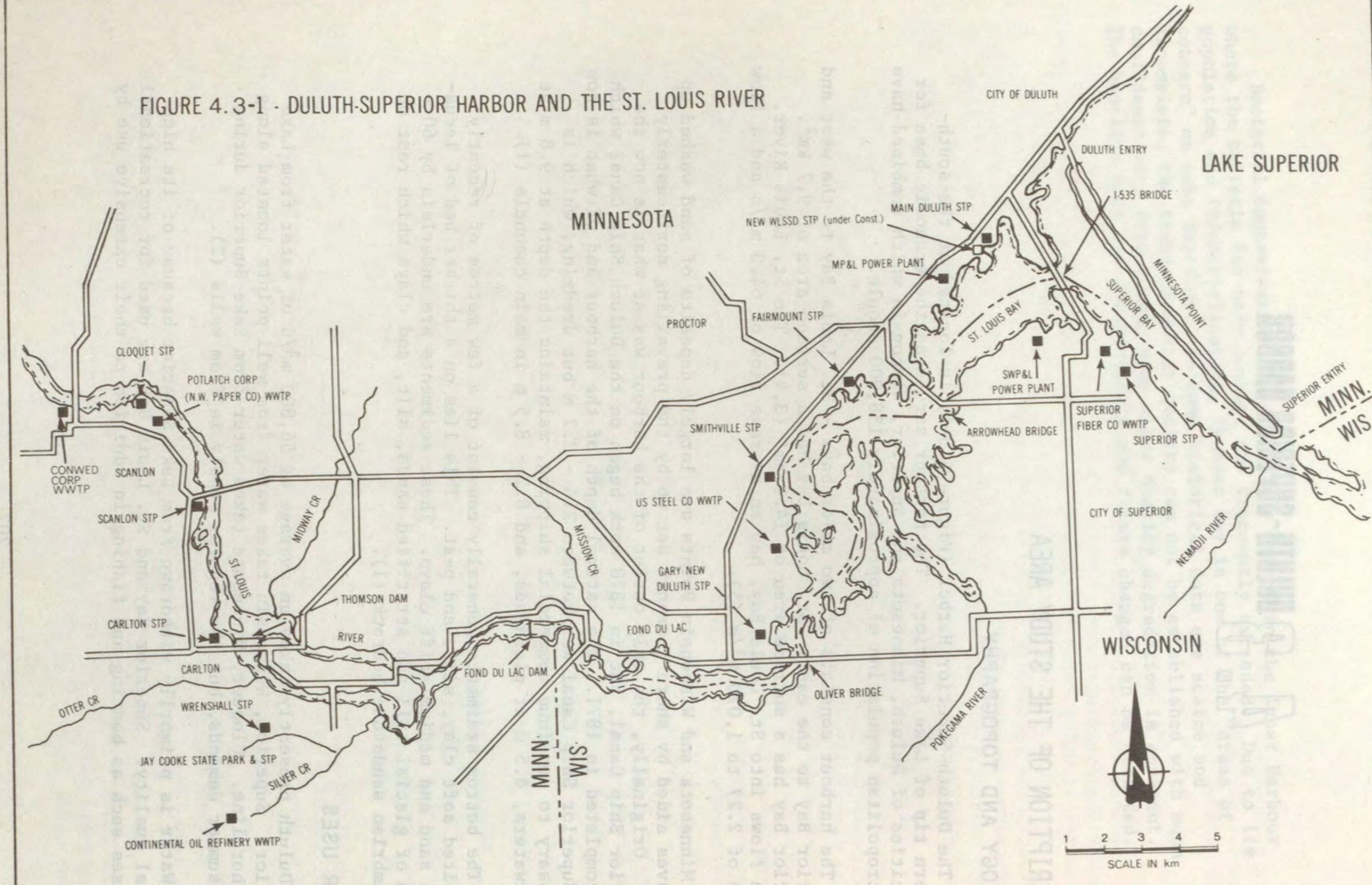
The bottom sediments generally consist of a few metres of recently deposited soft clay, silt, and peat. This lies on a thicker bed of lacustrine sand and medium stiff clays. These sediments are underlain by 60 - 170 m of glacial till and stratified sands, silt, and clays which rest on Precambrian sandstone bedrock (1).

WATER USES

Duluth presently takes an average of 56,800 m^3/d of water from Lake Superior. Superior, Wisconsin takes water from well points located along the shoreline. Cloquet, Minnesota takes water from Lake Superior during peak summer demands, but the regular supply is from wells (2).

Water is primarily withdrawn from Lake Superior because of its high natural quality. Superior Bay and St. Louis Bay are used for recreational purposes such as boating and fishing in addition to their extensive use by

FIGURE 4.3-1 - DULUTH-SUPERIOR HARBOR AND THE ST. LOUIS RIVER



commercial watercrafts. However, the bays are primarily known for their massive harbour facilities.

SOURCES OF POLLUTANTS

Water quality levels in the Duluth-Superior Harbor are affected by shipping wastes, municipal and industrial discharges, and agricultural and natural sources (1,3,4,6). Locations of significant point sources to the St. Louis River and St. Louis Bay directly up-stream of Superior Bay are shown in Figure 4.3-1. The significant discharges in Minnesota contribute in excess of 60,000 kg/d of BOD_5, 37,000 kg/d of total suspended solids, and 460 kg/d of phosphorus to the St. Louis River and St. Louis Bay, as shown in Table 4.3-1. The two Wisconsin discharges to Superior Bay, the Superior wastewater treatment plant and Superior Fiber Products, discharge over 4,500 kg/d of BOD_5 and 1,280 kg/d of suspended solids (7). The Superior wastewater treatment plant also discharges 160 kg/d of total phosphorus. Superior Water, Light and Power Company and Minnesota Power and Light Company discharge thermal effluent into St. Louis Bay.

There are 39 major docking facilities heavily concentrated in the harbour, St. Louis Bay, and Upper Superior Bay. Ships are serviced by a harbour disposal contractor to remove liquid wastes. A service barge picks up liquid wastes from vessel retention devices and delivers these to a dock, where they are pumped into the Duluth sewer system. However, the pumpout facilities available are not adaptable to some types of commercial watercraft and some of this liquid waste is dumped directly into the bay by vessel operators. Ballast, tanker hold cleanout wastes, and oil and grease from ship operations are uncontrolled.

The dredged channels in the harbour total 27.4 km in length. Since 1950 an average of 125,000 m^3 has been dredged annually to maintain the harbour. The primary sources of the sediment to the harbour are the St. Louis River and the Nemadji River. The St. Louis River carries industrial and municipal effluent as well as sediment. The Nemadji River flows through a low plain of red clay and carries large amounts of red sediments into the harbour (1).

LIMNOLOGY

PHYSICAL

The two main bays of the Duluth-Superior Harbor have relatively short hydraulic retention times. For St. Louis Bay the mean retention time is approximately six days and for Superior Bay the mean retention time is approximately eight days (3,4).

There is frequent wind-aided introduction of high quality Lake Superior water into Superior Bay and to a lesser extent this may extend into St. Louis Bay. This factor may also alter the levels of various physical and chemical parameters by creating an estuarine situation (Tables 4.3-3, 4.3-4, and 4.3-5).

TABLE 4.3-1

SIGNIFICANT DISCHARGERS TO ST. LOUIS BAY AND ST. LOUIS RIVER[a]

DISCHARGER	FLOW, in m^3/d	LOADINGS, in kg/d		
		BOD_5	Total Suspended Solids	Total Phosphorus
Duluth Main Sewage Treatment Plant	69,000	16,700	11,200	304
Duluth Gary New Duluth Sewage Treatment Plant	730	36	33	3.8
Duluth Smithville Sewage Treatment Plant	1,000	47	38	5.1
Duluth Fairmont Sewage Treatment Plant	2,800	138	125	15
Cloquet Sewage Treatment Plant	7,500	874	774	50
Conwed Corporation	7,400	2,810	2,880	4[c]
Potlatch Corporation (Northwest)	70,000	36,200	21,400	80[c]
U.S. Steel[b]	37,000	3,400	1,000	6
Superior Sewage Treatment Plant	19,000	1,600	1,000	160
Superior Fiber Products	940	2,900	280	-
Minnesota Power and Light Company[d]	426,000	-	-	-
Superior Water, Power and Light Company[e]	76,000	-	-	-
Carlton Sewage Treatment Plant	1,000	55	46	4.2
Scanlon Sewage Treatment Plant	290	36	29	3.8

a. Data based primarily on self-monitoring reports.

b. Discharge includes 1,420 kg/d ammonia, 380 kg/d phenol, and 54 kg/d cyanide.

c. Values based on only one sampling day during a compliance monitoring survey conducted by U.S. EPA, Minnesota-Wisconsin District Office, Minneapolis.

d. Thermal discharge is $296X10^6$ btu/h or 87MW.

e. Thermal discharge is $54X10^6$ btu/h or 16MW.

TABLE 4.3-2

MINNESOTA DISSOLVED OXYGEN WATER QUALITY STANDARDS FOR THE ST. LOUIS RIVER, ST. LOUIS BAY, AND SUPERIOR BAY[a]

WATER BODY	LOCATION	STANDARD
St. Louis River	Cloquet to Clough Island	Not less than 5 mg/ℓ from April 1 through November 30, and not less than 4 mg/ℓ at other times
St. Louis Bay and Superior Bay	Entire Bay	Not less than 6 mg/ℓ from April 1 through May 31 and not less than 5 mg/ℓ at other times.

a. Based on State of Minnesota Regulations WPC-15 and 25 (10).

TABLE 4.3-3

PHYSICAL PARAMETERS IN ST. LOUIS BAY (1)[a]

Parameter	June, 1973 Mean (Range)	July, 1973 Mean (Range)	Nov., 1972 Mean (Range)
Dissolved Oxygen (mg/ℓ)	5.2 (3.6-6.3)	4.8 (1.1-8.6)	-
Temperature (^oC)	17 (16.5-18)	19 (18.2-20)	1.0
Conductivity (μS/cm)	165 (150-177)	167 (140-193)	81 (80-82)
pH	7.3 (7.2-7.5)	7.4 (7.3-7.5)	7.1 (7.0-7.1)
Alkalinity (mg/ℓ)	49 (47-54)	60 (53-72)	76 (74-78)
Turbidity (JTU)	57 (25-95)	36 (4.0-65)	6.6 (6.4-6.8)

a. A total of 6 points were sampled once in both June and July and 2 additional points were sampled once in July. Samples were taken near the Duluth main waste water treatment plant and in the main channel directly upstream from the I-535 Bridge. In November two samples were taken directly upstream from the I-535 Bridge.

TABLE 4.3-4

PHYSICAL PARAMETERS BETWEEN ST. LOUIS BAY AND SUPERIOR BAY AT I-535 BRIDGE (11)[a]

Parameter	Spring[b] Mean(Range)	Summer[b] Mean(Range)	Fall[b] Mean(Range)	Winter[b] Mean(Range)
Dissolved Oxygen (mg/ℓ)	7.7(2.2-12.4)	6.7(5.8-7.5)	8.9(5.9-11.7)	3.9(2.4-4.7)
Conductivity (μS/cm)	128 (74-200)	130 (88-150)	178 (160-200)	188 (170-200)
pH	7.6(7.1-8.0)	7.5(7.0-7.7)	7.7(7.4-8.1)	7.2(6.8-7.8)
Alkalinity (mg $CaCO_3$/ℓ)	45 (24-83)	58 (40-80)	65 (56-71)	61 (48-77)
Total Hardness (mg $CaCO_3$/ℓ)	57 (35-100)	67 (47-90)	73 (64-82)	69 (56-85)
Turbidity (JTU)	9.6(3.1-30)	6.9(5.0-8.9)	8.1(4.5-12)	4.0(3.5-4.7)
Total Solids (mg/ℓ)(103°C)	132 (110-170)	130 (110-150)	157 (130-170)	154 (150-160)
Suspended Solids (mg/ℓ)(103°C)	14.4 (3-43)	5.3 (5-6)	8.3 (6-10)	7.2 (4-12)
Dissolved Solids (mg/ℓ)(180°C)	125 (86-185)	125 (104-145)	147 (121-161)	147 (138-154)
5-day BOD (mg/ℓ) (20°C)	3.1(1.7-6.2)	1.9(1.3-2.9)	2.9(1.9-3.6)	4.6(3.0-6.1)
Total Organic Carbon[c] (mg/ℓ)	18.2(12.5-23.7)			16

a. MPCA samples were collected at the I-535 bridge between December 6, 1973 and June 6, 1975. Samples for all parameters except as noted, were collected monthly. Also, several additional samples were collected in the spring period. A total of approximately 25 samples were collected during sampling period.

b. Spring (March 21 - June 21)
Summer (June 22 - September 22)
Fall (September 23 - December 21)
Winter (December 22 - March 20)

c. Samples for this parameter were taken only 7 times during the period from December 6, 1973 to June 6, 1975.

TABLE 4.3-5

PHYSICAL PARAMETERS IN SUPERIOR BAY (12)[a]

Parameters	May 14, 1975 Mean(Range)	Sept. 25, 1974 Mean(Range)	Oct. 25, 1974 Mean(Range)
Dissolved Oxygen (mg/ℓ)	9.3(9.3-9.4)	8.8 (8.2-9.6)	10.2 (9.7-10.6)
Temperature (°C)	13.5 (13-14)	11.8 (11.5-13.5)	7.3 (7.0-8.0)
Conductivity (µS/cm)	93 (91-95)	143 (130-150)	152 (120-180)
pH	7.6(7.5-7.8)	7.8 (7.6-8.1)	7.8 (7.6-8.1)
Alkalinity (mg $CaCO_3$/ℓ)	33 (32-34)	50 (49-52)	60 (51-64)
Total Hardness (mg $CaCO_3$/ℓ)	51 (50-54)	65 (61-68)	75 (68-80)
Turbidity (JTU)	6.2(5.8-6.6)	3.4 (2.3-6.0)	3.0 (2.5-3.7)
Total Solids (mg/ℓ) (103°C)	87 (68-100)	148 (110-310)	124 (96-150)
Suspended Solids (mg/ℓ) (103°C)	3.6(2.4-6.0)	10 (1.2-25)	8.7 (4.0-10)
Secchi Disc (m)	0.76	0.9 (0.8-0.95)	1.02(0.8-1.25)
Colour	100	83 (70-90)	56 (40-70)
5-Day BOD (mg/ℓ)(20°C)	0.94(0.84-1.0)	1.9 (1.3-2.3)	1.4 (0.7-2.0)

a. Once each sampling day samples were collected at four locations as part of the Lake Superior near shore water quality study. One location was near each entry to the lake and the other two locations were spaced between the entries.

DISSOLVED OXYGEN

Dissolved oxygen in the summer often falls to levels below Minnesota standards in St. Louis Bay (Tables 4.3-2 and 4.3-3). There is a summer oxygen low point below Minnesota standards in the vicinity of the Fond du Lac dam 32 km upstream from the Duluth entry (8) due primarily to the ∿ 39,000 kg/d of BOD_5 introduced by the Potlatch Corporation and Conwed Corporation of Cloquet. Much of this material becomes incorporated into the benthic sludge which removes oxygen from the impounded water. The effect from this depression of dissolved oxygen can be seen all the way to St. Louis Bay. However, there is a gradual recovery of oxygen levels so that by the time the water reaches Superior Bay the oxygen levels are generally not below Minnesota standards (Tables 4.3-2 and 4.3-5). Some of this recovery may be due to the "seiche effect" - the introduction of Lake Superior water into the harbour.

The lowest summer oxygen level (1.1 mg/ℓ) in St. Louis Bay was obtained near the Duluth main treatment plant in July 1973 (1). This plant introduces ∿ 16,000 kg of BOD_5 daily.

In the winter, the mean dissolved oxygen level in St. Louis Bay at the I-535 bridge is below Minnesota standards (Tables 4.3-2 and 4.3-4). The cold water during the winter reduces the rate of oxygen uptake in the river; therefore, the oxygen low point occurs in St. Louis Bay.

TURBIDITY

Turbidity in Superior Bay has been found to occasionally exceed the Minnesota water quality standard of 25 JTU (1,9). The turbidity has been found to be as high as 122 JTU in the ship channel between the Duluth and Superior Entries and as low as 2.3 JTU near the Duluth Entry. Ship propwash, dredging, and Nemadji River sediment contribute to the turbidity along with the loadings from the St. Louis River. The Nemadji River contains 1.37×10^6 kg/d of suspended solids at a mean flow of 41 m^3/s while the St. Louis River contains 179,000 kg/d at a mean flow of 112 m^3/s. The high suspended solids in the Nemadji River are caused by red clay erosion in that basin; however, the loading value may be high since it was determined during high runoff periods.

CHEMICAL

WATER CHEMISTRY

Tables 4.3-6, 4.3-7, 4.3-8, and 4.3-9 summarize selected chemical data which show the overall quality of the bays. When samples were averaged, "less than" values were assigned a value of half the detection limit.

St. Louis Bay is estimated (3,4) to be receiving a phosphorus load at least twelve times and Superior Bay 9 times the rate proposed by Vollenweider (13) as "dangerous" for promoting algal blooms; however, Vollenweider's model may not be applicable to bodies of water with short retention times.

TABLE 4.3-6

CHEMICAL PARAMETERS IN ST. LOUIS BAY (4)[a]

Parameter	July 13, 1973 Mean(Range)	Sept. 7, 1973 Mean(Range)	Oct. 18, 1973 Mean(Range)
Total Phosphorus (mg/ℓ)	0.4 (0.18-0.76)	0.21 (0.2 -0.22)	0.33
Dissolved Phosphorus (mg/ℓ)	0.3 (0.1 -0.6)	0.15 (0.14-0.16)	0.24 (0.24-0.25)
Ammonia (mg N/ℓ)	0.92(0.74-1.4)	0.65 (0.62-0.69)	1.35 (1.32-1.38)
Nitrite & Nitrate (mg N/ℓ)	0.21(0.21-0.22)	0.13 (0.11-0.14)	0.1 (0.1)

a. The sample location was in the main channel near Duluth's main sewage treatment plant. Samples were taken at several depths during each sample day.

TABLE 4.3-7

CHEMICAL PARAMETERS IN ST. LOUIS BAY (1)[a]

Parameter	June, 1973 Mean(Range)	July, 1973 Mean(Range)	November, 1972 Mean(Range)
Total Phosphorus (mg/ℓ)	0.15 (0.02-0.37)	0.3 (0.16-0.56)	
Total Nitrogen (mg/ℓ)	0.86 (0.62-1.14)	1.2 (0.14-3.5)	0.15 (0.15-0.16)

a. A total of 6 points were sampled once in both June and July and 2 additional points were sampled once in July. Samples were taken near the Duluth main sewage treatment plant and in the main channel directly upstream from the I-535 Bridge. In November two samples were taken directly upstream from the I-535 Bridge.

TABLE 4.3-8

WATER CHEMISTRY MEASURED AT I-535 BRIDGE BETWEEN ST. LOUIS BAY AND SUPERIOR BAY (11)[a]

Parameter (mg/ℓ unless otherwise noted)	Spring[b] Mean (Range)	Summer[b] Mean (Range)	Fall[b] Mean (Range)	Winter[b] Mean (Range)
Total Phosphorus	0.09 (<0.01-0.14)	0.11 (0.10-0.12)	0.13 (0.11-0.14)	0.15 (0.11-0.19)
Ammonia (as N)	0.21 (0.05-0.42)	0.31 (0.26-0.38)	0.18 (<0.05-0.34)	0.45 (0.27-0.57)
Organic Nitrogen	0.9 (0.05-1.3)	0.7 (0.25-1.0)	0.8 (0.29-1.2)	0.9 (0.4-1.3)
Nitrite (as N)	0.05 (0.01-0.06)	0.03 (0.01-0.05)	0.04 (0.02-0.07)	0.02 (0.01-0.04)
Nitrate (as N)	0.21 (<0.1-0.7)	0.5 (0.24-0.95)	0.23 (0.14-0.4)	0.24 (0.1-0.41)
Total Nitrogen	1.4 (0.26-1.85)	1.23 (0.73-2.16)	1.13 (0.5-1.75)	1.64 (1.48-2.05)
Sodium	6.8 (2.1-16)	6.6 (3.0-8.9)	12 (10-14)	14 (6.1-26)
Chloride	11 (2-19)	11 (3-15)	14 (7-23)	12 (9-15)
Potassium	1.9 (1.2-3.8)	1.5 (1.2-1.7)	1.8 (1.4-2.2)	2.0 (<1-5.2)
Calcium	37 (24-68)	52 (40-78)	54 (36-65)	48 (39-55)
Arsenic (µg/ℓ)[c]	<10	<10	–	<10
Silicate (as SiO_2)	7.9 (1.7-16)	5.1 (3.6-8.1)	9.7 (4.9-19)	11 (7.2-14)
Selenium (µg/ℓ)[c]	<2	<2	–	<2
Sulfate (as SO_4)	16 (<5-35)	11 (8-12)	20 (10-27)	21 (15-27)
Copper (µg/ℓ)	24 (<10-79)	28 (<10-75)	24 (<10-75)	<10
Cadmium (µg/ℓ)	<10	<10	<10	<10
Manganese (µg/ℓ)	105 (<10-240)	45 (<10-100)	136 (<10-300)	143 (95-180)
Zinc (µg/ℓ)	106 (<10-740)	15 (<10-25)	45 (<10-120)	35 (16-51)
Nickel (µg/ℓ)	<10 (<10-11)	12 (<10-25)	<10 (<10-16)	<10
Iron (µg/ℓ)	1170 (570-2300)	1010 (640-1400)	1050 (1000-1100)	750 (470-1100)
Mercury (µg/ℓ)[c]	0.3	0.3 (0.2-0.3)	–	0.3 (<0.1-0.3)
Lead (µg/ℓ)	9 (<10-26)	<10 (<10-14)	14 (<10-32)	<10
Fluoride	0.17 (<0.1-0.95)	0.1 (<0.1-0.13)	0.4 (0.10-1.1)	0.16 (0.13-0.23)
Total Chromium (µg/ℓ)[c]	2 (<2-3)	<2	–	3.5 (2-5)
Phenolic Compounds (µg/ℓ)	9.1 (3-17)	7 (3-15)	16 (8-23)	12 (10-15)
Cyanide[c]	<0.005	<0.005	–	<0.005 (<0.005-0.006)
Magnesium[c]	17.5 (11-24)	12	–	21.5 (13-30)
Oil & Grease[c]	1.9 (0.8-3.0)	<0.5	–	2.4 (1.3-3.4)

a. MPCA samples were collected between December 6, 1973 and June 6, 1975. Samples for all parameters except as noted were collected monthly. Also, several additional samples were collected in the spring period. Samples were collected approximately 25 times during sample period.

b. Spring (March 21 - June 21)
Summer (June 22 - September 22)
Fall (September 23 - December 21)
Winter (December 22 - March 20)

c. Samples for these parameters were only taken 4-6 times during the period December 6, 1973 to June 6, 1975.

TABLE 4.3-9

WATER CHEMISTRY IN SUPERIOR BAY (12)[a]

Parameter (mg/ℓ unless otherwise noted)	May 14, 1975 Mean(Range)	Sept. 25, 1974 Mean(Range)	October 25, 1974 Mean(Range)
Total Phosphorus	0.06 (0.05-0.07)	0.095 (0.07-0.12)	0.09 (0.05-0.15)
Ammonia (as N)	0.19 (0.13-0.23)	0.2 (0.08-0.32)	0.14 (<0.05-0.4)
Organic Nitrogen	0.88 (0.85-1,0)	0.66 (0.61-0.8)	0.24 (0.09-0.4)
Nitrite (as N)	0.075 (0.06-0.08)	0.08 (0.02-0.16)	0.03 (0.02-0.03)
Nitrate (as N)	0.07 (<0.1-1.1)	0.24 (0.11-0.40)	0.38 (0.29-0.42)
Total Nitrogen	1.2 (1.1-1.4)	1.2 (1.04-1.32)	0.79 (0.68-1.12)
Sodium	3.4 (3.1-3.7)	4.3 (3.3-5.7)	7 (4.7-11)
Chloride	8.1 (6.8-9.2)	8.7 (7.2-10)	16.2 (9.4-22)
Potassium	1.1 (1.0-1.1)	<1.0	2 (1.3-4.9)
Calcium	30	40	56 (50-65)
Arsenic (µg/ℓ)	<1 (<1-13)	<1 (<1-1.5)	<1 (<1-2)
Silicate (as SiO_2)	4.3 (4.1-4.6)	3.7 (3.2-5.0)	3.8 (3.2-4.4)
Selenium (µg/ℓ)	<2	<1 (<1-2.1)	<1
Sulfate (as SO_4)	15 (12-17)	12.2 (11-14)	15 (9.8-20)
Copper (µg/ℓ)	2.1	4.3 (2.9-4.9)	2.6 (2.3-2.9)
Cadmium (µg/ℓ)	<0.01 (<0.01-0.02)	0.1 (0.03-0.31)	0.02 (<0.01-0.05)
Manganese (µg/ℓ)	54 (48-59)	37 (30-50)	50 (38-65)
Zinc (µg/ℓ)	4.6 (4.1-4.8)	26 (9.2-34)	17 (11-25)
Nickel (µg/ℓ)	1.1 (<1-2.0)	1.8 (<1-4)	5.0 (3-6)
Iron (µg/ℓ)	660 (620-720)	520 (460-640)	480 (370-600)
Mercury (µg/ℓ)	<0.1	<0.1	<0.1 (<0.1-0.12)
Lead (µg/ℓ)	0.6 (0.5-0.6)	1.5 (1.2-1.7)	0.8 (0.7-0.9)
Total Chromium (µg/ℓ)	0.65 (0.6-0.7)	2.3 (1.1-6.5)	1.9 (<0.5-6.1)
Phenolic Compounds	0.003 (0.002-0.004)	0.005 (<0.002-0.019)	0.004 (<0.002-0.01)

a. Once each sampling day samples were collected at four locations. One location was near each entry to the lake and the other two locations were spaced between the entries.

The study by the U.S. Environmental Protection Agency (EPA) on St. Louis Bay found that the control yield of the assay alga, *Selenastrum capricornutum*, indicated that the potential primary productivity was high at the time the sample was collected. The lack of increase in yield when reactive phosphate was added and the significant increase in yield when only nitrogen was added indicated nitrogen limitation (4).

Chlorophyll α levels were only moderately high. Means for chlorophyll α were 9.8 μg/ℓ (St. Louis Bay) and 15.9 μg/ℓ (Superior Bay) in July (3, 4), 4.1 μg/ℓ in October for Superior Bay (12), and 0.02 μg/ℓ in December for Superior Bay (8). The moderate algal and chlorophyll α levels may be due to the generally high turbidity which restricts the amount of light for algal growth.

Among the heavy metals, copper has been found to be as high as 0.075 mg/ℓ at the I-535 bridge (11), and exceeded the Minnesota standard for protection of fish and aquatic life of 0.01 mg/ℓ about 40% of the time. The copper levels are largely the result of natural runoff in the St. Louis River watershed. Phenolic compounds also have been found to occasionally exceed the Minnesota standard of 0.01 mg/ℓ in Superior Bay (12) and at the I-535 bridge (11). The phenol levels are partially the result of discharges from Conwed Corporation, U.S. Steel, and Potlatch Corporation. Resuspension of decomposing river sludge deposits downstream from these discharges may also be contributing to the problem.

Total phosphorus and ammonia concentrations are higher in St. Louis Bay than Superior Bay. There is a decrease in total phosphorus, ammonia, and heavy metals concentrations from the I-535 bridge (11) to the sampling points distributed along Superior Bay (12). Much of this improvement has to be attributed to the "seiche effect" in Superior Bay.

The effects of the harbour on Lake Superior are discussed in Chapters 4.1 and 6.1.

SEDIMENT CHEMISTRY

Table 4.3-10 compares the EPA guidelines for polluted sediments with the results obtained in two studies of the bottom sediments. Sediments exceeding the guideline in a combination of some of the parameters listed are considered unsuitable for open lake disposal. Of the samples taken (14) near the Duluth and the Superior Entries, 36% were considered suitable for open lake disposal, 28% suitable for restricted open lake dumping, and 36% were considered unsuitable for open lake dumping. Mid-channel sediments appeared to be less polluted than those near the sides of the channels.

Mercury levels in the sediments appear to be on the decline (Table 4.3-11). In 1970, the bottom samples averaged above the EPA guideline of 1 mg/kg (1), but subsequent analysis has shown lower values (1, 14).

TABLE 4.3-10

COMPARISON OF EPA DREDGING GUIDELINES FOR SEDIMENTS WITH SAMPLES OBTAINED IN ST. LOUIS BAY AND SUPERIOR BAY IN 1970 AND 1975[a]

PARAMETER	EPA GUIDELINE FOR HEAVILY POLLUTED SEDIMENT	1970 (1)		1975 (14)	
		MEAN(RANGE)	% SAMPLES OVER GUIDELINE	MEAN(RANGE)	% SAMPLES OVER GUIDELINE
Volatile Solids (mg/kg)	60,000	54,000 (14,000-122,000)	30	51,000 (5,000-123,000)	18
Chemical Oxygen Demand (mg/kg)	50,000	66,700 (9,200-152,000)	38	68,000 (< 840-240,000)	33
Total Kjeldahl Nitrogen (mg/kg)	1,000	1,300 (125-2,500)	31	1,400 (120-4,700)	30
Total Mercury (mg/kg)	1.0	1.3 (0.1-3.5)	62	0.1 (<0.1-0.2)	0
Lead (mg/kg)	50	35 (10-72)	15	25 (<5-80)	7
Zinc (mg/kg)	50	74 (30-203)	8	110 (9-275)	12

a. Samples taken at different locations, and different sediment types may have been involved.

TABLE 4.3-11

MERCURY LEVELS IN THE SEDIMENTS IN THE THREE HARBOUR ZONES OF SUPERIOR BAY STUDIED IN 1970, 1973, AND 1975[a]

LOCATION	Hg mg/kg 1970 (1) MEAN (RANGE)	Hg mg/kg 1973 (1) MEAN (RANGE)	Hg mg/kg 1975 (14) MEAN (RANGE)
Near Duluth Entry	2.3 (1.6-3.0)	0.5 (0.3-0.7)	<0.1 (<0.1-0.2)
Duluth Turning Basin, Southwest of Duluth Entry	1.5 (0.6-2.3)	0.3 (0.1-0.8)	<0.1 (<0.1-0.1)
Superior Turning Basin, near Superior Entry	1.0 (0.1-1.9)	1.7 (0.3-5.4)	<0.1 (<0.1-0.2)

a. Samples taken at different locations and different sediment types may have been involved.

AQUATIC BIOLOGY

MICROBIOLOGY

Total coliforms have been found to range from <20 MPN/100 mℓ near the Highway I-535 bridge in September, 1974 (14) to 8,900 MPN/100 mℓ in Superior Bay between the two entries in August, 1973 (1). The relatively high counts of coliforms in August is believed to be the result of storm sewer discharge (1).

Fecal coliforms have been found to have geometric means ranging from <20 MPN/100 mℓ near the I-535 bridge in September, 1974 to 440 MPN/100 mℓ in May, 1974 (11). The Minnesota water quality standard for fecal coliforms is 200 MPN/100 mℓ. The high value was found during a high flow period and may have been due to non-point source urban runoff. Samples taken near the Duluth and Superior waste treatment plants in June and July, 1973 (1) did not exceed Minnesota water quality standards for fecal coliforms.

PHYTOPLANKTON

In September, 1974 (12) blue-green algae (Cyanophyceae) comprised 87% of the algal cells. The dominant blue-green species were *Spirulina okensis* and *Aphanizomenon flos-aquae*. The mean number was 11 x 10^6 cells/ℓ. In late October, the diatoms (Bacillariophyceae) became the dominant class. The mean number was ∿ 1.8 x 10^6 cells/ℓ for all algae. In general, high quantities of *Aphanizomenon flos-aquae*, euglenoids, and some species of cryptomonads are indicative of a high level of organic as well as inorganic nutrients (15).

ZOOPLANKTON

The mean number of crustacean and rotiferan zooplankton found in Superior Bay in October, 1974 was 13,100/m^3. The most abundant planktonic species were the rotifer *Keratella cochlearis* and the cladoceran *Bosmina longirostris* (12).

There was a low abundance of calanoid copepods (6%) compared to other crustacean and rotiferan zooplankton (12). Gannon (16) has concluded that the ratio of calanoid copopods to cladocerans and rotifers is a useful index to trophic change. This value was 0.08 in Duluth-Superior Harbor in October. This compares with the value of 0.17 found in eutrophic Lake Erie (17) and contrasts with oligotrophic Lake Superior which has a value of about 14.5.

BENTHOS

The mean of benthic macroinvertebrates in Superior Bay was found to be 6700/m^2 on silty substrates in the fall (12), and 3600/m^2 for a combination of substrate types in the spring (14). Oligochaetes comprise at least 90% of the benthic macroinvertebrates in most areas of the bay (9,12,14). The dominant oligochaete appears to be *Limnodrilus hoffmeisteri* (12). The chironomids are the second most abundant group (∿ 7% of the macroinvertebrates) and were dominated by a species of *Chironomus plumosus* type in the fall (12) and by *Cryptochironomus* sp. in the spring (14). In general, the benthic fauna is indicative of highly eutrophic conditions; however, significant numbers of pollution-intolerant macroinvertebrates, such as mayflies (*Hexagenia* sp.) and caddisflies (*Phylocentropus* sp.), have been found in the east end of Superior Bay near Allouez Bay (9) indicating that this portion of the harbour is relatively clean.

SUMMARY OF EXISTING AND DEVELOPING PROBLEMS

Based upon current nutrient loadings and biological indicators, the Duluth-Superior Harbor is in an eutrophic condition. Nutrient and BOD loadings contribute to low dissolved oxygen values in the harbour. Values of fecal coliform, turbidity, phenols, and copper are encountered in the harbour which violate Minnesota water quality standards. Contaminated sediments also are encountered which restrict dredging disposal methods.

REMEDIAL MEASURES

All dischargers in Minnesota shown in Figure 4.3-1 except for U.S. Steel are scheduled to be incorporated into the Western Lake Superior Sanitary District's new waste treatment plant to be located on St. Louis Bay. This new plant is scheduled to be completed in 1978 and will have effluent limitations of 25 mg/ℓ (4,170 kg/d) BOD_5, 30 mg/ℓ (5,000 kg/d) total suspended solids, and 1 mg/ℓ (166 kg/d) total phosphorus. This will result in a 93% reduction of BOD_5, 86% reduction of total suspended solids, and 64% reduction of phosphorus from existing discharges. A fecal coliform effluent standard of 200 MPN/100 mℓ and turbidity effluent standard of 25 JTU will also be required. However, at summer low-flow conditions the current Minnesota water quality standard for dissolved oxygen (5 mg/ℓ) in the St. Louis River will be violated for many years, even if there were no discharge to the river, as a result of benthic sludges accumulated over many years. The dissolved oxygen will have recovered in St. Louis Bay and Superior Bay to satisfactory levels (8).

In addition, a rehabilitation program was initiated during the summer of 1976 to patch broken sanitary sewer lines in Duluth and to stop sanitary sewer bypasses. Also, flow monitoring is being conducted to further evaluate the amount of infiltration of the sanitary sewers.

The Minnesota Pollution Control Agency has initiated a law suit against U.S. Steel for violation of Minnesota standards. A National Pollutant Discharge Elimination System (NPDES) permit has not been issued to them and issuance is dependent on a public hearing. NPDES permits have been issued to Minnesota Power and Light Company and Superior Water, Light and Power Company for thermal discharges; the companies are in compliance with these permits.

The two Wisconsin dischargers to Superior Bay also are required to upgrade their effluents. Superior Fiber must achieve 340 kg/d total suspended solids and 634 kg/d BOD_5. The Superior wastewater treatment plant must achieve 570 kg/d total suspended solids, 570 kg/d BOD$_5$, and 19 kg/d phosphorus (7).

Both Minnesota and Wisconsin have petitioned EPA for the establishment of a no-discharge zone for watercraft in the vicinity of Duluth-Superior Harbor. A decision on the application is pending.

A declaratory judgement action was brought against federal officials by Minnesota on the issue of whether or not the U.S. Army Corps of Engineers must comply with Minnesota laws and regulations governing pollution abatement in its dredging operation. The court declared in October 9, 1975 that Minnesota has the authority to require defendants to comply with state pollution abatement requirements including obtaining a state discharge permit. However, this was subsequently overturned by the U.S. Court of Appeals and has been further appealed to the U.S. Supreme Court. Sampling programs are being accomplished to determine pollution potential of dredged material.

4.4 SILVER BAY

DESCRIPTION OF THE STUDY AREA

GEOLOGY AND TOPOGRAPHY

Silver Bay Harbor is located on the north shore of Lake Superior approximately 90 km northeast of Duluth, Minnesota. The harbour was developed by the Reserve Mining Company which has operated a taconite ore beneficiation plant at this site for approximately the last twenty years (see Figure 4.4-1).

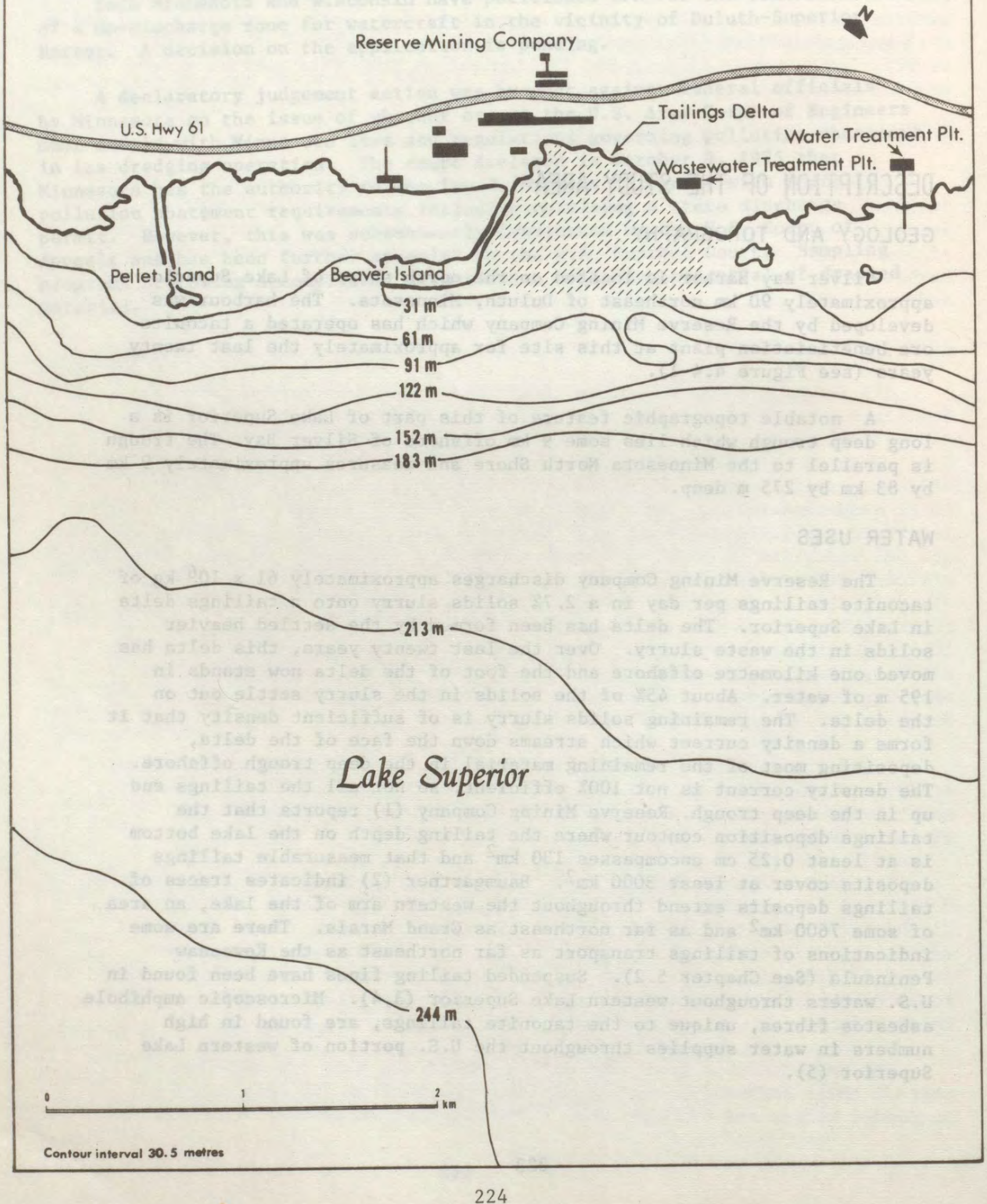
A notable topographic feature of this part of Lake Superior is a long deep trough which lies some 9 km offshore of Silver Bay. The trough is parallel to the Minnesota North Shore and measures approximately 9 km by 83 km by 275 m deep.

WATER USES

The Reserve Mining Company discharges approximately 61 x 10^6 kg of taconite tailings per day in a 2.7% solids slurry onto a tailings delta in Lake Superior. The delta has been formed by the settled heavier solids in the waste slurry. Over the last twenty years, this delta has moved one kilometre offshore and the foot of the delta now stands in 195 m of water. About 45% of the solids in the slurry settle out on the delta. The remaining solids slurry is of sufficient density that it forms a density current which streams down the face of the delta, depositing most of the remaining material in the deep trough offshore. The density current is not 100% efficient, so not all the tailings end up in the deep trough. Reserve Mining Company (1) reports that the tailings deposition contour where the tailing depth on the lake bottom is at least 0.25 cm encompasses 130 km^2 and that measurable tailings deposits cover at least 3000 km^2. Baumgartner (2) indicates traces of tailings deposits extend throughout the western arm of the lake, an area of some 7600 km^2 and as far northeast as Grand Marais. There are some indications of tailings transport as far northeast as the Keweenaw Peninsula (See Chapter 5.2). Suspended tailing fines have been found in U.S. waters throughout western Lake Superior (3,4). Microscopic amphibole asbestos fibres, unique to the taconite tailings, are found in high numbers in water supplies throughout the U.S. portion of western Lake Superior (5).

Figure 4.4-1

MAP OF LAKE SUPERIOR IN THE VICINITY OF SILVER BAY, MINNESOTA



The Silver Bay municipal secondary sewage treatment plant discharges to Lake Superior. This discharge has an insignificant impact on the lake and has effluent limitations of 78.6 kg/d of BOD_5, 94.3 kg/d of suspended solids, and 3.1 kg/d of total phosphorus.

In addition to utilizing Lake Superior as the source of process water for use in the taconite beneficiation process, Reserve Mining Company also utilizes Lake Superior water for condenser cooling in their steam generating plant. The City of Silver Bay withdraws its municipal water supply from Lake Superior; the intake is located approximately 1.6 km northeast of Reserve Mining's discharge area (Figure 4.4-1). (See Table 4.4-1 for the water volumes used.)

Other water uses in the Silver Bay area include commercial navigation for the transport of processed taconite via ore carriers, and recreational uses, primarily boating.

LIMNOLOGY

PHYSICAL

THERMAL STRUCTURE

Lake Superior is stratified from July until October. The lake is isothermal from early November until late December. Winter stratification occurs from late December until mid-April. The lake is isothermal again from mid-April until July. The highest surface water temperature of 12 - 14°C occurs in September (6).

TURBIDITY

The discharge from Reserve has increased the turbidity in Lake Superior, particularly in the area southwest of the plant and, to a lesser extent, in other nearby areas (7). Figure 4.4-2 shows that tailings reduce bottom water clarity 25% or more over an area of at least 1,500 km^2 (2,8). Glass (9) found a statistically significant increase in bottom water turbidity southwest of the plant (Table 4.4-2).

SUSPENDED SOLIDS

Baumgartner (2) measured the inorganic suspended solids in bottom water to determine the transport of tailings at a time when natural stream input was at a low level. The contours in Figure 4.4-3 show a counterclockwise circulation of material from Silver Bay, across the lake where it meets the northeast currents that flow along the Wisconsin south shore. A portion of this material may also be deflected by the steep side wall of the trench, and flow in both directions along the trench axis. It appears, however, that the general counterclockwise circulation that exists in western Lake Superior does eventually dominate the flow with material flowing across the Wisconsin state boundary some 40 to 50 km downstream of the discharge.

TABLE 4.4-1

WATER USES BY VOLUME (m^3/s)

Water Withdrawals	
Silver Bay Public Water Intake	0.031
Reserve Mining Company	26.181
Total	26.212
Water Discharges	
Silver Bay Sewage Treatment Plant	0.036
Reserve Mining Company	26.141
Total	26.177
Net withdrawal:	0.035

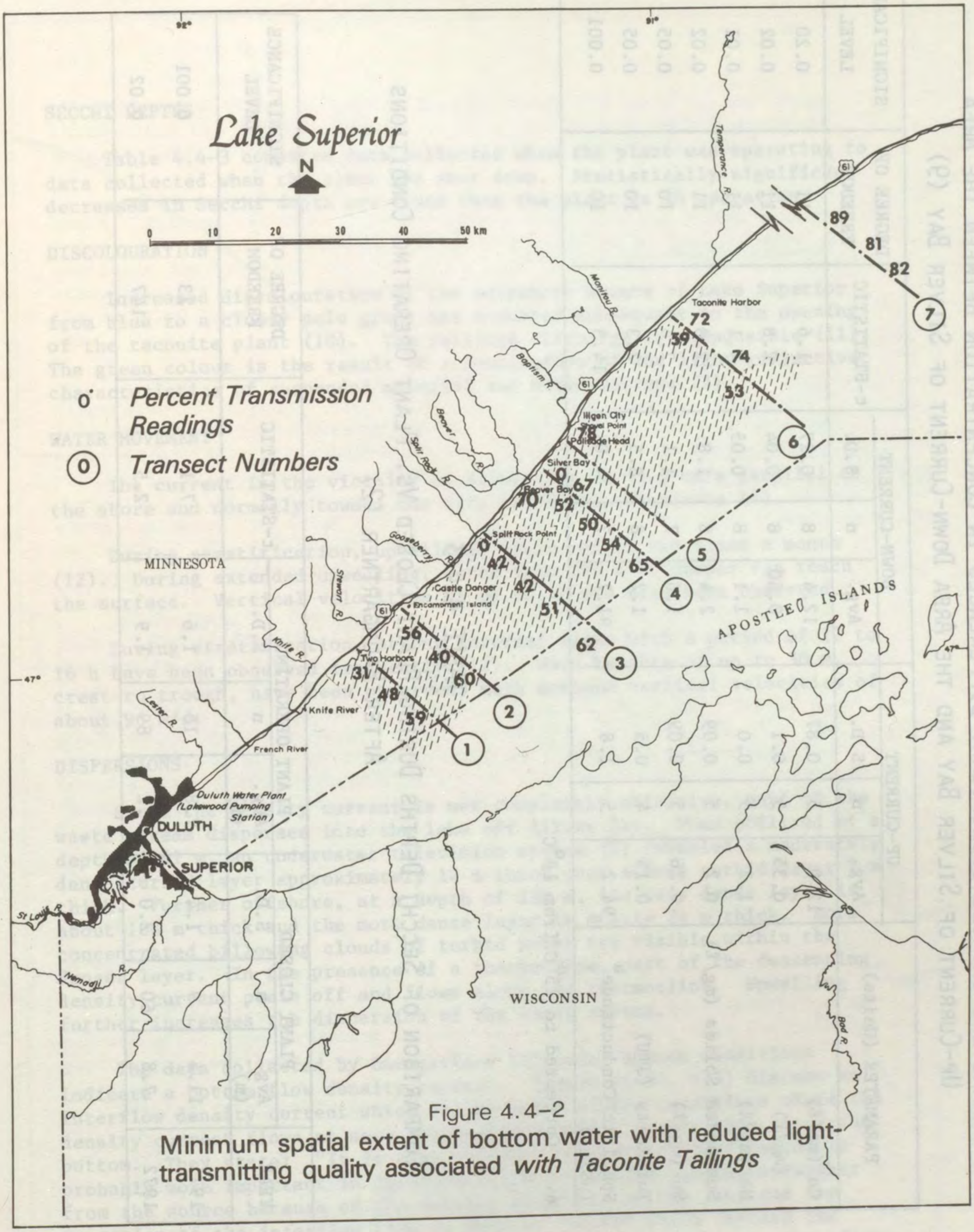


Figure 4.4-2

Minimum spatial extent of bottom water with reduced light-transmitting quality associated *with Taconite Tailings*

TABLE 4.4-2

PARAMETERS SHOWING SIGNIFICANT DIFFERENCES IN CONCENTRATION BETWEEN THE AREA UP-CURRENT OF SILVER BAY AND THE AREA DOWN-CURRENT OF SILVER BAY (9)

PARAMETER (Units)	UP-CURRENT			DOWN-CURRENT			t-STATISTIC	DEGREE OF FREEDOM	SIGNIFICANCE LEVEL
	Avg.	n	S.D.	Avg.	n	S.D.			
Ca (mg/ℓ)	12.9	5	0.87	12.4	8	0.27	1.6	11	0.20
K (mg/ℓ)	0.35	5	0.1	0.40	8	0.04	2.8	11	0.02
Na (mg/ℓ)	1.2	5	0.0	1.1	8	0.05	4.1	11	0.01
Suspended Solids (mg/ℓ)	0.2	5	0.09	2.4	8	1.8	2.8	11	0.02
Mn (mg/ℓ)	0.26	5	0.09	1.6	7	1.1	2.6	10	0.05
Turbidity (JTU)	0.15	4	0.5	1.2	8	8.5	2.3	10	0.05
Specific Conductance[a] (μS/cm)	94.2	5	1.8	91.7	7	4.0	14.3	10	0.001

a. Corrected to 25°C from 18°C

TABLE 4.4-3

COMPARISON OF SECCHI DEPTHS DURING PLANT CLOSED VS. PLANT OPERATING CONDITIONS AFTER BAUMGARTNER (2)

YEAR	PLANT CLOSED			PLANT OPERATING			t-STATISTIC	DEGREE OF FREEDOM	SIGNIFICANCE LEVEL
	Avg. (m)	n	S.D.	Avg. (m)	n	S.D.			
1971	11.4	9	1.4	7.8	16	1.6	7.1	23	0.001
1972	7.8	60	2.0	7.2	89	1.9	2.5	147	0.02

SECCHI DEPTHS

Table 4.4-3 compares data collected when the plant was operating to data collected when the plant was shut down. Statistically significant decreases in Secchi depth are found when the plant is in operation.

DISCOLOURATION

Increased discolouration of the nearshore waters of Lake Superior from blue to a cloudy pale green has occurred subsequent to the opening of the taconite plant (10). The tailings discharge is responsible (11). The green colour is the result of a combination of the light reflective characteristics of suspended material and other factors (2).

WATER MOVEMENT

The current in the vicinity of Silver Bay is ∿3.5 cm/s parallel to the shore and normally toward the city of Duluth, Minnesota (4).

During stratification, upwellings occur one or two times a month (12). During extended upwelling, water from 190 m or deeper can reach the surface. Vertical velocities of up to 30 m/d have been observed.

During stratification, strong internal waves with a period of 12 to 16 h have been observed frequently (12). Wave heights of up to 30 m, crest to trough, have been observed, with maximum vertical velocities of about 96 m/d.

DISPERSIONS

Since the density current is not completely effective, part of the waste stream disperses into the lake off Silver Bay. When utilized at a depth of 61 m, an underwater television system (2) revealed a moderately dense turbid layer approximately 12 m thick over a more turbid layer 2 m thick. Further offshore, at a depth of 230 m, the less dense layer is about 108 m thick and the more dense layer is nearly 24 m thick. More concentrated billowing clouds of turbid water are visible within the denser layer. In the presence of a thermocline, part of the descending density current peels off and flows along the thermocline. Upwelling further increases the dispersion of the waste stream.

The data collected by Baumgartner (2) under summer conditions indicate a bottom flow density current. Gerard *et al.* (13) discuss an interflow density current which occurs under winter conditions where the density current flows at some intermediate depth, rather than along the bottom. They state: "It is also apparent that winter circulation is probably more important in distributing the taconite sediments further from the source because of the density structure of the lake and the operation of the interflow type of density current which carries the suspended material." Baumgartner (2) concludes: "The density interflow that occurs during winter conditions distributes the bulk of the tailings

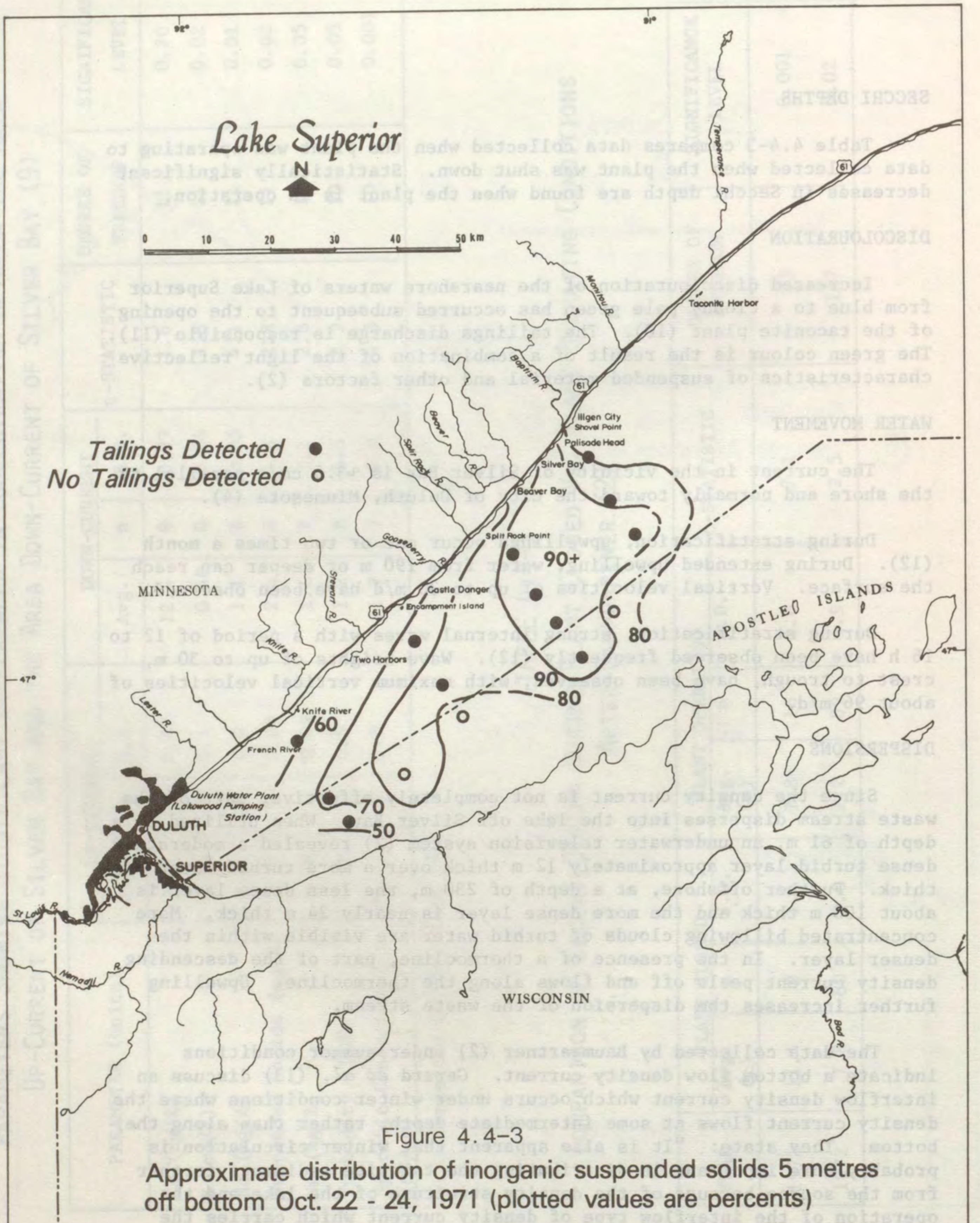


Figure 4.4–3

Approximate distribution of inorganic suspended solids 5 metres off bottom Oct. 22 - 24, 1971 (plotted values are percents) throughout the water column immediately below the level of the winter thermocline and when no distinct thermocline exists, this suspended material could be mixed in the surface waters."

Internal waves result in no net vertical motion except when they break. When an internal wave encounters the upsloping bottom near a coast, it can become unstable and break. Although no measurements are available for breaking internal waves near Silver Bay, because of the steep lake bottom in the vicinity of Silver Bay and the large size of the internal waves observed, this dispersal mechanism cannot be ruled out.

In summary, the waters offshore of Silver Bay constitute a highly dispersive environment. Vertical mixing due to upwelling has been documented. Internal breaking waves can well be expected to enhance vertical mixing. The rapid deepening of the lake offshore of Silver Bay results in a large volume of water very close to the shore. Alongshore currents persist throughout the year to transport material down current along the shore. No real bay exists in the area to restrict circulation and mixing. The net effect is a very effective mixing, dilution, and dispersion of material discharged to the waters off Silver Bay.

An estimate of the degree of dilution can be obtained using the depth contours given in Figure 4.4-1, and assuming a mean alongshore current velocity of 3.5 cm/s. Based upon this calculation, the calculated loading needed to effect an increase of 0.1 mg/ℓ in a chemical constituent in the waters within 4 km of the shore and down current of Silver Bay would be on the order of 10^5 kg/d. As will be shown later, only the estimated loadings of suspended solids and dissolved solids from the Reserve Mining Company discharge are of this order. Therefore, even though a wealth of data has been collected in connection with the protracted Reserve Mining Company trial, only a very small part of that data has shown a statistically significant increase in chemical constituents in the lake due to the tailings discharge.

CHEMISTRY

WATER CHEMISTRY

Water quality in the vicinity of Silver Bay has been studied before and after the Reserve Mining Company commenced operations. Recent water quality data are summarized in Table 4.4-4.

Samples taken on transects northeast and southwest of Silver Bay (9) show statistically significant increases in suspended solids, turbidity, potassium, and manganese southwest (down current) of Silver Bay (Table 4.4-2).

SEDIMENT CHEMISTRY

Taconite tailings comprise the topmost layer of sediment in the Silver Bay area. The chemical characteristics of taconite tailings are

TABLE 4.4-4

SUMMARY OF 1969 WATER QUALITY DATA FROM AREA ADJACENT TO THE TAILINGS DELTA OF THE RESERVE MINING COMPANY(14)

PARAMETER	NUMBER OF SAMPLES	CONCENTRATION RANGE[a]	CONCENTRATION MEAN[a]
Turbidity (JTU)	21	0.2 - 1.2	0.4
Total Solids	20	58 - 70	61
Total Volatile Solids	20	19 - 29	24
Suspended Solids	21	1 - 4	2.4
Suspended Volatile Solids	21	1 - 4	2.1
pH (unitless)	21	7.5 - 8.0	7.6
Colour (colour units)	21	<1	
Dissolved Oxygen	20	12.3 - 12.4	12.3
Specific Conductivity (μS/cm)	21	82 - 160	101
Copper	21	<0.01	
Cadmium	21	<0.01	
Zinc	21	<0.01 - 0.02	<0.01[b]
Nickel	21	<0.01	
Iron	21	<0.02 - 0.02	<0.02[b]
Manganese	21	<0.02 - 0.02	<0.02[b]
Lead	21	<0.01	
Reactive Silicate, as SiO_2	21	2.0 - 2.5	2.3
5-day BOD	9	1.3 - 1.9	1.5
Total Phosphorus	18	<0.01 - 0.03	0.01[b]
Ammonia, as N	8	<0.05 - 0.09	0.05[b]
Organic Nitrogen	8	0.07 - 0.26	0.13
Nitrate, as N	8	0.18 - 0.28	0.24
Nitrite, as N	8	<0.02	

a. In milligrams per litre unless indicated otherwise.
b. Median value

complex and variable. Analyses have shown that taconite tailings contain a large number of elements. The primary components are iron, silicon, magnesium, calcium, manganese, potassium, aluminum, phosphorus, sulphur, sodium, barium, titanium, and zinc. Traces of zirconium, cesium, cobalt, copper, lead, arsenic, and others are also found (9). (See also Chapter 5.2.)

The tailings sediments dissolve at a measurable rate and contribute significant loadings of some chemicals and elements to the lake (9, 15-17). Kizlauskas (18) conservatively estimated the long term dissolution of taconite tailings. The estimates in Table 4.4-5 thus represent a lower limit on the dissolved loading from the deposited tailings. For example, the data presented in Table 4.4-2, when coupled with typical flows, produce dissolved loading estimates a factor of ten greater for potassium and manganese than those in Table 4.4-5. The tailings discharge contributes some 33.5 x 10^6 kg/d of suspended solids to the lake (19).

ASBESTOS

Chrysotile asbestos, which accounts for 95% of the world's asbestos consumption (20), is found in the waters of all the Great Lakes (21, 22). Chrysotile probably enters the surface waters by a combination of leaching from natural mineral deposits and contamination from its many (estimated at 3000) commercial uses. Chrysotile is the predominant form of asbestos in Lake Superior except in the western arm where amphibole asbestos, discharged in high concentrations in the taconite tailings, predominates (23). Based upon geological and limnological data from 1939 to the present, the discharge of taconite tailings to the lake is the only source of the amphibole in the western arm of the lake (3).

An estimated 10^{21} amphibole asbestos fibres per day are discharged to the lake in the tailings waste stream from the Reserve Mining Company (24, 25).

In 1973, study of the morphology of amphibole particles in taconite tailings first revealed the asbestiform nature of the particles. Prior studies of the Duluth, Minnesota drinking water supply had already detected the presence of taconite tailings. Transmission electron microscope analysis of Duluth water samples confirmed the presence of many amphibole fibres (5).

The data in Figure 4.4-4 give a clear indication of the source and geographical distribution of amphibole asbestos in the western end of Lake Superior (26). The data indicate that the Reserve Mining Company is the source of the amphibole. The decrease in fibre counts in the counterclockwise direction is consistent with the observed counterclockwise circulation in this part of the lake (See Chapters 5.1 and 4.1) and is consistent with the observed transport of tailings indicated in Figure 4.4-3.

The presence of amphibole asbestos in the Thunder Bay water intake could be accounted for by the circulation patterns, but the high fibre

TABLE 4.4-5

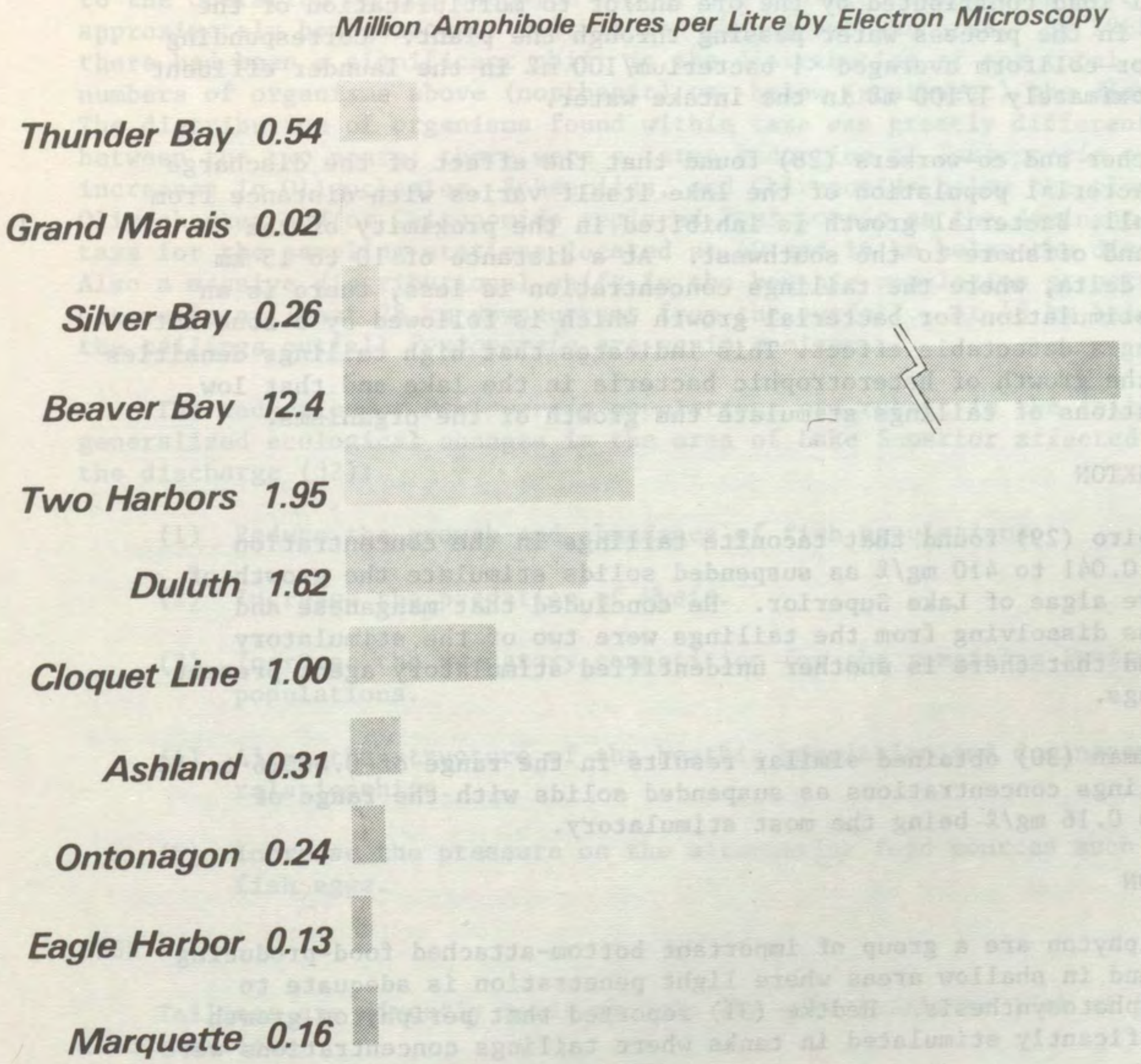
ESTIMATE OF DISSOLVED LOADING TO LAKE SUPERIOR FROM THE RESERVE MINING COMPANY (18)

PARAMETER	LOADINGS, kg/d
Calcium	20,000
Magnesium	8,300
Sodium	2,800
Potassium	5,500
Alkalinity	30,000
Sulfate, as SO_4	1,700
Chloride	3,400
Reactive Silicate, as SiO_2	24,000
Manganese	150
Phosphorus	Negligible
Iron	Negligible
Copper	Negligible
Zinc	Negligible
Nickel	Negligible
Cadmium	Negligible
Lead	Negligible
Ammonia, as N	Negligible
Nitrite, as N	Negligible
Nitrate, as N	90
Dissolved Solids	83,000

Figure 4.4-4

WESTERN LAKE SUPERIOR AVERAGE CONCENTRATIONS OF AMPHIBOLE ASBESTOS FIBRES IN POTABLE WATER INTAKES

Information from Reference (26)



counts and the large fibres found indicate that a local source is responsible. Thunder Bay is surrounded by the Gunflint iron formation, where pockets of amphibole have been found (27). (See Chapter 4.2.)

AQUATIC BIOLOGY

MICROBIOLOGY

The total heterotrophic bacterial densities in the launder effluent exceed that observed in the intake water. Fischer and co-workers (28) reported an average heterotrophic bacterial density in the untreated launder effluent of 6,200 bacteria/mℓ compared to a value of 2,000/mℓ in the intake water. This increase is attributable to the heterotrophic bacterial load contributed by the ore and/or to multiplication of the bacteria in the process water passing through the plant. Corresponding levels for coliform averaged <1 bacterium/100 mℓ in the launder effluent and approximately 1/100 mℓ in the intake water.

Fischer and co-workers (28) found that the effect of the discharge on the bacterial population of the lake itself varies with distance from the outfall. Bacterial growth is inhibited in the proximity of the outfall and offshore to the southwest. At a distance of 10 to 15 km from the delta, where the tailings concentration is less, there is an area of stimulation for bacterial growth which is followed by a zone not exhibiting a detectable effect. This indicates that high tailings densities inhibit the growth of heterotrophic bacteria in the lake and that low concentrations of tailings stimulate the growth of the organisms.

PHYTOPLANKTON

Shapiro (29) found that taconite tailings in the concentration range of 0.041 to 410 mg/ℓ as suspended solids stimulate the growth of the native algae of Lake Superior. He concluded that manganese and phosphorus dissolving from the tailings were two of the stimulatory agents and that there is another unidentified stimulatory agent present in tailings.

Goldman (30) obtained similar results in the range of 0.00016 to 16 mg/ℓ tailings concentrations as suspended solids with the range of 0.0016 to 0.16 mg/ℓ being the most stimulatory.

PERIPHYTON

Periphyton are a group of important bottom-attached food-producing algae found in shallow areas where light penetration is adequate to maintain photosynthesis. Hedtke (31) reported that periphyton growth was significantly stimulated in tanks where tailings concentrations were $\geq$ 5 mg/ℓ.

BENTHOS

The enormous tonnage of tailings discharged each day causes reductions of benthic organisms immediately below the Reserve outfall launders. How much reduction occurs, the size of the area affected, and how the change will affect other components of the ecosystem are important questions.

The small freshwater shrimp of the genus *Pontoporeia* is recognized as a dominant form of Lake Superior bottom fauna which serves as a primary food for lake trout and other species of fish. Henson (32) and his co-workers concluded that significant changes in the number of organisms and their community structure have occurred. In 1949, prior to the operation of the taconite plant, the benthic communities were approximately homogeneously distributed throughout the area. By 1968 there had been a significant shift in the distribution of the total numbers of organisms above (northeast) *vs.* below (southwest) the discharge. The distribution of organisms found within taxa was greatly different between the two years; there were a large reduction of *Pontoporeia* and increases in Oligochaetes, Sphaeriids, and Chironomids below the plant. Oligochaetes and/or Chironomids replaced *Pontoporeia* as the dominant taxa for the sampling stations located at 40 and 16 km below the discharge. Also a massive distributional shift in the benthic population structure occurs to at least 28 km downcurrent from the outfall. At 48 km below the tailings outfall *Pontoporeia* are again dominant.

The reduction of *Pontoporeia* populations can result in the following generalized ecological changes in the area of Lake Superior affected by the discharge (32):

(1) Reduce the growth and abundance of fish populations.

(2) Increase the predation of *Mysis*.

(3) Increase the predatory competition for the remaining *Pontoporeia* populations.

(4) Alter the structure of the benthic population and dominance relationships.

(5) Increase the pressure on the alternative food sources such as fish eggs.

FISH

Tailings are directly toxic to only the more sensitive fish at high concentrations.

A number of elements in tailings are biologically available (33). The liver and/or kidney of rainbow trout accumulated sodium, potassium, bromine, iron, cesium, cobalt, and rubidium. Not all the elements that may be taken up by the test fish were measured.

Fish are known to avoid the tailings-discoloured water (10).

SUMMARY OF EXISTING AND DEVELOPING PROBLEMS

The amphibole asbestos particles discharged at Silver Bay have been detected in high numbers in the water supplies of Silver Bay, Beaver Bay, Two Harbors, Duluth, and Cloquet, Minnesota (5). These asbestos particles pose a potential health hazard and their discharge has been ruled and sustained to be in violation of Minnesota water quality standards (34, 35). In addition, it has been ruled and sustained that the discharge constitutes pollution of waters endangering the health and welfare of persons within the terms of the Federal Water Pollution Control Act (34, 35).

The problems caused by the approximately twenty years of discharge will remain in Lake Superior for a long time. The presence of asbestiform fibres in the municipal drinking water of North Shore communitities will remain and will necessitate treatment for fibre removal.

The sediments will continue to contribute dissolved components to the interstitial and the overlying water of the lake. The sediments which are deposited in the shallower areas of the lake are subject to continued resuspension (3, 25, 36). Significant wind transport of tailings into the air and water from the dry tailings delta has been observed during one of the periods when the plant was shut down. "This mechanism of tailings input into the lake must be considered significant in terms of the particle sized involved (small), the point of entry (surface), and the tacit presumption that water quality might be improved during this abstinence from overt tailings discharged" (2). Slumping of the delta under wave action, precipitation run-off over the delta, and upwelling are mechanisms for maintaining the presence of suspended taconite particles and asbestos.

Based upon the current patterns, transboundary movement of amphibole could occur but would be at low levels, probably below the present detection limits. Therefore, the amphibole contamination is a problem local to the U.S. waters of western Lake Superior.

The latency period between initial exposure to asbestos and resultant diseases is generally from 20 to 40 years (21). Thus, any actual health effects from ingestion of asbestos in drinking water may not be evident for at least 20 years. City of Duluth samples indicate that elevated levels of amphibole asbestos fibres have been present in the water supply for at least the last 10 years (3). Further cause for alarm results from the finding that even short-term exposures to airborne asbestos can result in increased disease rates (11). The effects of ingested asbestos could follow a similar pattern.

The data presented in Table 4.4-2 indicate a violation in 1971 of the proposed Agreement objective for settleable and suspended solids and light transmission since that data indicate a decrease in Secchi disk depth of greater than 10%.

The discharge degrades the aesthetic enjoyment of the lake by increasing the green water phenomenon along the north shore of the lake.

The discharge violates the Minnesota effluent limitations for turbidity and suspended solids which are 25 JTU and 30 mg/ℓ, respectively.

The discharge has been shown to be harmful to benthic organisms, since it has decreased their numbers and caused a distributional shift in the community structure in the vicinity of Silver Bay.

The discharge degrades the water quality by reducing its clarity and results in significant dissolved loadings of some chemical parameters.

Studies cited above indicate that by being stimulatory to phytoplankton and heterotrophic bacteria growth the tailings may contribute to the enrichment of the waters of the lake.

ABATEMENT PROGRAMS

The outcome of the current litigation is expected to be that the tailings discharged to Lake Superior from the Reserve Mining Company will be eliminated and that the tailings will be diverted to an on-land disposal site. This expectation is clearly demonstrated in the U.S. Court of Appeals decision. The court concluded that "the pollution of Lake Superior must cease as quickly as feasible." The stay of the District Court's injunction forbidding the discharge was further conditioned by the requirement that Reserve Mining take prompt steps to abate its discharges, both to the air and the water (35).

Toward this end, public hearings held for consideration of the permit for a proposed on-land disposal site were concluded early in 1976. The primary question is the location of an acceptable site and when the current discharge to the lake will be terminated.

The technique of ordinary sand filtration removes about 90% of the asbestos fibres in the water supplies (21). A pilot plant research study conducted at Duluth, Minnesota in 1974 demonstrated that asbestiform fibre counts can be effectively removed by municipal filtration plants. Removal of asbestiform fibres to a level near or below the detectable limits of the analytical test was achieved with both granular filtration and pressure diatomaceous earth filtration (37). Using chemical coagulation with iron salts and polyelectrolytes followed by filtration, up to 99.8% fibre removal has been achieved (21). The city of Duluth has completed a water filtration plant to remove the asbestiform fibres. The cities of Two Harbors, Cloquet, Beaver Bay, Silver Bay, and Thunder Bay are taking action to construct water filtration plants to remove asbestiform fibres.

The data presented in Table 4.4-2 indicate a violation in 1971 of the proposed Agreement objective for settleable and suspended solids and light transmission since that data indicate a decrease in Secchi disk depth of greater than 10%.

The discharge degrades the aesthetic enjoyment of the lake by increasing the green water phenomenon along the north shore of the lake.

The discharge violates the Minnesota effluent limitations for turbidity and suspended solids which are 25 JTU and 30 mg/l, respectively.

The discharge has been shown to be harmful to benthic organisms, since it has decreased their numbers and caused a distributional shift in the community structure in the vicinity of Silver Bay.

The discharge degrades the water quality by reducing its clarity and results in significant dissolved loadings of some chemical parameters.

Studies cited above indicate that by being stimulatory to phytoplankton and heterotrophic bacteria growth the tailings may contribute to the enrichment of the waters of the lake.

ABATEMENT PROGRAMS

The outcome of the current litigation is expected to be that the tailings discharged to Lake Superior from the Reserve Mining Company will be eliminated and that the tailings will be diverted to an on-land disposal site. This expectation is clearly demonstrated in the U.S. Court of Appeals decision. The court concluded that "the pollution of Lake Superior must cease as quickly as feasible." The stay of the District Court's injunction forbidding the discharge was further conditioned by the requirement that Reserve Mining take prompt steps to abate its discharges, both to the air and the water (35).

Toward this end, public hearings held for consideration of the permit for a proposed on-land disposal site were continued early in 1976. The primary question is the location of an acceptable site and when the current discharge to the lake will be terminated.

The technique of ordinary sand filtration removes about 90% of the asbestos fibres in the water supplies (21). A pilot plant research study conducted at Duluth, Minnesota in 1974 demonstrated that asbestiform fibre counts can be effectively removed by municipal filtration plants. Removal of asbestiform fibres to a level near or below the detectable limits of the analytical test was achieved with both granular filtration and pressure diatomaceous earth filtration (37). Using chemical coagulation with iron salts and polyelectrolytes followed by filtration, up to 99.8% fibre removal has been achieved (21). The city of Duluth has completed a water filtration plant to remove the asbestiform fibres. The cities of Two Harbors, Cloquet, Beaver Bay, Silver Bay, and Thunder Bay are taking action to construct water filtration plants to remove asbestiform fibres.

4.5 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 (Chapter 4.2, Volume II) and also the Thunder Bay section of this volume (Chapter 4.2).

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.