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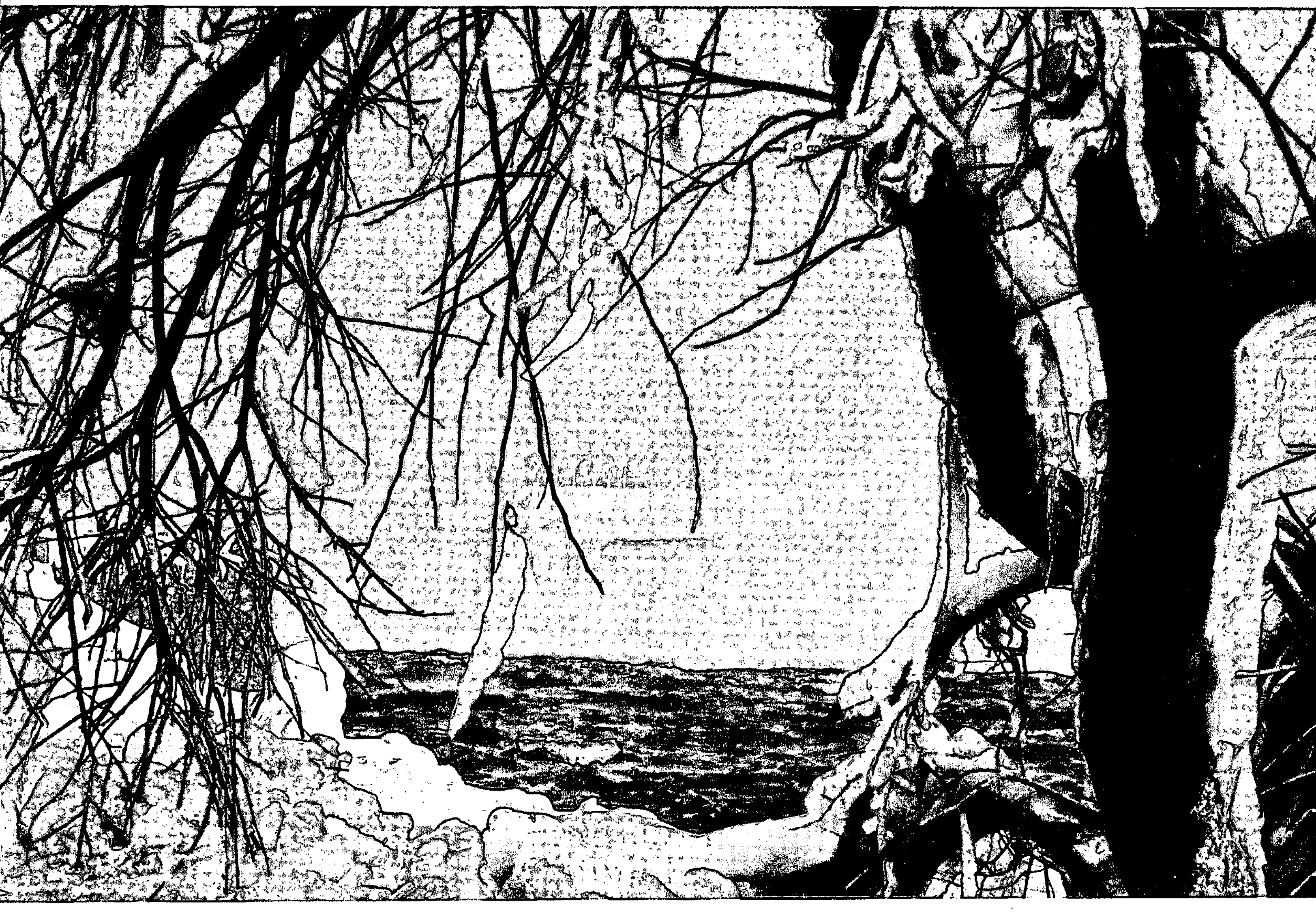

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WATER QUALITY BRANCH
BURLINGTON, ONTARIO, 1985

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Contents

Tables

Tables (Cont.)

Illustrations

Abstract

During the period April to November 1980, six surveillance cruises were conducted on Lake Huron, the North Channel and Georgian Bay, sampling 138 stations for physical, chemical and biological variables.

Ambient water quality conditions in 1980, based on nutrient data and phytoplankton biomass estimators, indicated that the Lake Huron-Georgian Bay system was generally oligotrophic. Specific areas in Lake Huron, where conditions ranged from mesotrophic to eutrophic as a result of nutrient enrichment, included the southern nearshore areas, Cheboygan-Black River, Alpena-Thunder Bay River and the St. Marys River.

Lake Superior via the St. Marys River, and Lake Michigan via the Straits of Mackinac, exerted the most pronounced influence on Lake Huron water quality. Marked differences in the ion chemistry of Lake Huron and Georgian Bay highlighted the degree of separation of these two water bodies.

A comparison of nutrient data in 1980 and the baseline survey years (1971 for Lake Huron and 1974 for Georgian Bay) revealed that total phosphorus demonstrated no statistically significant change in Lake Huron, while a decrease was noted in Georgian Bay. Nitrate + nitrite exhibited a significant increase of 48.8 $\mu g/L$ N and 26.8 $\mu g/L$ N in Lake Huron and Georgian Bay, respectively. Soluble reactive silica also demonstrated a significant increase of 102 $\mu g/L$ SiO_2 in Lake Huron. In contrast, a significant decrease of 196 $\mu g/L$ SiO_2 was observed in Georgian Bay. The real significance of these changes could not be assessed based on only two years of data. Therefore an annual surveillance program is recommended.

Résumé

Entre avril et novembre 1980, six missions ont été effectuées sur le lac Huron, le chenal Nord et dans la baie Georgienne. Au cours de ces missions, on a recueilli des données physiques, chimiques et biologiques dans 138 stations d'échantillonnage.

Les conditions ambiantes de qualité de l'eau observées en 1980, basées sur les éléments nutritifs et des estimateurs de la biomasse du phytoplancton, montrent que le réseau du lac Huron-baie Georgienne était en général oligotrophe. Certaines régions du lac Huron (zones proches de la rive sud, Cheboygan-rivière Black, Alpena-rivière Thunder Bay et rivière St. Marys) se trouvaient dans un état mésotrophe à eutrophe à la suite d'un apport d'éléments nutritifs.

Ce sont le lac Supérieur, par la rivière St. Marys, et le lac Michigan, par les détroits de Mackinac, qui ont affecté considérablement la qualité de l'eau du lac Huron. Des différences marquées dans la composition ionique des eaux du lac Huron et de la baie Georgienne ont mis en évidence le degré de séparation de ces deux masses d'eau.

Une comparaison des données relatives aux éléments nutritifs recueillies en 1980 et de celles recueillies durant les premières années de surveillance (1971 pour le lac Huron, 1974 pour la baie Georgienne) a montré que la concentration de phosphore total n'avait pratiquement pas varié dans le lac Huron, alors qu'elle avait diminué dans la baie Georgienne. La concentration de nitrates + nitrites a notablement augmenté, de 48.8 $\mu g/L$ N dans le lac Huron et de 26.8 $\mu g/L$ N dans la baie Georgienne. On a aussi observé une augmentation importante de la concentration de silice réactive soluble dans le lac Huron, soit 102 $\mu g/L$ SiO_2. Par contre, on a noté une diminution importante de sa concentration dans la baie Georgienne, soit 196 $\mu g/L$ SiO_2. Il est impossible d'évaluer la signification réelle de ces variations en se basant seulement sur deux années, aussi recommande-t-on un programme de surveillance annuel.

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INTRODUCTION

Detailed studies of Lake Huron, Georgian Bay and the North Channel in 1971 and 1974 demonstrated that apart from localized degradation of a few nearshore areas, the open waters of these water bodies were oligotrophic. The Upper Lakes Reference Group (ULRG, 1977) concluded that as degradation of water quality attributable to anthropogenic inputs would occur slowly, intensive sampling of the open lake should be conducted on a nine-year cycle. This recommendation was incorporated by the Surveillance Subcommittee of the Great Lakes Water Quality Board into the Great Lakes International Surveillance Plan (International Joint Commission, 1980), wherein it specified that an intensive surveillance program of the open lake should be undertaken in 1980.

As identified in the 1978 Canada-United States Water Quality Agreement, the management philosophy adopted for Lake Huron was one of nondegradation. The principal objective of the 1980 intensive program, therefore, was to ensure that this goal was being met. Specific objectives within this framework were to

(a) provide a detailed assessment of main lake conditions, statistically comparable to the 1971 and 1974 baseline data sets, so that "trends" in water quality could be determined;

(b) identify and characterize any new or emerging problem areas that may have altered the water quality of the lake; and

(c) assess the impact of regulatory controls on whole lake water quality, i.e. determine the adequacy of remedial programs.

This report summarizes the findings of the open lake water quality portion of the 1980 intensive surveillance program on Lake Huron, the North Channel and Georgian Bay undertaken by the Water Quality Branch, Ontario Region, Environment Canada, in cooperation with the United States Environmental Protection Agency (U.S. EPA). Specific discussion is focussed on the thermal regime of the lake, the major ion and nutrient chemistry, as well as comparison of current and past data to document changes in water quality.

STUDY DESIGN

Several factors were considered in the development of a sampling strategy for the 1980 open lake surveillance program. First, the station pattern had to reflect the high degree of spatial variability characteristic of large lakes (El-Shaarawi, 1984), i.e., areas exhibiting greater variability should have a greater station density. As well, seasonal variability had to be considered in the temporal component of the design. Secondly, although a fixed station design is considered optimal for determining long-term trends in water quality, a design that continuously changes the station pattern is best for detecting short-term water quality variations attributable to point source inputs (El-Shaarawi, 1984). As the ULRG determined that in most instances water quality degradation was confined to localized nearshore areas, a fixed station pattern was adopted.

Station locations for the years 1971, 1974 and 1980 are illustrated in Figures 1, 2 and 3, respectively. While there has been a slight shift in emphasis from the open lake areas to southern Lake Huron in 1980, reflecting the comparatively greater spatial variability exhibited by this region, 125 of the 138 stations coincide with previous station locations. Furthermore, since Saginaw Bay was found to be highly eutrophic in 1971, 1980 stations were concentrated at the Lake Huron-Saginaw Bay interface (ULRG, 1977). Because of this shift in station pattern, caution had to be exercised to avoid introducing bias when data from 1980 were compared with those of previous years.

In reviewing the results of the ULRG study, it was concluded that a minimum of six cruises would be required to estimate seasonal variability. The scheduling of these cruises, given as follows, encompassed the onset of vernal

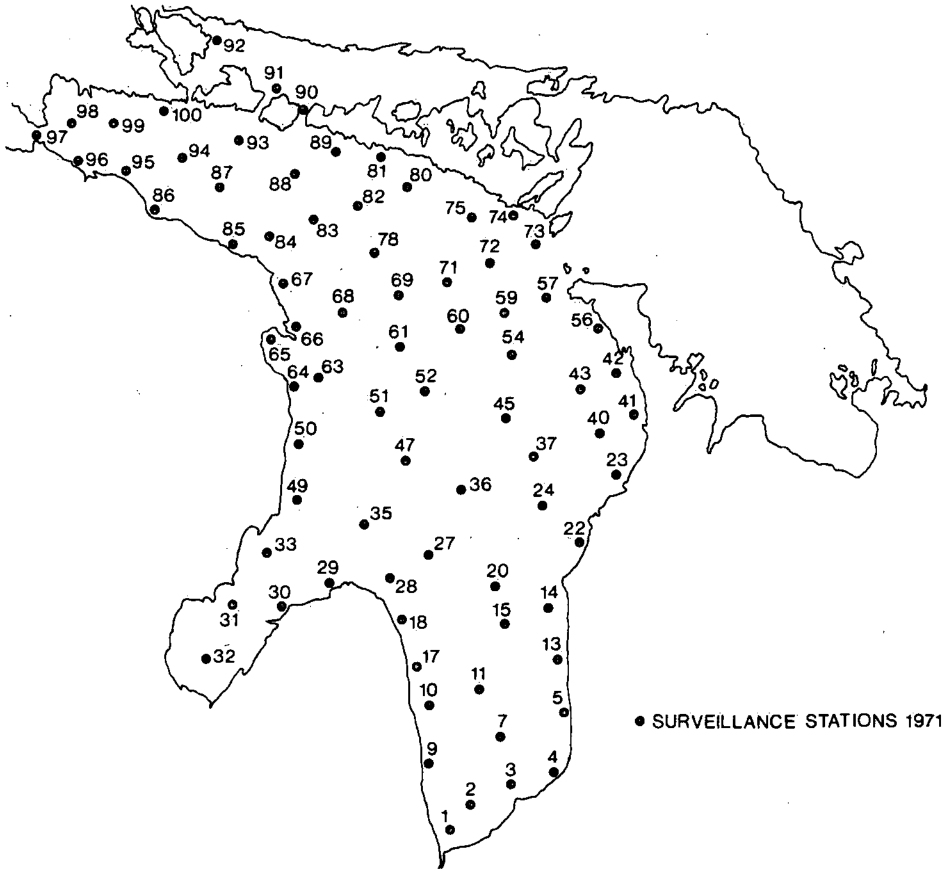


Figure 1. Lake Huron, the North Channel and Georgian Bay, surveillance stations, 1971.

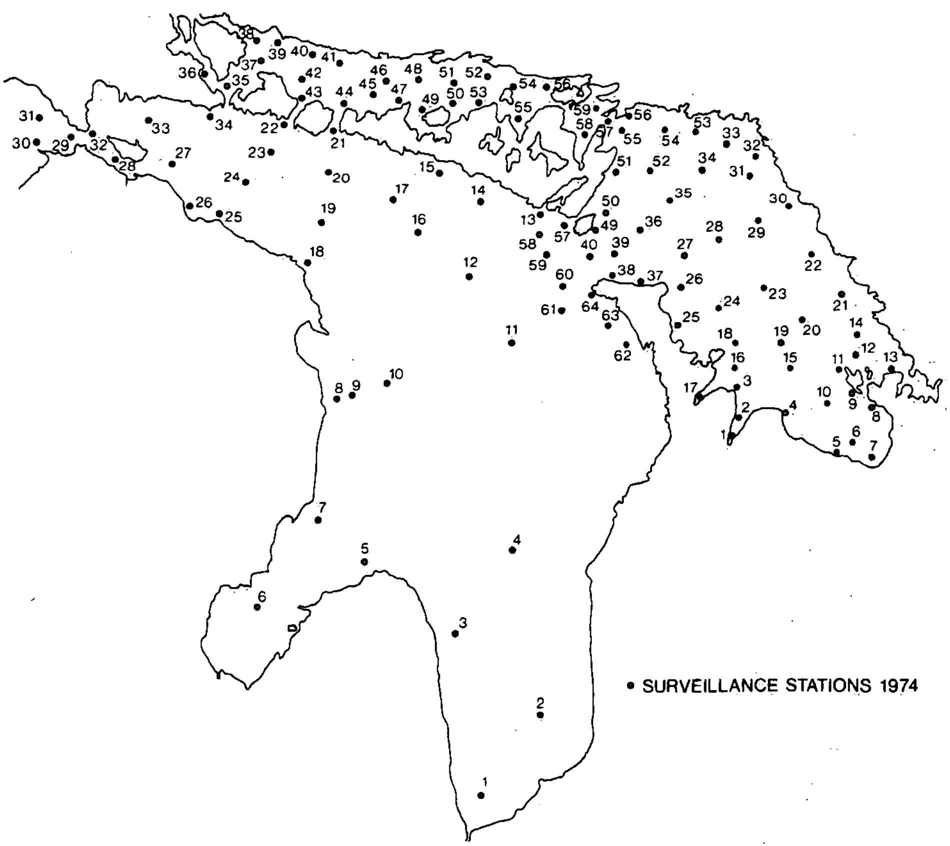


Figure 2. Lake Huron, the North Channel and Georgian Bay, surveillance stations, 1974.

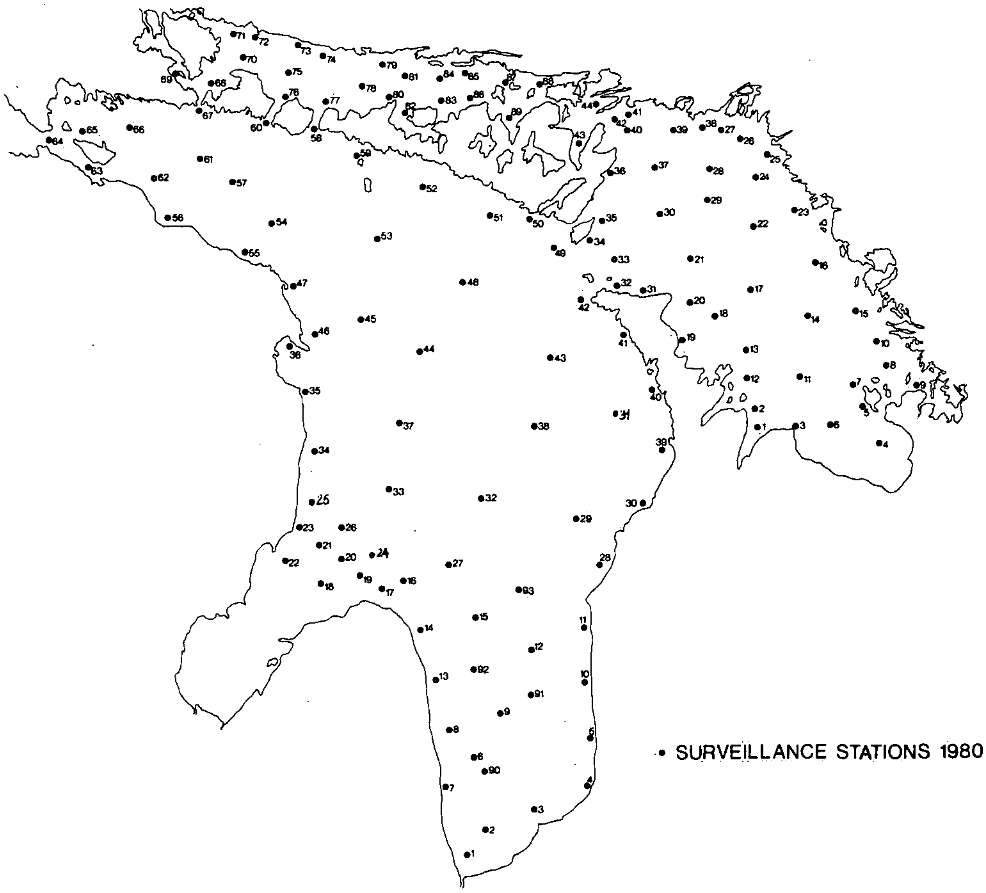


Figure 3. Lake Huron, the North Channel and Georgian Bay, surveillance stations, 1980.

turnover and the development and subsequent loss of thermal stratification.

Location	Cruise number	Date
Lake Huron	8022201	April 13–23
	8022202	May 10–17
	8022203	May 28–June 15
	8022207	July 18–27
	8022208	September 8–16
	8022209	October 22–November 1
Georgian Bay	8022501	April 24–27
	8022502	May 18–21
	8022503	June 5–7
	8022506	July 27–30
	8022507	September 16–21
	8022508	November 2–4

The first three cruises were concentrated during spring conditions, for practical and interpretive reasons. The adverse weather conditions frequently encountered in this season necessitated scheduling multiple cruises to ensure a complete spring database. Furthermore, increased loading of nutrients associated with spring runoff results in a "worst case" situation, particularly in the nearshore waters. This phenomenon is accentuated by the development of the thermal bar which restricts inshore-offshore water mass exchange. Finally, isothermal and isochemical conditions associated with vernal turnover ensure that vertical variability is at a minimum. Consequently, spring surface nutrient concentrations are representative of conditions over the whole lake.

As indicated, the open water surveillance component of the 1980 Lake Huron intensive survey was a joint venture undertaken by Environment Canada and the U.S. Environmental Protection Agency. The U.S. EPA Great Lakes National Program Office provided technical support for cruises 8022201, 8022202 and 8022207, and the Technical Operations Division, Environment Canada, provided support for cruises 8022203, 8022208 and 8022209. To eliminate uncertainties associated with interlaboratory data comparability, each agency was responsible for all analyses of a particular set of parameters. A list of parameters monitored during the six cruises along with the responsible agency is presented in the Appendix. All sampling, apart from biomass indicators (particulate organic carbon, total particulate nitrogen, chlorophyll *a*), was completed with a modified Rosette sampler fitted with Niskin bottles. To provide adequate assessment of the vertical structure of the lake, the following sampling strategy was employed:

> During nonstratified conditions, the sampling depths were 1 m, mid-depth if station depth was greater than 50 m, bottom-minus-10 m and bottom-minus-2 m. During stratified conditions, sampling depths were 1 m, 2 m above the upper knee of the thermocline, mid-thermocline, 2 m below the lower knee of the thermocline, bottom-minus-10 m and bottom-minus-2 m.

Particulate organic carbon, total particulate nitrogen and chlorophyll *a* samples were collected with a 20-m integrating sampler. Details on preservation and analytical methods employed can be found in Environment Canada (1979) and Rockwell *et al.* (1980).

DATA INTERPRETATION

In studying a large lake, inconsistencies in data interpretation can arise owing to spatial and temporal variation, complicated by a relatively coarse station pattern and the serrated profiles being sampled. Spatial variability can be accommodated by regarding the lake as a set of discrete "homogeneous" zones. The zonation pattern adopted for this study, illustrated in Figure 4, was subjectively determined on the basis of basin geomorphology, location of nearshore inputs and the summer epilimnetic circulation patterns, all of which serve to determine nutrient distributions in the lake.

Data synthesis was completed using two methods. To summarize the 1980 cruises, area- and volume-weighted

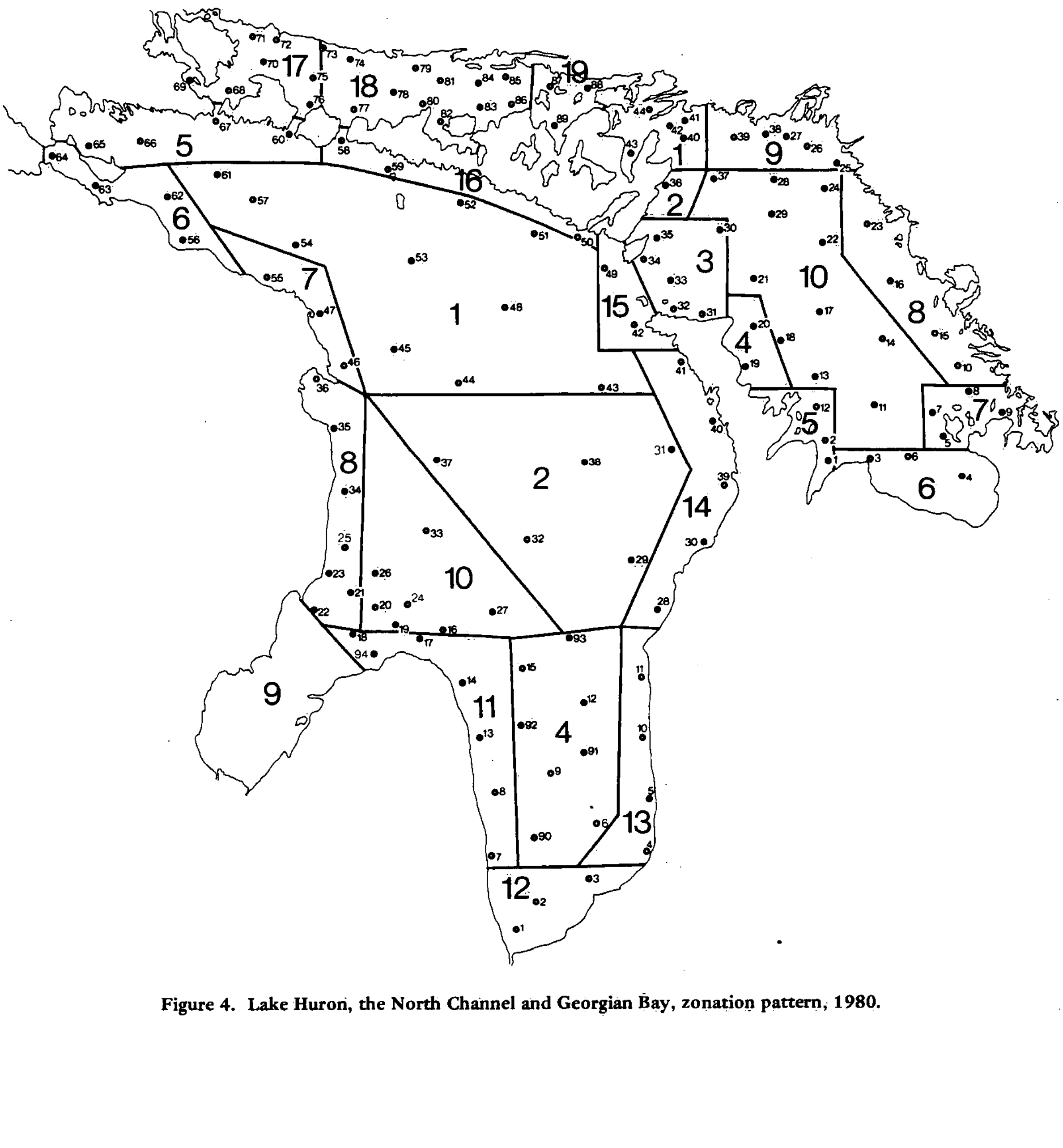


Figure 4. Lake Huron, the North Channel and Georgian Bay, zonation pattern, 1980.

concentrations for each zone were derived using the computer program ALDAR (Neilson *et al.*, 1983). Inter-year comparisons were based on the spring surface (1 m) values of those stations located at similar positions from year to year, surface concentrations being representative of the entire water column at this time.

DISCUSSION

Temperature

The thermal regime of Lake Huron and Georgian Bay is typical of northern temperate dimictic lakes. In general, the spatial distribution of surface temperature was a reflection of latitude and lake bathymetry, with the nearshore areas and southern basin of Lake Huron warming faster in the spring and cooling more rapidly in the fall.

The first cruise in April was scheduled to coincide with spring turnover, when the lake was essentially isothermal. Minor horizontal and vertical gradients were in evidence, related primarily to external inputs, but were of insufficient magnitude to resist mixing. The development and subsequent offshore migration of the thermal bar during the next two cruises indicated the onset of thermal stratification. Stations nearshore of the thermal bar were directly stratified during the May and June cruises, with mean surface temperatures of 6.7°C and 8.4°C, respectively, in Lake Huron, and 7.1°C and 8.9°C in Georgian Bay. In general, offshore stations were still isothermal during this period at temperatures of less than 4°C. During these two cruises, however, rapid differential heating of the lake, accompanied by relatively calm conditions, resulted in the formation of minor temperature inversions at several stations. These inversions, of only 0.05°C to 0.15°C, were similar to those reported for Lake Ontario (Lee and Rodgers, 1972) and would not be expected to provide effective resistance to vertical mixing.

By July, the thermal bar had dissipated and lakewide stratification was established. During this period, the anticyclonic circulation pattern of Lake Huron dominates the epilimnion (ULRG, 1977), maintaining a central core of colder, denser water surrounded by warmer, less dense water. This circulation pattern also exerted a profound influence on nutrient distributions in the lake. Although there was a tendency toward a similar circulation pattern in Georgian Bay, basin morphometry and exchange processes with Lake Huron precluded its complete development.

Declining air temperatures in late summer and fall, coupled with decreasing periods of solar radiation, led to a gradual cooling of surface waters. This was particularly evident during July in the shallower, eastern regions of Georgian Bay, where surface temperatures were less than those of deeper regions. The cooling and subsequent sinking of surface waters, combined with wind-induced mixing, resulted in a steady erosion of the metalimnion and a corresponding increase in epilimnion thickness. This progressive deepening of the thermocline in Lake Huron, from 5 m in July to 65 m in late October/November, was exponential and can be described by the equation:

$$y = 6.06 \times 10^{.016a}$$

where y = mean epilimnion thickness in metres and a = days elapsed since the establishment of thermal stratification.

By the final cruise, only those stations in the deepest basins of Lake Huron were not yet isothermal. This residual stratification has been shown to persist throughout most of the winter (Miller and Saylor, 1981).

The volume-weighted temperatures of three water masses (whole lake, 0–10 m and 60–120 m) are presented to demonstrate the process of seasonal heating in Lake Huron and Georgian Bay (Figs. 5a, 5b). Note that the whole lake volume-weighted temperature is directly proportional to the heat income of the lake. While heating of Lake Huron continued until the fifth cruise in September/October, the maximum rate of increase (0.07°C/day) occurred between June and late July. A gradual cooling trend began during late August, when temperatures decreased at a rate of approximately 0.03°C/day. The cycle was more advanced in Georgian Bay, peaking approximately two weeks earlier and showing a marked decline by the fifth cruise. Heating and cooling rates in Georgian Bay exceeded those of Lake Huron, with a maximum rate of increase of 0.11°C/day between June and July and a maximum rate of decrease of 0.06°C/day between September and November.

The 0 to 10-m layer exhibited a much more pronounced seasonal pattern. Beginning with isothermal conditions in April, the temperature of the surface layer gradually diverged from that of the whole lake and deep (60–120 m) layers. With the establishment of thermal stratification, this divergence increased markedly, owing to the 0.20°C/day rate of warming between June and July in both Lake Huron and Georgian Bay. With the progressive deepening of the surface-mixed layer after July, reduced insolation and increased entrainment of metalimnetic water into the epilimnion, the rate of warming decreased. Between mid-September and late October, temperatures in the 0 to 10-m layer declined at a rate of 0.19°C/day in Lake Huron and 0.17°C/day in Georgian Bay.

The deep (60-120 m) layer showed a somewhat different seasonal pattern from that of both the whole lake and the surface layer. During the first four cruises, a slight warming trend was observed. However, once lakewide stratification was established, this rate decreased to almost zero, indicating that the hypolimnion was effectively isolated from the warmer overlying waters. A temperature increase was noted only when the deepening thermocline penetrated this layer prior to the November cruise.

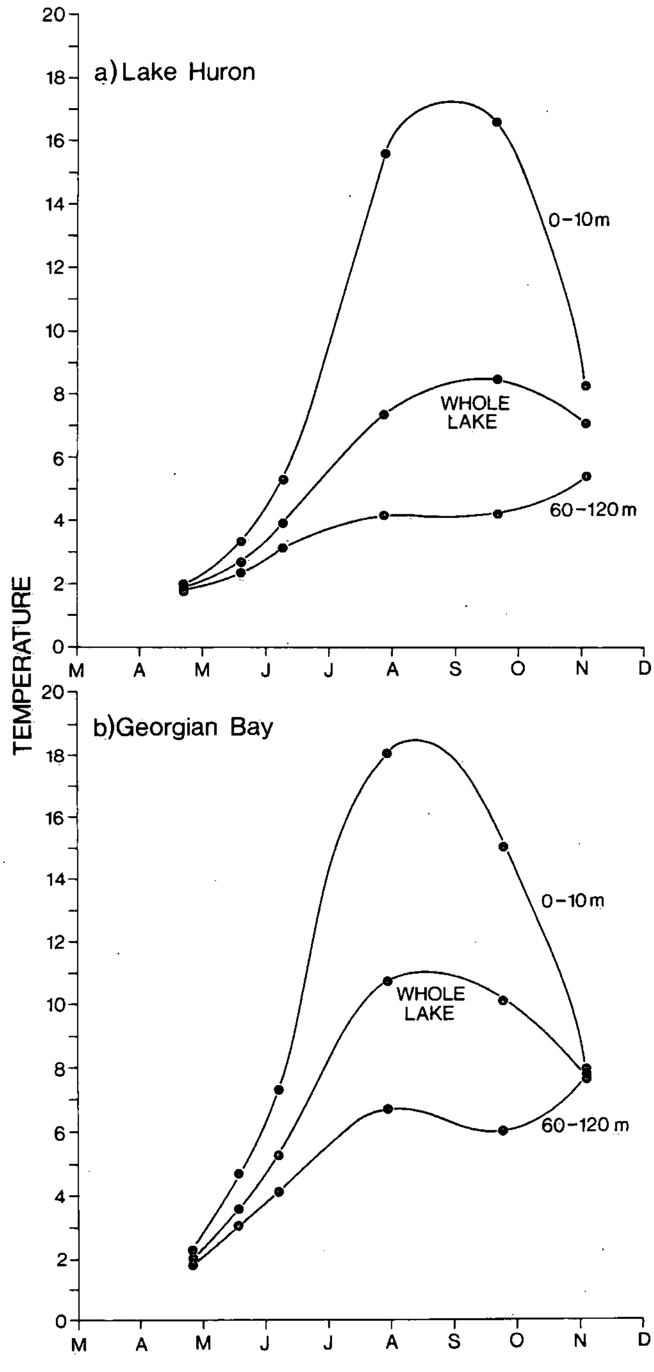


Figure 5. Thermal regime of Lake Huron and Georgian Bay.

Major Ions, Conductivity, Alkalinity and pH

The ionic composition of the Lake Huron-Georgian Bay system is governed largely by the composition of influents from adjoining drainage basins, atmospheric inputs, and contributions from Lakes Michigan and Superior. The lithology of the numerous drainage basins in the system varies markedly. The north shore of Georgian Bay and the North Channel is dominated by the Precambrian Shield, the runoff from which is of low salinity owing to its resistance to weathering. In contrast, the south shores are predominantly dolomitic limestone which, being both rich in carbonates and more susceptible to weathering, contribute runoff of comparatively high salinity. The catchment area of Lake Huron is more varied, but in general is dominated by a variety of limestones in the north, and shales and sandstones in the south (Sly and Thomas, 1974). While these areas are susceptible to weathering, thereby serving as a source of ions, the waters of Lake Huron are also strongly influenced by inputs from Lakes Superior and Michigan. The relative impact of these various sources on Lake Huron and the North Channel is best illustrated by examining the distribution of specific conductance in the surface waters throughout the study period. Area-weighted mean surface values of conductivity, as well as alkalinity and chloride, summarized by cruise and zone, are presented in Tables 1, 2 and 3, respectively, for Lake Huron, the North Channel and Georgian Bay.

Specific conductance is a measure of the total ionic strength of the water and, consequently, is directly proportional to the concentrations of the major ions. Listed in order of their dominance in the Lake Huron-Georgian Bay system, these ions are

(a) Cations: calcium, magnesium, sodium and potassium

(b) Anions: bicarbonate, sulphate, chloride.

Apart from bicarbonate, all other ion concentrations were determined by direct analysis. Bicarbonate concentrations were approximated by determining alkalinity, since at pH values characteristic of Lake Huron and Georgian Bay (pH 8), alkalinity is imparted largely by the bicarbonate ion (Hutchinson, 1957).

During the first two spring cruises of April and May, the main water mass of Lake Huron was essentially homogeneous at approximately 203 μS (1 μSiemen = 1 μmho/cm^2). Principal exceptions were in zone 6 where levels averaged 215 μS, reflecting both surface influx from Lake Michigan and discharge from Cheboygan, Michigan, via the Little Black River (Fig. 6), and zone 5 (185 μS), reflecting inputs from Lake Superior via the St. Marys

TABLE 1. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON

PARAMETER: SPECIFIC CONDUCTANCE (µSIEMENS)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	202.9	202.2	204.0	194.0	192.8	207.6
2	204.9	203.4	203.9	202.2	192.5	209.2
4	203.6	203.3	210.6	206.5	194.0	209.3
5	187.2	182.4	171.7	195.1	184.2	203.3
6	210.3	220.9	221.8	215.0	200.6	231.1
7	203.4	207.0	208.4	184.7	193.1	213.6
8	205.0	206.0	212.7	205.9	193.3	211.0
10	205.5	203.8	210.8	205.2	185.3	209.3
11	209.4	213.2	216.1	209.1	192.6	212.5
12	207.0	207.4	216.2	210.5	195.0	211.5
13	209.0	214.6	217.4	210.3	193.1	217.0
14	208.7	208.3	208.5	204.6	196.2	212.1
15	202.3	202.6	207.7	203.8	195.5	207.6
16	200.1	197.7	198.7	194.3	187.8	203.2
25	203.7	203.3	205.1	200.9	192.3	209.3

1980 NORTH CHANNEL

PARAMETER: SPECIFIC CONDUCTANCE (µSIEMENS)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	130.9	131.3	129.6	130.7	144.4	169.0
18	173.4	158.8	158.8	155.1	159.9	176.5
19	ICE	163.8	168.3	160.8	157.6	175.8
25	152.2	151.1	151.2	148.4	154.9	174.1

1980 GEORGIAN BAY

PARAMETER: SPECIFIC CONDUCTANCE (µSIEMENS)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	186.3	186.3	184.6	182.4	178.1	192.4
2	190.0	190.6	190.1	185.7	180.8	186.9
3	191.0	190.9	192.5	196.2	183.7	190.8
4	191.5	189.8	190.8	186.6	182.1	196.3
5	191.0	190.4	191.1	187.9	182.0	193.9
6	191.9	190.9	193.4	186.8	180.3	195.3
7	191.2	183.9	185.2	183.9	176.7	192.5
8	187.8	176.3	176.9	176.9	172.0	191.2
9	167.7	160.9	166.4	183.6	176.3	194.1
10	190.7	188.8	188.7	184.3	177.4	192.2
25	188.2	184.6	185.4	184.4	177.7	192.5

TABLE 2. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON — PARAMETER: ALKALINITY (MG/L) — DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	76.83	76.05	79.94	75.08	75.63	78.27
2	77.37	77.30	78.39	77.72	79.65	79.05
4	76.43	77.65	75.60	79.76	78.39	80.84
5	73.25	68.91	68.52	79.15	74.95	80.01
6	82.45	84.67	82.30	85.67	82.26	88.07
7	77.74	78.08	81.11	72.40	78.29	79.48
8	78.85	78.33	81.51	80.56	81.08	80.29
10	77.94	77.36	79.36	80.13	76.85	79.65
11	78.34	79.54	77.73	80.86	78.41	81.51
12	76.80	78.81	80.83	80.79	78.74	80.96
13	77.61	81.10	77.64	80.72	79.22	83.71
14	79.57	80.10	81.29	78.15	79.61	80.60
15	75.63	76.47	79.94	79.91	78.19	78.24
16	75.79	74.40	78.69	75.13	73.76	74.79
25	77.10	77.00	78.70	77.90	77.96	79.61

1980 NORTH CHANNEL — PARAMETER: ALKALINITY (MG/L) — DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	51.00	50.82	53.49	53.29	58.63	66.34
18	64.96	58.97	57.66	56.88	61.25	64.17
19	ICE	60.77	60.69	59.17	58.98	60.39
25	57.98	56.73	56.78	56.08	60.17	64.35

1980 GEORGIAN BAY — PARAMETER: ALKALINITY (MG/L) — DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	69.11	70.84	72.09	68.75	69.96	69.96
2	71.25	73.00	74.14	70.56	71.68	71.75
3	71.68	73.28	78.17	74.66	74.26	71.51
4	71.38	73.68	74.43	70.11	74.04	72.06
5	71.03	73.09	74.02	70.78	72.88	72.88
6	71.00	73.67	75.45	70.67	72.75	72.95
7	70.52	69.16	70.42	69.55	72.47	71.83
8	69.76	65.22	67.85	66.12	71.01	71.56
9	59.87	58.00	62.29	69.17	69.73	71.12
10	70.60	71.91	73.50	69.46	71.61	72.11
25	69.63	69.88	72.03	69.49	71.75	71.83

TABLE 3. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON — PARAMETER: CHLORIDE UNFILTERED (MG/L) DEPTH: 1.0

CRUISE	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	5.37	5.58	5.22	5.32	5.54
2	5.40	5.51	5.50	5.35	5.54
4	5.49	5.70	5.75	5.96	5.70
5	4.73	4.11	5.17	5.25	5.48
6	5.97	5.97	5.53	5.62	6.25
7	5.48	5.60	5.06	5.50	5.71
8	5.33	5.81	5.75	5.41	5.57
10	5.45	6.10	5.58	5.59	5.57
11	6.44	6.37	6.07	5.83	5.81
12	5.69	6.10	5.93	6.12	5.78
13	6.00	5.83	5.98	5.92	6.43
14	5.47	5.64	5.62	5.37	5.58
15	5.40	5.50	5.52	5.34	5.37
16	5.22	5.49	5.35	5.21	5.44
25	5.45	5.58	5.50	5.48	5.61

1980 NORTH CHANNEL — PARAMETER: CHLORIDE UNFILTERED (MG/L) DEPTH: 1.0

CRUISE	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	2.93	2.81	2.77	3.95	4.01
18	4.32	4.39	4.17	4.45	4.51
19	4.44	4.33	4.20	4.50	4.40
25	4.21	3.90	3.75	4.30	4.34

1980 GEORGIAN BAY — PARAMETER: CHLORIDE UNFILTERED (MG/L) DEPTH: 1.0

CRUISE	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	5.07	4.77	4.85	4.90	4.91
2	4.78	5.09	4.63	5.00	4.93
3	4.81	5.01	5.20	5.08	5.06
4	4.75	4.97	5.20	4.98	5.09
5	4.92	4.83	4.76	5.09	4.99
6	4.49	4.89	4.67	5.06	5.07
7	4.96	4.98	5.09	4.96	5.13
8	4.55	4.63	4.57	4.78	5.00
9	4.56	4.24	4.63	4.84	4.99
10	4.87	4.87	4.73	4.89	5.03
25	4.77	4.79	4.77	4.92	5.02

River (Figs. 7 and 8). Impacts of considerably lesser magnitude were evident offshore of major tributaries and/or communities in southern Lake Huron owing to increased urbanization and drainage through calcareous regions.

The extent to which these inputs influenced the waters of Lake Huron increased in conjunction with thermal bar advancement caused by its resistance to water mass exchange. Consequently, the areal extent of impact increased from April to June (cruise 8022201 to 8022203) (Fig. 9), with vertical profiles revealing that these inputs impacted the entire water column. With the establishment of thermal stratification by July, these impacts were confined primarily to the epilimnion. The resulting decrease in mixing depth caused the zone of influence of many of these inputs to increase dramatically, the most significant being that of Lake Superior (via the St. Marys River) which now extended past Thunder Bay along the western shore of Lake Huron (Fig. 10). In contrast, the tributaries in southern Lake Huron exhibited lesser impact owing to reduced discharge during the summer months.

By early November (cruise 8022209), autumnal turnover was nearly complete, and with water temperatures decreasing, conductivity increased to 209 μS (area-weighted lake-wide mean) due principally to the increasing solubility of calcium at colder temperatures (Weast, 1972). The most notable feature at this time was the marked increase of the surface areal extent of influence of Lake Michigan inputs. Whereas during the previous cruise inputs from Lake Michigan were restricted to the immediate vicinity of the Straits of Mackinac, they now extended across northern Lake Huron, nearing the Main Channel of Georgian Bay (Fig. 11).

The distribution of conductivity in the North Channel is determined primarily by discharge from its major tributaries, especially the St. Marys River, and exchange with Lake Huron and, to a lesser extent, Georgian Bay (Warry, 1978a). Circulation patterns, as evidenced by distribution of conductivity, are quite complex in the North Channel. Impacts from the St. Marys River are largely restricted to the western end (zone 17) of the North Channel and

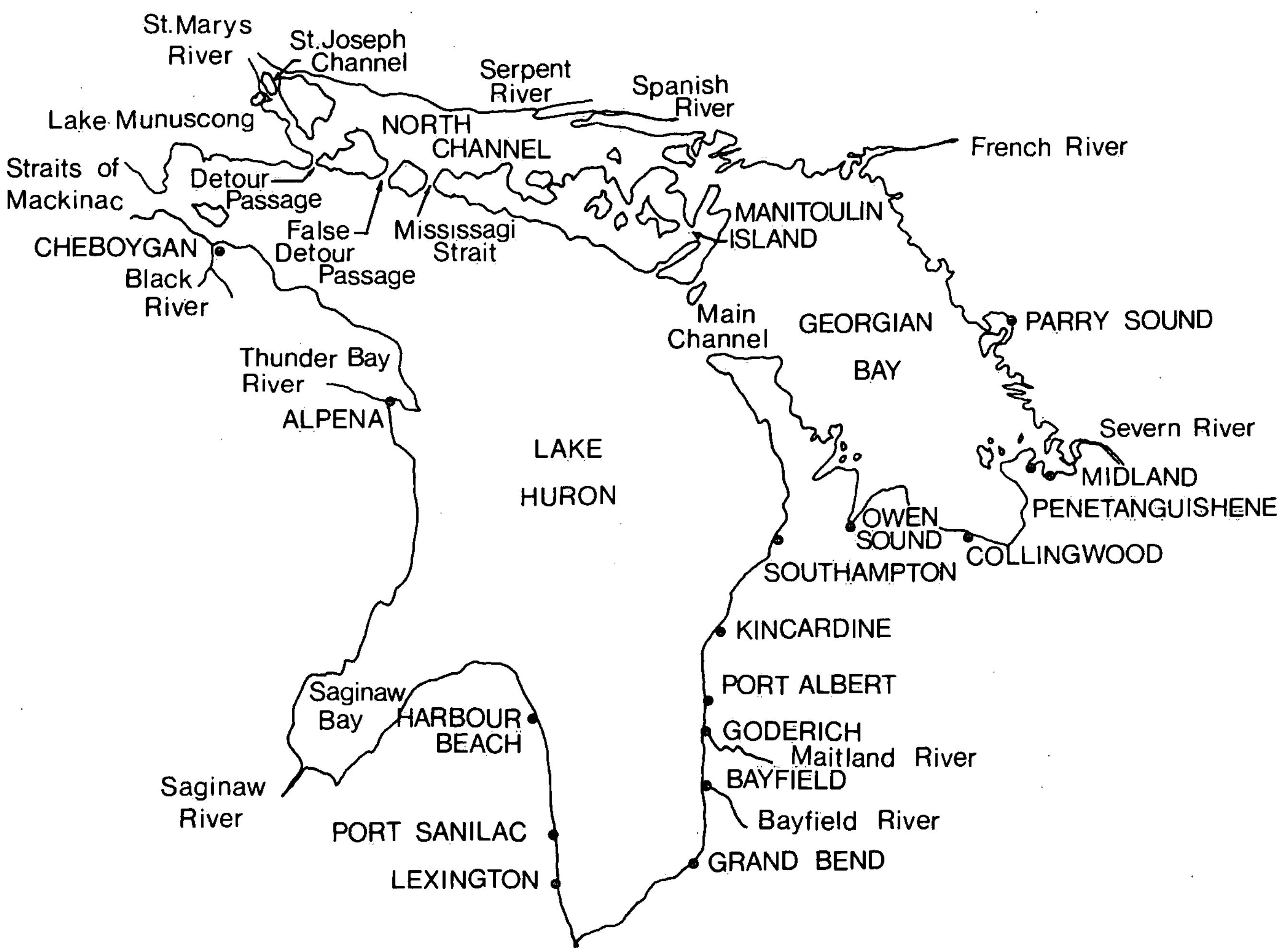


Figure 6. Reference map of Lake Huron, the North Channel and Georgian Bay.

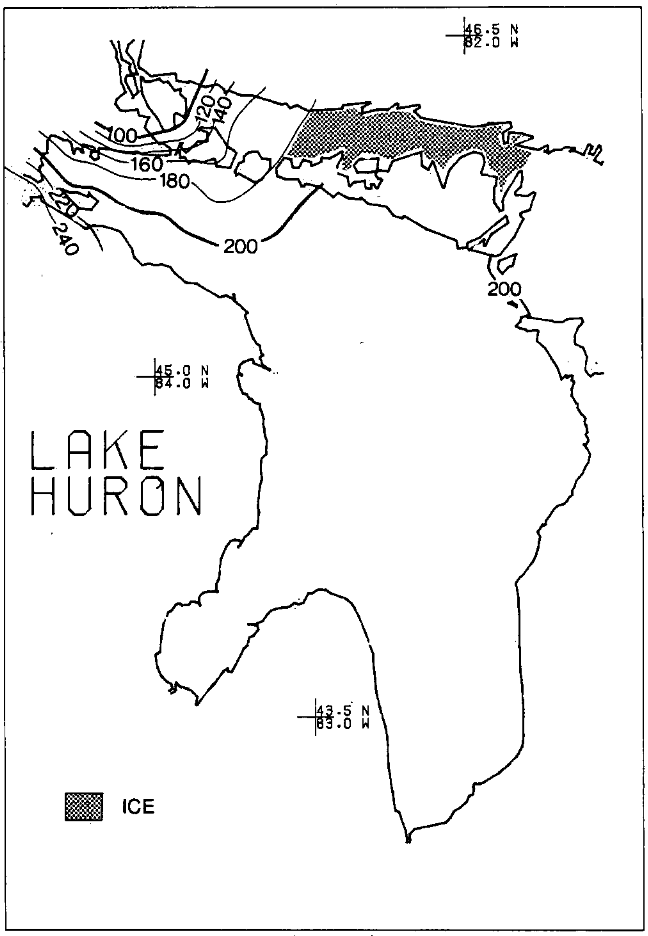


Figure 7. Isopleths of specific conductance (μS) at 1 m, cruise 8022201.

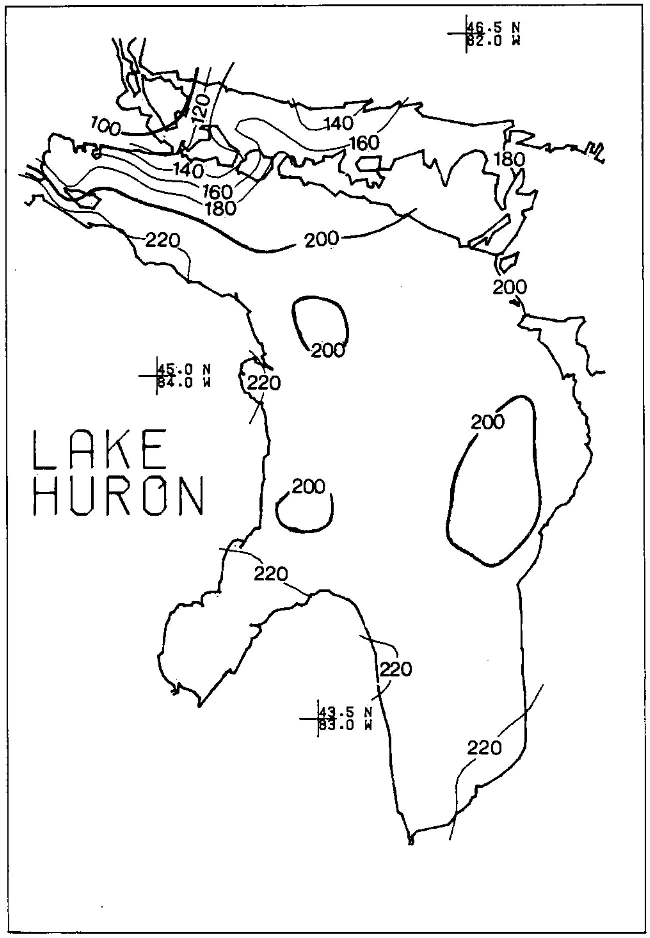


Figure 9. Isopleths of specific conductance (μS) at 1 m, cruise 8022203.

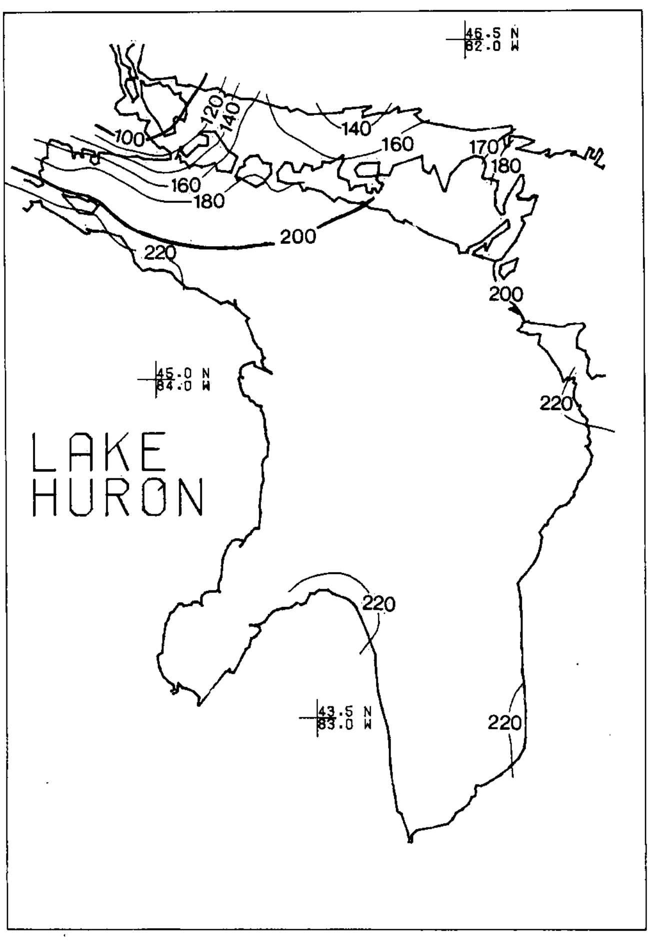


Figure 8. Isopleths of specific conductance (μS) at 1 m, cruise 8022202.

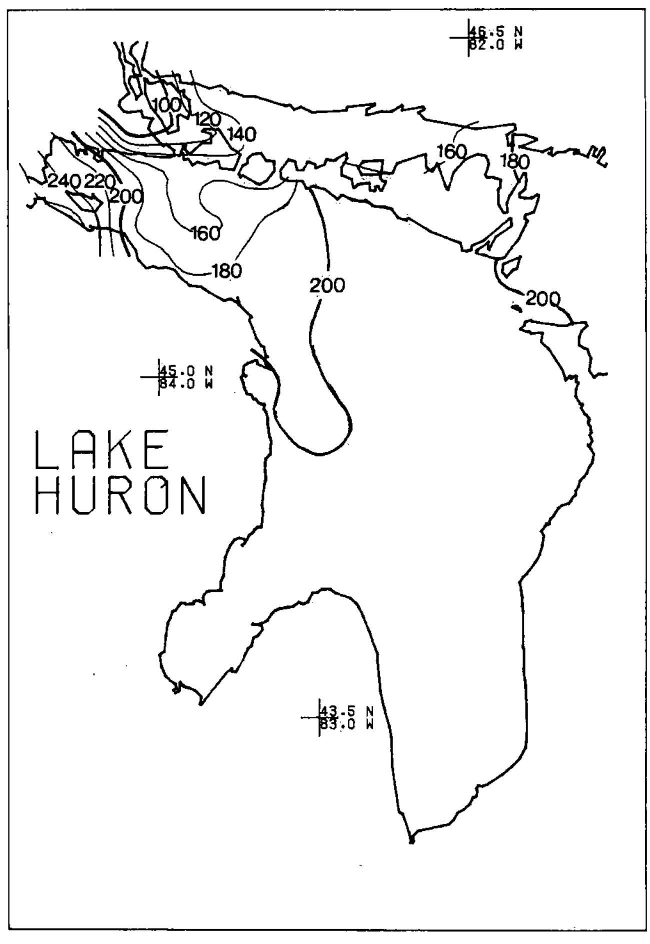


Figure 10. Isopleths of specific conductance (μS) at 1 m, cruise 8022207.

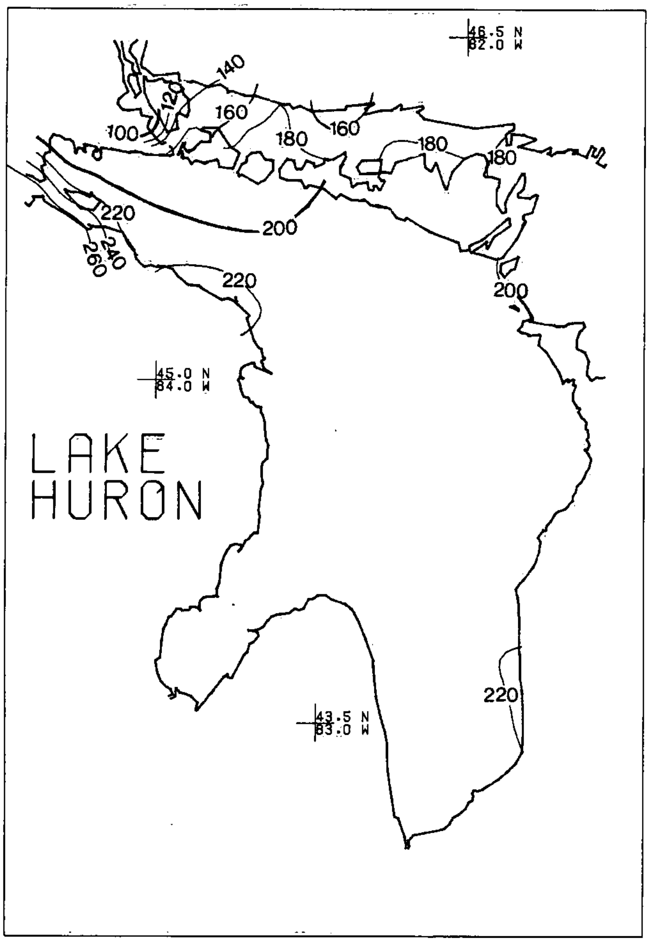


Figure 11. Isopleths of specific conductance (μS) at 1 m, cruise 8022209.

directed through Detour Passage into Lake Huron. However, it appears that flow is not partitioned consistently between the north (St. Joseph) and south (Munuscong) channels of the river. During the three spring cruises in April, May and June (Figs. 7, 8 and 9), the impact of St. Marys River flow on the surface waters of the North Channel through these channels appeared equal. During the July, September and October cruises, however, discharge through the south channel exhibited a considerably greater influence.

Exchange processes between the North Channel and Lake Huron are also variable. To reiterate, flow from the St. Marys River is directed through Detour Passage and, to a lesser extent, False Detour Passage. Balancing these outputs are inputs from Lake Huron via the Mississagi Strait. During the nonstratified period from April to June (cruises 8022201 to 8022203), flow was directed primarily into the North Channel through this gap, as indicated by vertical profiles. With the establishment of a distinct thermocline by July (cruise 8022207), stratified flow was observed, with inflow (into the North Channel) confined largely to the hypolimnion. Using data from the 1974 surveys, Warry (1978a) determined the influx from Lake Huron between May and October to equal a volume of approximately 1.5 x 10^{10} m^3, equivalent to 55% of the inflow from the St. Marys River during the same period (P. Yee, personal communication). Concomittant with this phenomenon was a marked increase in the extent of impact of the St. Marys River on the North Channel, because the influx of Lake Huron waters was restricted to the hypolimnion and the summer discharge of the Spanish and Serpent rivers, the only other large tributaries to the North Channel, was reduced.

Exchange between the North Channel and Georgian Bay via the Little Current channel determines the ionic chemistry of zone 19, with moderate contributions from runoff of adjacent lands. Using a materials balance for chloride, this exchange was estimated to be 27 m^3/s, directed into the North Channel (D. Dolan, personal communication). Consequently, this zone exhibited the highest average conductivity levels during the study period, at 165 μS compared with 164 μS in zone 18 and 139 μS in zone 17.

The areal distribution of conductivity in Georgian Bay, which is determined by the geology of its drainage basin, exchange with Lake Huron and inputs from the French River, was reasonably consistent throughout the study period. As demonstrated during the 1974 surveys, a distinct southwest to northeast gradient was observed (Warry, 1978b). The shallower waters along the northern and eastern shorelines were consistently lower in conductivity, reflecting drainage through the Precambrian Shield, while maximum values, reported in the southern and western waters, were due to both surface inflow from Lake Huron and drainage through the carbonaceous limestones of the southern shore.

During the three spring cruises (April to June), mixing at the Lake Huron-Georgian Bay interface occurred throughout the water column, as evidenced by vertical profiles, and delineation of the two water masses, based on the 200-μS contour, was sharply defined. Once thermal stratification was established by July (cruise 8022506), stratified flow developed, with resultant surface influx into Lake Huron. Similar findings were reported by Warry (1978b) based on 1974 data. Using materials balance of 1980 chloride data, net inflow into Lake Huron at this interface was determined to be 520 m^3/s during the study period (D. Dolan, personal communication). Despite this exchange, specific conductance in Georgian Bay was approximately 10 μS less than in Lake Huron, indicating a significant degree of separation between the two water masses.

Since conductivity is directly proportional to the major ion content of the water, examination of ion distributions could provide insight into the controlling mechanisms of conductivity. However, this interpretation is limited, as the major cations were only investigated on the first cruise. Furthermore, while the major anions were monitored during all six cruises, owing to analytical problems, no results for chloride or sulphate are available for the first cruise. Consequently, it is not possible to calculate total ionic balances for any cruise.

Areal distributions of alkalinity, sulphate and chloride in Lake Huron were strongly similar to conductivity, as indicated by their high correlation coefficients ($r = 0.92$, 0.77, 0.84, respectively). To determine which of these parameters was the most important in influencing the variation in conductivity, data were subjected to a stepwise linear multiple regression analysis. Essentially, this technique attempts to account for variation in conductivity by considering the influence of the three major anions in order of importance. Note that this analysis does not attempt to assess the relative contribution of the ions to the magnitude of conductivity.

Results of this analysis indicate that chloride was the best determining variable, accounting for 84% of the annual (i.e. seasonal and spatial) variation in conductivity. Of the remaining 16% variation, alkalinity could account for only 3% and sulphate for only 0.1%, leaving approximately 13% of the variation unaccounted for by the major anions. That chloride was the largest anionic determinant of the variation exhibited by conductivity suggests that the ionic composition of Lake Huron waters is determined primarily by inputs from Lakes Michigan and Superior. The magnitude of these influxes is such that they mask any biologically mediated changes in the less conservative anions.

Similar treatment of data in Georgian Bay indicates that its anionic chemistry differs markedly from that of Lake Huron. Whereas in Lake Huron, 87% of the variation could be accounted for by chloride, alkalinity and sulphate over the period May to November, these three ions accounted for only 50% of the variation in conductivity in Georgian Bay over a similar period. Of these, alkalinity was the most important controlling variable in Georgian Bay, accounting for 46% of the variation. Sulphate and chloride accounted for 3.5% and 1.0% of the remaining variation, respectively.

That almost 50% of the annual (May to November) variation in conductivity in Georgian Bay remains unaccounted for suggests two interpretations. First, it is possible that one linear equation may be inadequate to describe the relationship between the major anions and conductivity throughout the sampling period. This situation could arise if biologically mediated changes and/or changes in inputs resulted in differing relationships between the anions and conductivity between cruises. A second interpretation, not necessarily exclusive of the first, is that much of this residual variation can be accounted for by the cations.

To investigate the first interpretation, the regression was repeated on Georgian Bay data on a cruise-by-cruise basis. Results of this analysis are summarized in the following table which gives the variation in conductivity due to anions (%).

Ion	Cruise number				
	8022502	8022503	8022506	8022507	8022508
Alkalinity	96.7	82.2	88.7	32.6	16.2
Chloride	0.1	1.6	0.5	12.6	6.3
Sulphate	0.0	0.3	0.2	0.0	0.0

From May to July (cruises 8022502 to 8022506), alkalinity was principal in influencing the variation in conductivity, accounting for at least 82% of its variation. This influence, however, decreased markedly to approximately 33% and 16% in September and November, respectively, suggesting a more pronounced influence by the other major cations.

Results for the four major cations, expressed as area-weighted values in milliequivalents, for the surface waters of Lake Huron, the North Channel and Georgian Bay, are presented in Table 4. While absolute concentrations varied between zones, relative proportions were remarkably consistent throughout the entire system. Calcium, for instance, when expressed as a percentage of the total cation concentration (in milliequivalents), ranged from 62.8% in zone 6 of Lake Huron to 65.0% in zone 17 of the North Channel, whereas magnesium ranged from 26.4% in zone 17 to 28.9% in zone 6 of Lake Huron. This reflects the differing ionic composition of Lake Michigan and Lake Superior inputs, respectively. Sodium ranged from a low of 5.8% in zone 8 of Georgian Bay to 7.7% in adjacent zone 9, illustrating the difference between drainage from the north shore and that of the French River basin. Finally, potassium ranged from 1.0% in zone 5 of Georgian Bay to 1.6% in zone 17 of the North Channel.

In terms of absolute concentrations, zone 17 of the North Channel, dominated by inflow from Lake Superior, had the lowest total cation concentration (1.24 epm), while zone 11 of Lake Huron had the highest (2.15 epm), reflecting the outflow of Saginaw Bay. Georgian Bay, reporting concentrations slightly less than Lake Huron,

TABLE 4. CATION CONCENTRATIONS (EPM) IN LAKE HURON, THE NORTH CHANNEL AND GEORGIAN BAY: CRUISES 8022201 & 8022501

LAKE HURON

ZONE	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	Σ
1	1.307	0.584	0.144	0.026	2.061
2	1.317	0.584	0.144	0.026	2.068
4	1.347	0.609	0.152	0.026	2.134
5	1.238	0.543	0.148	0.023	1.952
6	1.322	0.609	0.148	0.026	2.105
7	1.307	0.584	0.148	0.026	2.065
8	1.352	0.600	0.152	0.026	2.130
10	1.342	0.592	0.152	0.026	2.112
11	1.362	0.600	0.161	0.026	2.149
12	1.317	0.592	0.144	0.023	2.076
13	1.317	0.584	0.139	0.023	2.063
14	1.332	0.600	0.144	0.023	2.099
15	1.312	0.576	0.152	0.026	2.066
16	1.307	0.584	0.148	0.028	2.067
25	1.317	0.584	0.148	0.026	2.075

NORTH CHANNEL

ZONE	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	Σ
17	0.808	0.329	0.087	0.020	1.244
18	1.113	0.485	0.135	0.026	1.759
19	ICE	ICE	ICE	ICE	ICE
25	0.961	0.407	0.111	0.022	1.501

GEORGIAN BAY

ZONE	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	Σ
1	1.213	0.535	0.139	0.023	1.910
2	1.297	0.568	0.130	0.023	2.018
3	1.327	0.592	0.117	0.020	2.056
4	1.208	0.535	0.126	0.020	1.889
5	1.233	0.543	0.135	0.020	1.931
6	1.248	0.543	0.135	0.020	1.946
7	1.257	0.543	0.148	0.023	1.971
8	1.362	0.592	0.122	0.023	2.099
9	1.068	0.461	0.130	0.023	1.682
10	1.277	0.559	0.135	0.023	1.994
25	1.262	0.551	0.135	0.023	1.971

showed a more pronounced variation in total cation content on a zonal basis. Zone 9, which is dominated by inputs from the French River at this time, had the lowest cation concentrations at 1.68 epm, while zone 8, immediately adjacent to it, had the highest at 2.99 epm.

To determine which of the major cations contributed most to the variability of conductivity, data were subjected to multiple regression. Magnesium accounted for 87.4% of the variation in conductivity in Lake Huron and the North Channel, and the remaining cations accounted for only a further 1.4%. Distributions of cations in Georgian Bay, as with anions, was more complex. Magnesium accounted for only 47.6% of the variation, with the remaining cations accounting for a further 8.7% of the variation. Since a complete data set is lacking, results of this regression cannot be related to those of the anions, but merely demonstrate which of the major cations and anions were most important in determining conductivity.

Nutrients

The distribution of nutrients in the open waters of Lake Huron and Georgian Bay is the result of anthropogenic inputs, thermal structure, regeneration within the water column and assimilation by phytoplankton (Gachter *et al.*, 1974). Maximum concentrations were generally observed during the spring in the nearshore zones, associated with increased loadings owing to runoff and thermal bar formation which restricts nearshore/offshore water mass exchange. Accompanying these high nutrient levels was a spring pulse of phytoplanktonic growth, comprised primarily of diatoms (Lin and Schelske, 1981; Munawar and Munawar, 1979).

While production of the vernal diatom crop is attributed to a combination of factors including light, temperature and physical regime (Happey, 1970a,b), the net result is the assimilation of available dissolved nutrients into particulate (phytoplanktonic) matter. This process of assimilation is accelerated in the warmer nutrient-rich nearshore areas and, if of sufficient magnitude to exceed loading rates, can lead to depletion of dissolved nutrients in the nearshore relative to the offshore. This phenomenon is illustrated in Table 5 for five nutrient parameters: total phosphorus (TP), soluble reactive phosphorus (SRP), soluble reactive silica (SRS), filtered nitrate + nitrite (NO_3+NO_2) and filtered ammonia (NH_3). The progression of the thermal bar during the first three cruises is represented by the 4°C isotherm in the three figures in the table, and the mean surface (1 m) concentrations for the nearshore and offshore stations are given below. Of the four dissolved forms listed, only soluble reactive silica showed consistent and significant ($p < 0.001$) depletion in the nearshore zone for all three cruises, reflecting the large demand by diatoms. Soluble reactive phosphorus, which is rapidly depleted to limiting levels in the lower lakes, showed only a marginally significant ($p < 0.01$) depletion during the third cruise.

With the onset of thermal stratification, the epilimnion and hypolimnion are effectively isolated from one another. Subsequent losses of colloidal and particulate fractions from the trophogenic zone result in a summer minimum in the surface waters, while decomposition of this material in the tropholytic zone enriches solubilized fractions in the hypolimnion. This process is demonstrated in Figure 12 for TP, SRP, (NO_3+NO_2), NH_3, and SRS. Epilimnetic nutrient concentrations, in general, increased in the fall as the deepening thermocline entrained waters from the nutrient-rich hypolimnion. This bimodal distribution, with maxima in spring and fall, is characteristic of moderately productive, dimictic lakes.

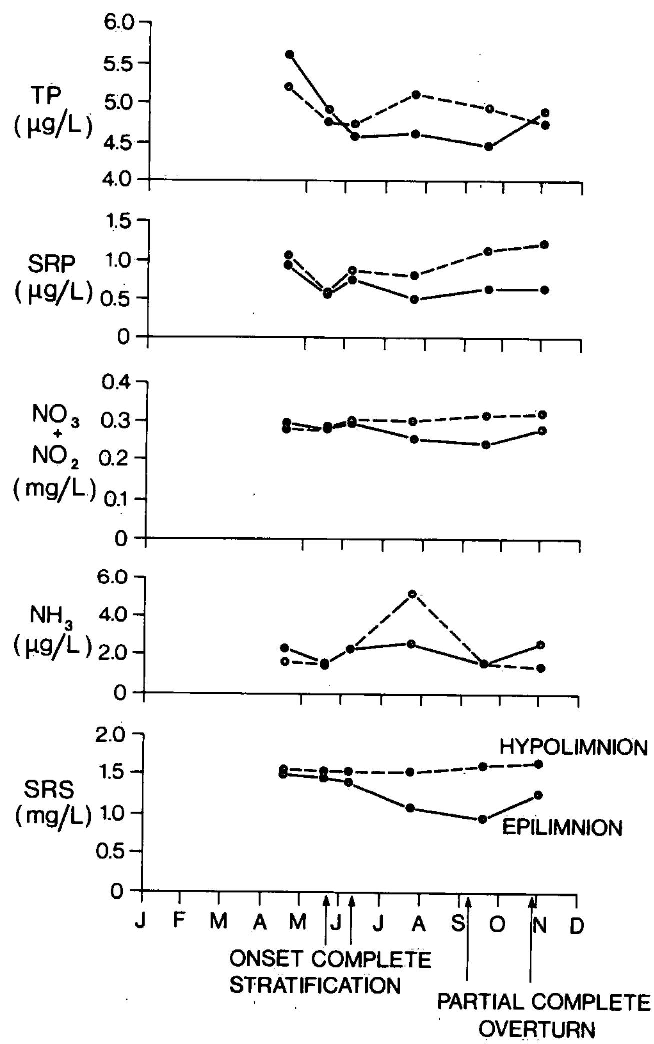
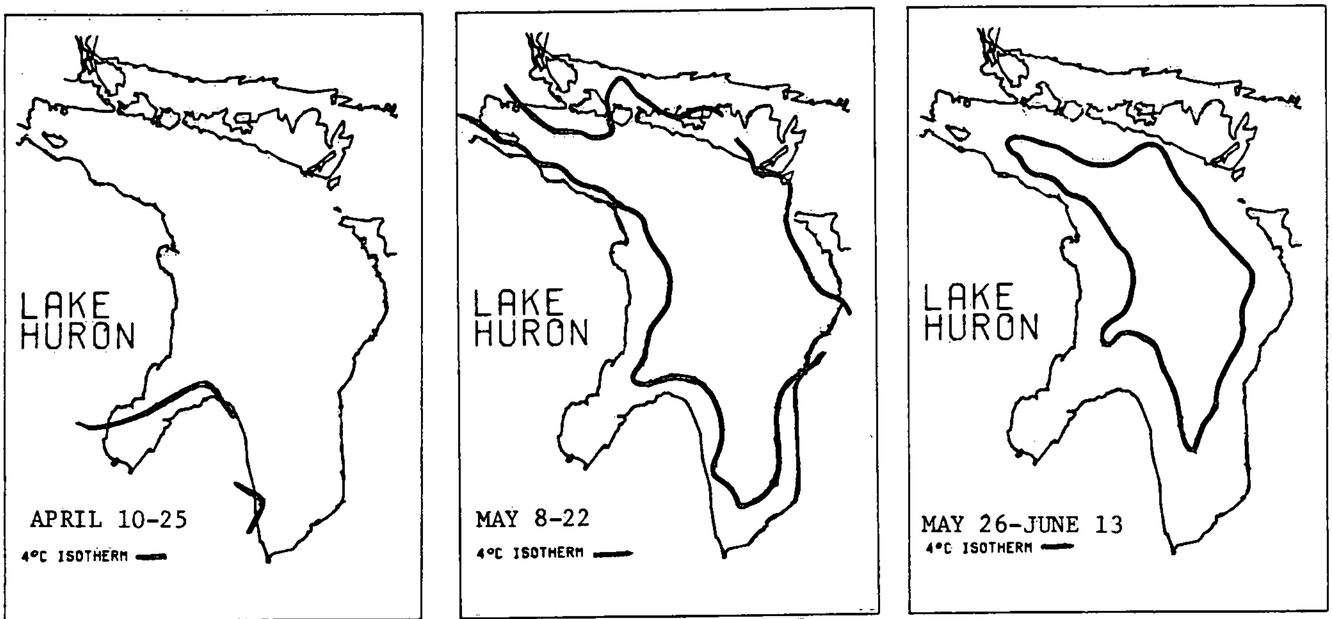


Figure 12. Seasonal variation of nutrients in the epilimnion and hypolimnion.

TABLE 5. NUTRIENT VARIATION ACROSS THERMAL BAR



PARAMETER		APRIL 10-25		MAY 8-22		MAY 26-JUNE 13	
TOTAL	NEARSHORE	6.5		5.8	**	4.7	
PHOSPHORUS (µg/L)	OFFSHORE	5.5		4.7		4.4	
SOLUBLE REAC.	NEARSHORE	1.1		0.6		0.7	
PHOSPHORUS (µg/L)	OFFSHORE	1.0		0.6		0.8	
SOLUBLE REAC.	NEARSHORE	1.4	**	1.2	**	1.2	**
SILICA (mg/L)	OFFSHORE	1.5		1.5		1.5	
NITRATE +	NEARSHORE	308.0		295.3		292.6	
NITRITE (µg/L)	OFFSHORE	290.1		282.2		296.8	
AMMONIA (µg/L)	NEARSHORE	2.4		1.6		2.4	
	OFFSHORE	2.2		1.6		2.1	

** SIGNIFICANT DIFFERENCE ($P > 0.05$)

Phosphorus

One objective of the 1978 Great Lakes Water Quality Agreement is to maintain the oligotrophic state and relative algal biomass of Lake Huron. As various authors have demonstrated that phytoplankton growth in Lake Huron is generally limited by phosphorus availability (Lin and Schelske, 1981; Schelske and Roth, 1973), control programs have been instituted, where appropriate, to control phosphorus input. To assess the effectiveness of these remedial programs, as well as to identify significant inputs and determine ambient concentrations, monitoring of phosphorus levels in Lake Huron, the North Channel and Georgian Bay was undertaken. Three forms of phosphorus were measured: total phosphorus (TP), a measure of both particulate (i.e. incorporated into living matter and adsorbed onto inorganic complexes or detrital organic matter) and dissolved P, made up of orthophosphate,

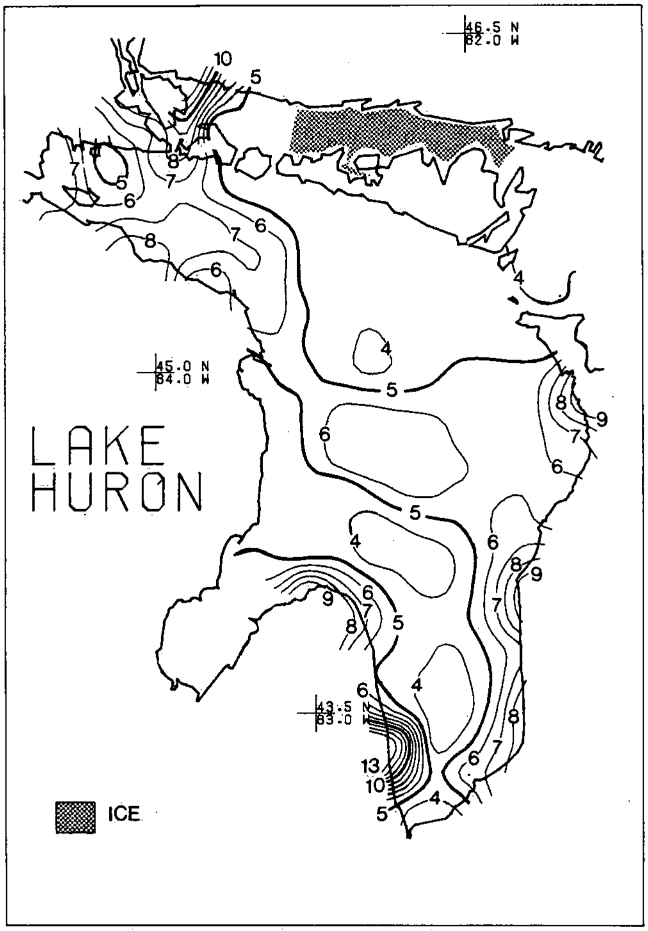


Figure 13. Isopleths of total phosphorus (μg/L P) at 1 m, cruise 8022201.

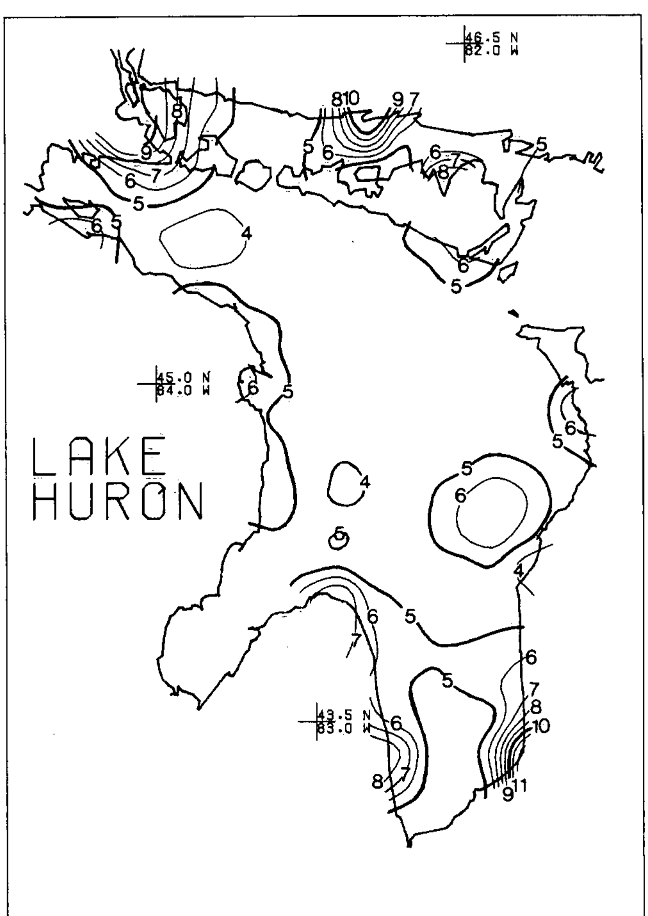


Figure 14. Isopleths of total phosphorus (μg/L P) at 1 m, cruise 8022202.

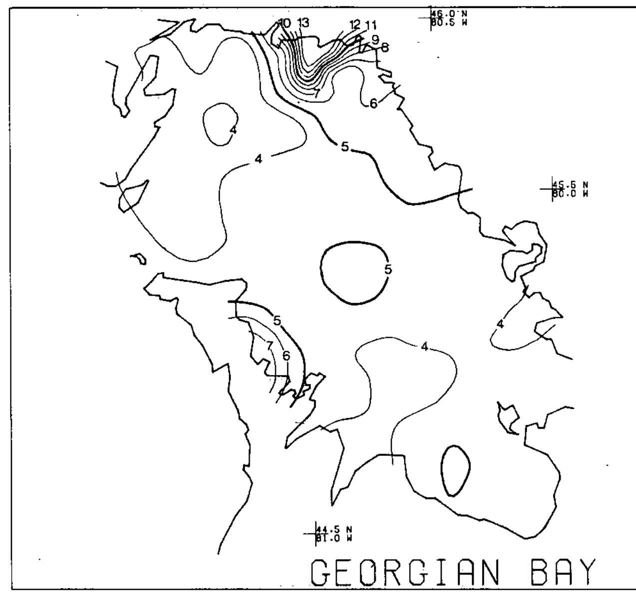


Figure 15. Isopleths of total phosphorus (μg/L P) at 1 m, cruise 8022501.

polyphosphates and organic colloids; total filtered phosphorus (TFP), a measure of dissolved P; and soluble reactive phosphorus (SRP), which is assumed to be roughly equivalent to, but may be greater than, orthophosphate (i.e. that component of TFP most readily available for phytoplanktonic utilization).

Areal surface distributions of TP in Lake Huron and Georgian Bay are presented for the April and May cruises (Figs. 13 to 16), when spring runoff was at a maximum, thereby delineating the sources of anthropogenic and tributary inputs to the lake. In addition, the area-weighted mean values for TP, TFP and SRP are listed by zone and cruise in Tables 6, 7 and 8, respectively, to demonstrate the relative impact of these inputs upon ambient water quality.

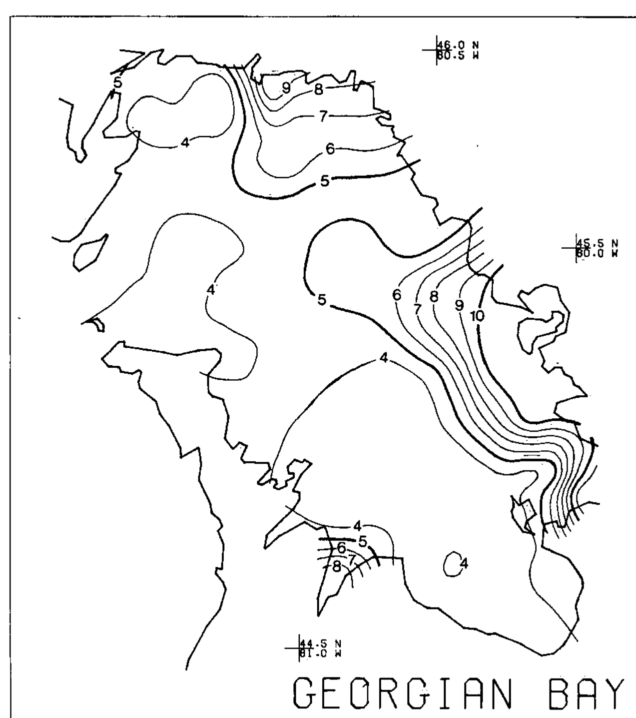


Figure 16. Isopleths of total phosphorus (μg/L P) at 1 m, cruise 8022502.

TABLE 6. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON PARAMETER: TOTAL PHOSPHORUS (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	.0058	.0045	.0042	.0044	.0051	.0047
2	.0055	.0048	.0046	.0046	.0039	.0049
4	.0046	.0049	.0048	.0037	.0039	.0046
5	.0062	.0049	.0041	.0044	.0051	.0056
6	.0074	.0055	.0046	.0040	.0050	.0054
7	.0071	.0047	.0038	.0038	.0053	.0047
8	.0047	.0051	.0049	.0046	.0045	.0055
10	.0047	.0048	.0049	.0041	.0035	.0047
11	.0063	.0057	.0052	.0044	.0041	.0059
12	.0059	.0050	.0052	.0040	.0039	.0072
13	.0079	.0075	.0048	.0045	.0050	.0078
14	.0064	.0049	.0046	.0040	.0041	.0059
15	.0041	.0047	.0046	.0033	.0036	.0046
16	.0051	.0050	.0039	.0035	.0053	.0045
25	.0055	0049	.0045	.0043	.0044	.0051

1980 NORTH CHANNEL PARAMETER: TOTAL PHOSPHORUS (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	.0078	.0060	.0047	.0064	.0062	.0075
18	.0047	.0056	.0050	.0042	.0045	.0059
19	ICE	.0062	.0046	.0053	.0052	.0053
25	.0063	.0058	.0048	.0050	.0051	.0063

1980 GEORGIAN BAY PARAMETER: TOTAL PHOSPHORUS (MG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	.0042	.0046	.0036	.0038	.0044	.0049
2	.0037	.0046	.0043	.0025	.0041	.0038
3	.0040	.0040	.0039	.0033	.0038	.0036
4	.0053	.0042	.0037	.0038	.0034	.0038
5	.0044	.0048	.0039	.0042	.0042	.0044
6	.0043	.0039	.0033	.0033	.0040	.0041
7	.0045	.0054	.0047	.0044	.0038	.0049
8	.0047	.0075	.0043	.0036	.0039	.0043
9	.0062	.0061	.0051	.0028	.0044	.0050
10	.0044	.0046	.0041	.0034	.0035	.0043
25	.0046	.0051	.0041	.0035	.0038	.0043

TABLE 7. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON — PARAMETER: TOTAL FILTERED PHOSPHORUS (MG/L) — DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	.0029	.0023	.0021	.0022	.0023	.0023
2	.0030	.0023	.0023	.0023	.0020	.0025
4	.0027	.0022	.0024	.0023	.0022	.0027
5	.0041	.0021	.0021	.0024	.0021	.0019
6	.0048	.0021	.0020	.0022	.0020	.0022
7	.0034	.0021	.0019	.0021	.0021	.0023
8	.0022	.0026	.0025	.0026	.0023	.0024
10	.0025	.0022	.0021	.0022	.0020	.0024
11	.0030	.0026	.0023	.0024	.0022	.0029
12	.0028	.0025	.0029	.0028	.0023	.0037
13	.0027	.0026	.0023	.0024	.0021	.0038
14	.0032	.0024	.0022	.0021	.0019	.0023
15	.0022	.0026	.0021	.0022	.0022	.0020
16	.0030	.0023	.0021	.0021	.0021	.0022
25	.0030	.0023	.0022	.0023	.0021	.0025

1980 NORTH CHANNEL — PARAMETER: TOTAL FILTERED PHOSPHORUS (MG/L) — DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	.0039	.0023	.0021	.0027	.0021	.0025
18	.0025	.0026	.0023	.0023	.0021	.0022
19	ICE	.0030	.0020	.0025	.0024	.0025
25	.0032	.0026	.0022	.0024	.0021	.0023

1980 GEORGIAN BAY — PARAMETER: TOTAL FILTERED PHOSPHORUS (MG/L) — DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	.0023	.0024	.0019	.0023	.0021	.0022
2	.0017	.0028	.0018	.0017	.0020	.0019
3	.0021	.0025	.0019	.0023	.0019	.0018
4	.0023	.0018	.0016	.0020	.0019	.0019
5	.0019	.0022	.0021	.0022	.0022	.0019
6	.0021	.0018	.0017	.0020	.0023	.0023
7	.0024	.0022	.0028	.0021	.0020	.0021
8	.0026	.0022	.0018	.0021	.0019	.0019
9	.0031	.0031	.0021	.0018	.0021	.0022
10	.0023	.0021	.0018	.0019	.0020	.0022
25	.0023	.0022	.0019	.0020	.0020	.0021

TABLE 8. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON PARAMETER: SOLUBLE REACTIVE PHOSPHORUS (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	.0009	.0005	.0008	.0004	.0007	.0007
2	.0011	.0006	.0008	.0006	.0007	.0007
4	.0009	.0006	.0009	.0006	.0007	.0008
5	.0010	.0005	.0008	.0003	.0009	.0006
6	.0010	.0007	.0008	.0004	.0009	.0005
7	.0010	.0006	.0008	.0004	.0007	.0007
8	.0007	.0006	.0008	.0005	.0006	.0007
10	.0011	.0006	.0006	.0004	.0007	.0006
11	.0008	.0007	.0007	.0005	.0007	.0006
12	.0008	.0010	.0007	.0013	.0011	.0011
13	.0007	.0006	.0006	.0009	.0009	.0016
14	.0008	.0006	.0008	.0004	.0007	.0005
15	.0008	.0005	.0006	.0005	.0005	.0005
16	.0009	.0005	.0007	.0004	.0004	.0006
25	.0009	.0006	.0008	.0005	.0007	.0007

1980 NORTH CHANNEL PARAMETER: SOLUBLE REACTIVE PHOSPHORUS (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	.0011	.0006	.0007	.0004	.0008	.0007
18	.0010	.0008	.0006	.0005	.0008	.0005
19	ICE	.0008	.0007	.0005	.0010	.0006
25	.0010	.0008	.0006	.0005	.0008	.0006

1980 GEORGIAN BAY PARAMETER: SOLUBLE REACTIVE PHOSPHORUS (MG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	.0006	.0007	.0008	.0011	.0008	.0004
2	.0008	.0007	.0006	.0003	.0012	.0004
3	.0009	.0008	.0006	.0004	.0007	.0004
4	.0009	.0005	.0006	.0003	.0008	.0004
5	.0006	.0006	.0007	.0004	.0008	.0003
6	.0004	.0006	.0006	.0003	.0006	.0003
7	.0006	.0006	.0007	.0004	.0006	.0004
8	.0006	.0004	.0005	.0003	.0006	.0003
9	.0006	.0004	.0006	.0005	.0006	.0003
10	.0007	.0005	.0007	.0003	.0006	.0004
25	.0007	.0005	.0006	.0004	.0007	.0004

Levels of TP were low throughout the system, averaging 5.0 μg/L P (area-weighted mean) in the surface waters of Lake Huron and 4.2 μg/L P in Georgian Bay for the period April to November, suggesting that Lake Huron and Georgian Bay are oligotrophic (Dobson *et al.*, 1974). In contrast, concentrations in Lake Ontario are nearly three times higher, averaging 14.0 μg/L P (Neilson, 1983). The highest zone area-weighted mean values in Lake Huron were observed in April in the vicinity of St. Marys River (zone 5, 6.2 μg/L P), the Straits of Mackinac (zone 6, 7.4 μg/L P), Cheboygan (zone 7, 7.1 μg/L P) and the Ontario shore of southern Lake Huron (zone 13, 7.9 μg/L P). There are, in fact, several significant inputs along the Ontario shore of southern Lake Huron. These include the towns of Grand Bend, Bayfield, Goderich, Port Albert and Kincardine as well as the Bayfield, Maitland and Ausable rivers. Although it is difficult to differentiate between the effects of the tributaries and municipal discharges, it is evident from Figures 13 and 14 that these inputs are having an adverse impact on the adjoining waters. The Upper Lakes Reference Group (1977) noted high phosphorus levels offshore of Goderich and the Maitland River and indicated that spring peak loadings of both phosphorus and nitrogen were four to five times greater than in 1966. In comparing 1980 results to the baseline condition established in 1971, it would appear that no improvement in water quality has occurred and, in fact, conditions may have deteriorated.

Water quality in the nearshore waters along the Michigan shoreline showed two principal areas of degradation: offshore of Lexington, Michigan, and waters influenced by outflow from Saginaw Bay. In fact, the single highest total phosphorus concentration of the 1980 survey, 13.2 μg/L P, was reported at the station immediately offshore of Lexington. Substantial improvement since 1971 of water quality in the vicinity of Saginaw Bay was evident. In 1971, values in excess of 10 μg/L P were common offshore and south of Saginaw Bay, whereas in 1980 the highest value noted was 9.6 μg/L P and only at station 94 during the first cruise. Another area showing notable improvement in 1980 was Thunder Bay, Lake Huron, receiving inputs from Alpena, Michigan, and the Thunder Bay River, with a maximum observed value of 7.2 μg/L P in 1980 as compared with 10.4 μg/L P in 1971.

As would be anticipated from the distribution of conductivity, TP concentrations in the North Channel were reflective of three different water masses. Zone 18, receiving substantial inflow from Lake Huron through False Detour Channel and Mississagi Strait, exhibited nutrient levels characteristic of Lake Huron with an area-weighted average concentration of 5.0 μg/L P during the study period compared with 4.8 μg/L P in zone 1 of Lake Huron. The slightly higher levels reported in zone 18 were likely due to inputs from the Serpent and Spanish rivers (Fig. 14), the only principal tributaries to the North Channel other than the St. Marys River. Zone 19, despite receiving some inflow from zone 1 of Georgian Bay where TP concentrations averaged 4.3 μg/L P from April to November, had markedly higher levels at 5.3 μg/L P, indicating that minor local sources were present. Most distinctive were the consistently high values of TP reported in zone 17, owing to inputs from the St. Marys River. The average area-weighted TP concentration during the study period was 6.4 μg/L P, the highest zonal average reported in the entire Lake Huron–Georgian Bay system. Considering an average monthly flow of approximately 2200 m^3/s from the St. Marys River in 1980 (P. Yee, personal communication), this represents a substantial loading of phosphorus to Lake Huron, presumably owing to inputs from Sault Ste. Marie, Ontario, and Sault Ste. Marie, Michigan.

The highest average concentration from April to November in Georgian Bay was in zone 9 at 4.9 μg/L P (area-weighted mean). While this value is only marginally higher than the 4.8 μg/L P average concentration of zone 1 in Lake Huron, it represents a 22% increase over the open water zone (zone 10) of Georgian Bay. As is apparent in Figures 15 and 16, these elevated values derived from inputs from the French River, the principal tributary to Georgian Bay. During the first two cruises, high values offshore of the French River (15.3 and 9.4 μg/L P, respectively) were related to its flow regime during spring thaw. Two weeks prior to the April cruise (8022501), a sudden thaw increased the flow from 120 m^3/s to 460 m^3/s within seven days (Environment Canada, 1981). This decreased slightly to 380 m^3/s during the first two cruises in April and May. By June (cruise 8022503), the flow had decreased by more than half to 170 m^3/s, with values offshore consequently declining to 6.8 μg/L P. By July (cruise 8022506), an average flow of 80 m^3/s was attained and no impact of river discharge was apparent in the bay.

Zone 8 also demonstrated elevated TP concentrations relative to zone 10, particularly during the May cruise (8022502) (Fig. 16). This shallow area is characterized by myriad bays and inlets and is likely subject to considerable sediment resuspension as well as domestic waste inputs from a thriving cottage industry. Zone 7, receiving inputs from Penetanguishene, Midland, Meaford and the Severn River, also exhibited levels which, during the study period, averaged 14% higher than zone 10 levels. Waters adjacent to Collingwood (zone 5), identified as sites of local enrichment by the Upper Lakes Reference Group (1977), had average TP concentrations only slightly (7%) higher than offshore levels despite being the location of the two largest municipal treatment plants discharging to Georgian Bay

(IJC, 1979). This represents a slight improvement over conditions in 1974 (ULRG, 1977; Warry, 1978b).

Total filtered phosphorus (TFP) comprised approximately 50% of total phosphorus at an area-weighted mean value of 2.4 μg/L P in Lake Huron and the North Channel and 2.1 μg/L P in Georgian Bay averaged over the six cruises. There was no strong linear relationship between TP and TFP during any cruise in Lake Huron and Georgian Bay. Furthermore, TFP concentrations showed considerably less variability than TP concentrations, indicating that the two parameters were not controlled by similar environmental mechanisms. Besides showing little spatial variation, TFP concentrations showed little seasonal variation. There was no appreciable summer depletion that could be associated with phytoplankton uptake. This contrasts with the 1974 results of Warry (1978b) for Georgian Bay, who reported at least a 50% decrease in TFP concentrations from April to May.

Unlike total filtered phosphorus, total particulate phosphorus (calculated as TP-TFP) was highly correlated with TP ($r > 0.90$) during all cruises in Lake Huron, the North Channel and Georgian Bay, indicating a strong association between the two parameters. Lakewide, TPP concentrations averaged approximately 50% of TP concentrations. Zones showing the largest variation in TPP:TP ratios (0.25 to 0.67) were the nearshore zones and, in particular, the zones in southern Lake Huron, areas most subject to sediment resuspension, tributary inputs and phytoplankton development. Maximum TPP:TP ratios were observed in the spring, whereas minimum ratios were found in the summer. The causes of the ratios were a decline in tributary inputs resulting in decreased particulate loadings, a decline in phytoplankton growth resulting in reduced assimilation, and settling of particulate matter into the hypolimnion.

A similar pattern was observed in Georgian Bay with a spring maximum ratio of 0.70 for zone 8 and summer minimum of 0.29 for zone 2. The rapid increase in the average TPP:TP ratio observed from April to May in 1974 (from approximately 0.27 to 0.55), and attributed to rapid phytoplankton uptake (Warry, 1978b), was not observed in 1980.

In both Lake Huron and Georgian Bay, the TPP:TP ratio, when regressed against TP, demonstrated an increasing correlation and slope that were maximal during the July cruises (8022506 and 8022207) and declined thereafter. This indicated that during the summer period, the TPP:TP ratio was proportional to TP concentrations (i.e., at higher TP levels, TPP was proportionately higher). Examination of the data revealed that two dominant processes were responsible for phosphorus distributions during these cruises. Those stations exhibiting higher TP concentrations during the July cruise in general showed little depletion since the spring cruises and, in many instances, actually showed an increase. These were the areas most subject to anthropogenic and tributary inputs and, consequently, received relatively high particulate loadings. The lower TP values appeared to be due primarily to phytoplankton assimilation, with subsequent losses caused by settling of particulate matter. Those areas exhibiting the lowest TP concentrations were likely subject to more intensive depletion. During the other cruises, any relationship was masked by other processes such as sediment resuspension and deep vertical mixing of the water column in the absence of a thermocline.

Soluble reactive phosphorus (SRP) constituted approximately 30% of the TFP and 15% of the TP at area-weighted mean values of 0.9 μg/L P in Lake Huron and 0.7 μg/L P in Georgian Bay during the spring. Maximum values of 1.1 μg/L P (area-weighted mean) in Lake Huron were reported in zones 2 and 10, presumably a remnant of winter circulation and low phytoplankton abundance. High concentrations observed during the April cruise (8022201) in the North Channel (1.1 μg/L P) were caused by inputs from the St. Marys River, and in zone 12 in May (cruise 8022202) (1.0 μg/L P), by elevated levels offshore of Lexington, Michigan.

During July, when chlorophyll *a* concentrations (i.e. phytoplankton standing crop) were at a minimum, implying nutrient limitation, minimum levels of SRP were reported for both Lake Huron (0.5 μg/L P) and Georgian Bay (0.4 μg/L P). The open lake zones of Lake Huron (zones 1 and 2) and Georgian Bay (zone 10), least subject to nearshore influences, showed depletions relative to spring maximums of 50% and 57%, respectively. Although enrichment studies demonstrated that summer phytoplankton populations are limited by phosphorus availability (Schelske *et al*., 1974), SRP concentrations never decreased to less than 0.2 μg/L P. This is indicative of the oligotrophic state of Lake Huron and Georgian Bay, as more eutrophic systems, such as Lake Ontario, have summer minimums below detectable (0.1 μg/L P) levels (M. Neilson, personal communication).

With the onset of fall turnover and the resulting entrainment of hypolimnetic waters, surface SRP values increased again to an area-weighted mean value of 0.7 μg/L P in both Lake Huron and Georgian Bay. The resulting SRP:TFP and SRP:TP ratios were, respectively, 27% and 18% for Lake Huron and 34% and 18% for Georgian Bay, similar to spring conditions.

Nitrogen

The principal sources of nitrogen to a lake are atmospheric loading, nitrogen fixation, and inputs from surface and groundwater drainage. Balancing these inputs are losses from effluent outflow, bacterial denitrification and sedimentation. Atmospheric loading contributes substantially more nitrogen (37%) to the total load of Lake Huron than it does phosphorus (14%) (ULRG, 1977). Since this source is essentially uncontrollable, and since phytoplankton growth is limited by phosphorus availability, no control measures for nitrogen inputs exist.

Of the numerous forms of nitrogen occurring in fresh water, four were measured: nitrate + nitrite, ammonia, total Kjeldahl nitrogen (TKN) and total particulate nitrogen (TPN). Nitrogen as (NO_3+NO_2) and NH_3 is readily available for assimilation by photoplankton. Total Kjeldahl nitrogen (excluding NH_3) is a measure of the total organic nitrogen, both particulate and dissolved, including products of biological processes such as amino acids, polypeptides and proteins. Total particulate nitrogen was collected as a biomass indicator and therefore will be discussed under the heading Phytoplankton Indicators.

Area-weighted mean values of (NO_3+NO_2), NH_3 and TKN, respectively, for Lake Huron, North Channel and Georgian Bay are given in Tables 9, 10 and 11. Nitrate + nitrite concentrations, averaged over the six cruises, were greater in Lake Huron (274 μg/L N) and the North Channel (271 μg/L N) than in Georgian Bay (253 μg/L N). The highest area-weighted values (greater than 300 μg/L N) reported for 1980 were in the nearshore zones of southern Lake Huron, specifically zones 11, 12, 13 and 14, between April and June. The shoreline of southern Lake Huron is composed mainly of sedimentary rock, which is high in inorganic nitrogen (Sly and Thomas, 1974). Weathering of this material, therefore, would contribute to the elevated levels of (NO_3+NO_2) in these southern waters. In addition, it is apparent from the areal distribution maps in Figures 17 and 18 that these elevated levels were associated with spring snowmelt from tributaries. For example, concentrations

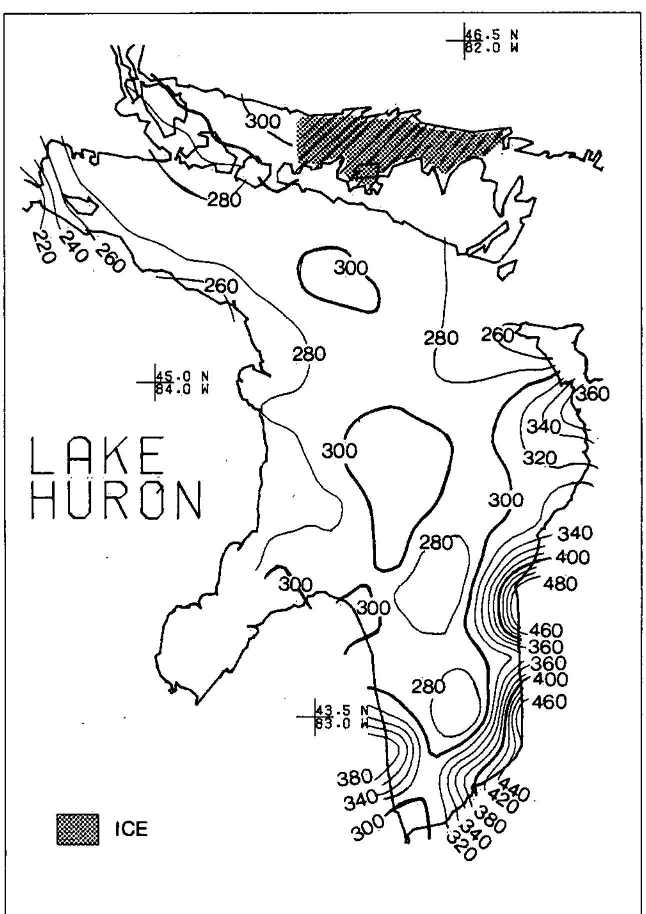


Figure 17. Isopleths of nitrate + nitrite (μg/L N) at 1 m, cruise 8022201.

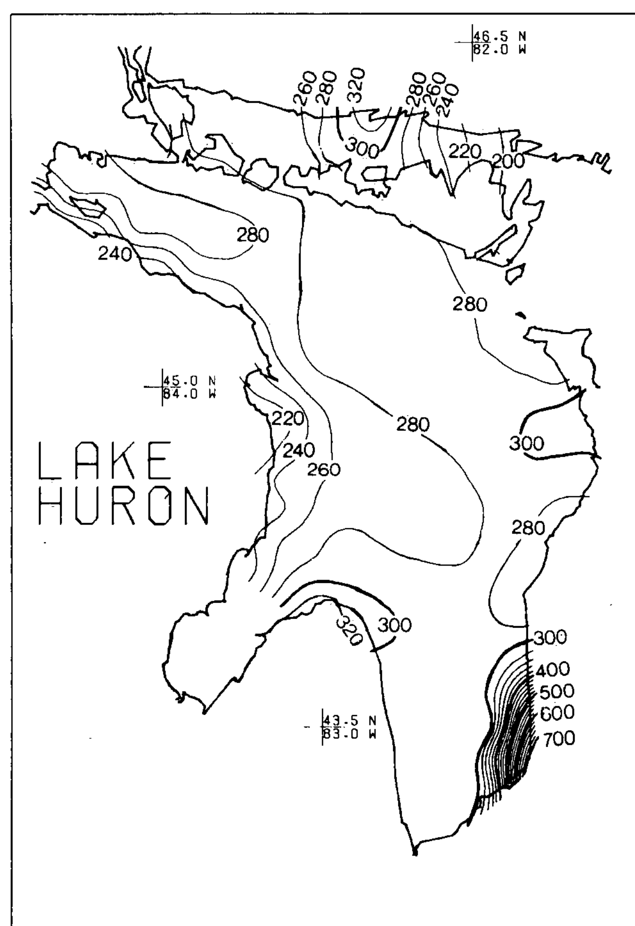


Figure 18. Isopleths of nitrate + nitrite (μg/L N) at 1 m, cruise 8022202.

TABLE 9. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON PARAMETER: NITRATE + NITRITE (MG/L) (FILTERED)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	.2883	.2828	.2956	.2524	.2396	.2902
2	.2970	.2751	.2943	.2612	.2359	2732
4	.2939	.2872	.3079	.2716	.2405	.2538
5	.2810	.2779	.2671	.2139	.2321	.2871
6	.2648	.2413	.2463	.1949	.2246	.2366
7	.2766	.2607	.2785	.2367	.2127	.2775
8	.2769	.2423	.2619	.2173	.2100	.2358
10	.2910	.2865	.2929	.2478	.2234	.2591
11	.3035	.2957	.2904	.2532	.2299	.2379
12	.3382	.3031	.4161	.2970	.2348	.2501
13	.4168	.4377	.3576	.2845	.2425	.2780
14	.3226	.2828	.2812	.2493	.2470	.2614
15	.2568	.2734	.2807	.2531	.2534	.2714
16	.2887	.2815	.2821	.2481	.2524	.2973
25	.2975	.2845	.2965	.2541	.2363	.2719

1980 NORTH CHANNEL PARAMETER: NITRATE + NITRITE (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	.2940	.2886	.2677	.2352	.2693	.2894
18	.3012	.2894	.2857	.2518	.2554	.2811
19	ICE	.2295	.2124	.2256	.2124	.2350
25	.2976	.2815	.2710	.2435	.2542	.2770

1980 GEORGIAN BAY PARAMETER: NITRATE + NITRITE (MG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	.2353	.2375	.2103	.1748	.2068	.2433
2	.2528	.2825	.2538	.2163	.2360	.2801
3	.2668	.2823	.2697	.2449	.2410	.2777
4	.2811	.2824	.2773	.2423	.2413	.2719
5	.2747	.2820	.2722	.2470	.2362	.2661
6	.2807	.2833	.2644	.2409	.2319	.2596
7	.2728	.2541	.2363	.2224	.2178	.2438
8	.2709	.2619	.2502	.2067	.2261	.2544
9	.2519	.2452	.2257	.2175	.2313	.2730
10	.2769	.2781	.2688	.2381	.2307	.2690
25	.2699	.2702	.2568	.2273	.2296	.2643

TABLE 10. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON PARAMETER: FILTERED AMMONIA (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	.0017	.0019	.0016	.0011	.0015	.0015
2	.0025	.0015	.0024	.0028	.0012	.0025
4	.0024	.0014	.0022	.0038	.0028	.0049
5	.0026	.0018	.0016	.0028	.0012	.0010
6	.0017	.0014	.0017	.0010	.0010	.0010
7	.0013	.0020	.0018	.0010	.0013	.0020
8	.0014	.0014	.0032	.0040	.0012	.0030
10	.0025	.0013	.0033	.0030	.0015	.0040
11	.0037	.0017	.0024	.0050	.0025	.0040
12	.0047	.0012	.0039	.0070	.0053	.0060
13	.0019	.0021	.0019	.0060	.0021	.0052
14	.0016	.0016	.0032	.0040	.0012	.0041
15	.0024	.0020	.0010	.0020	.0010	.0025
16	.0017	.0013	.0015	.0010	.0017	.0013
25	.0023	.0016	.0022	.0030	.0017	.0027

1980 NORTH CHANNEL PARAMETER: FILTERED AMMONIA (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	.0140	.0068	.0035	.0034	.0022	.0026
18	.0021	.0075	.0068	.0035	.0010	.0026
19	ICE	.0017	.0017	.0047	.0023	.0036
25	.0081	.0065	.0052	.0036	.0015	.0027

1980 GEORGIAN BAY PARAMETER: FILTERED AMMONIA (MG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	.0026	.0019	.0020	.0035	.0010	.0022
2	.0020	.0019	.0002	.0021	.0010	.0010
3	.0022	.0020	.0010	.0032	.0010	.0010
4	.0024	.0017	.0010	.0018	.0010	.0010
5	.0025	.0024	.0010	.0016	.0010	.0020
6	.0024	.0014	.0010	.0029	.0010	.0020
7	.0023	.0020	.0020	.0026	.0012	.0040
8	.0026	.0024	.0010	.0031	.0010	.0010
9	.0073	.0028	.0010	.0029	.0010	.0010
10	.0021	.0017	.0010	.0022	.0010	.0020
25	.0027	.0020	.0010	.0026	.0010	.0020

TABLE 11. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON PARAMETER: TOTAL KJELDAHL NITROGEN (MG/L) (UNFILTERED)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	.1802	.1440	.0978	.1468	.1777	.1553
2	.1712	.1553	.1092	.1633	.1839	.1671
4	.1789	.1483	.1272	.1625	.1995	.1799
5	.1942	.1395	.1003	.1124	.1706	.1516
6	.2035	.1213	.1232	.1147	.1500	.1820
7	.1918	.1418	.0965	.1136	.1524	.1507
8	.1618	.2269	.1235	.1697	.2309	.2052
10	.1890	.2072	.1124	.1639	.1680	.2076
11	.1920	.1797	.1356	.1642	.1883	.2345
12	.1702	.1660	.1676	.1988	.1734	.2667
13	.1678	.1890	.1240	.1806	.1820	.1857
14	.1619	.1939	.1124	.1673	.1677	.1586
15	.2173	.1172	.1172	.1551	.1643	.1395
16	.1748	.1595	.0932	.1398	.1990	.1319
25	.1781	.1585	.1116	.1556	.1825	.1719

1980 NORTH CHANNEL PARAMETER: TOTAL KJELDAHL NITROGEN (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	.2100	.1500	.0990	.1512	.1560	.1362
18	.1730	.1570	.1260	.1505	.1800	.1738
19	ICE	.1200	.1470	.1367	.1909	.1482
25	.1915	.1500	.1200	.1490	.1741	.1592

1980 GEORGIAN BAY PARAMETER: TOTAL KJELDAHL NITROGEN (MG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	.1589	.1238	.1388	.1350	.1839	.1744
2	.1399	.1403	.1136	.1547	.1687	.1275
3	.2340	.1080	.1054	.1752	.1836	.1474
4	.2269	.1538	.1476	.1358	.1624	.1604
5	.1561	.1381	.1419	.1318	.1663	.2091
6	.2004	.1345	.1197	.1326	.1478	.2355
7	.1767	.2049	.1543	.1631	.1844	.1669
8	.1770	.1656	.1535	.1672	.1605	.1542
9	.1908	.1464	.1439	.1392	.1734	.1549
10	.1755	.1455	.1290	.1432	.1661	.1603
25	.1830	.1458	.1344	.1480	.1676	.1674

offshore of the Ausable River were consistently high in the spring, reaching a maximum of 765 $\mu g/L$ N at station 3 by the June cruise.

Consistently lower values of (NO_3+NO_2) were observed in zones 6, 7 and 8 of Lake Huron. While inputs into these zones from Lake Michigan, Little Black River and Thunder Bay River were relatively reduced in nitrate content, thereby contributing to the low observed values, phytoplanktonic assimilation of dissolved inorganic nitrogen was undoubtedly a contributing factor, attested to by the elevated chlorophyll concentrations observed in these areas throughout the study period (Tables 13 and 14).

The high levels of nitrate observed in Lake Huron have been attributed to inputs from Lake Superior (Lin and Schelske, 1981; Schelske and Roth, 1973). Although such inputs are likely to be a contributing factor to ambient concentrations, it is unlikely, considering the complexity of the nitrogen cycle and the numerous other sources in the lake, that they are the predominant cause. In fact, if ambient concentrations were merely a result of partitioning between Lake Michigan and Lake Superior inputs, then levels in zone 1 of Lake Huron should be approximately 60 $\mu g/L$ N lower.

The distribution of nitrate + nitrite in the North Channel was similar to that reported by Warry (1978a), with a concentration gradient from high to low moving from west to east. The elevated concentrations observed in the west were a result of inputs from the St. Marys River. However, the maximum station concentration observed in zone 17 was only 307 $\mu g/L$ N, considerably less than values reported in southern Lake Huron. Substantial input of (NO_3+NO_2) to the North Channel was also contributed by the Serpent River, where a maximum concentration of 345 $\mu g/L$ N was observed at station 79 in June. Concentrations of (NO_3+NO_2) in zone 19 were considerably less than zones 17 and 18 as a result of influx of waters low in nitrate from Georgian Bay.

Nitrate + nitrite levels averaged approximately 7% less in Georgian Bay than in Lake Huron during the study period. Unlike Lake Huron, large point source inputs of (NO_3+NO_2) are lacking in Georgian Bay. There was, however, a distinct southwest to northeast gradient in concentration apparent during all cruises. The higher values in the southwest, in particular zones 3, 4, 5 and 6, were a result of drainage through the sedimentary rock of this shoreline, as well as water mass exchange with Lake Huron. Low values observed along the north and east coasts reflected the low nitrogen content of drainage through the shield rock of this coast and were particularly apparent offshore from the French River.

Ammonia levels were low throughout most of the Lake Huron-Georgian Bay system, ranging from 1 to 7 $\mu g/L$ N (area-weighted zone surface values). Unlike other nutrients, ammonia levels in the epilimnion reached their maximum in the summer in most zones. This was particularly evident in the more productive zones in southern Lake Huron, where levels increased up to 7 $\mu g/L$ N. Several processes are responsible for this increase, but it is difficult to differentiate between their relative impacts. During July (cruises 8022207 and 8022506), phytoplankton development, indicated by chlorophyll *a* levels, was at a minimum. This decline, accompanied by an increase in the detrital fraction, probably resulted in increased heterotrophic decomposition in the relatively shallow (5 m), warmer epilimnion. In addition, tributary inputs are at a minimum during this period (Environment Canada, 1981), and as such, industrial and, particularly, municipal discharges have a considerably greater impact on the shallow, epilimnetic waters.

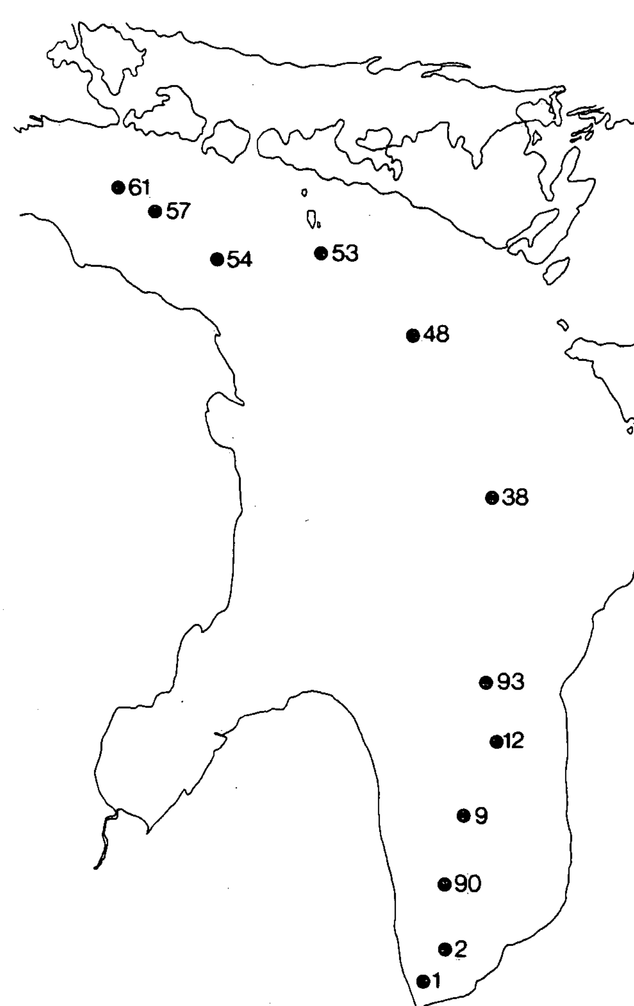


Figure 19. Midlake transect selected for determination of vertical temperature structure.

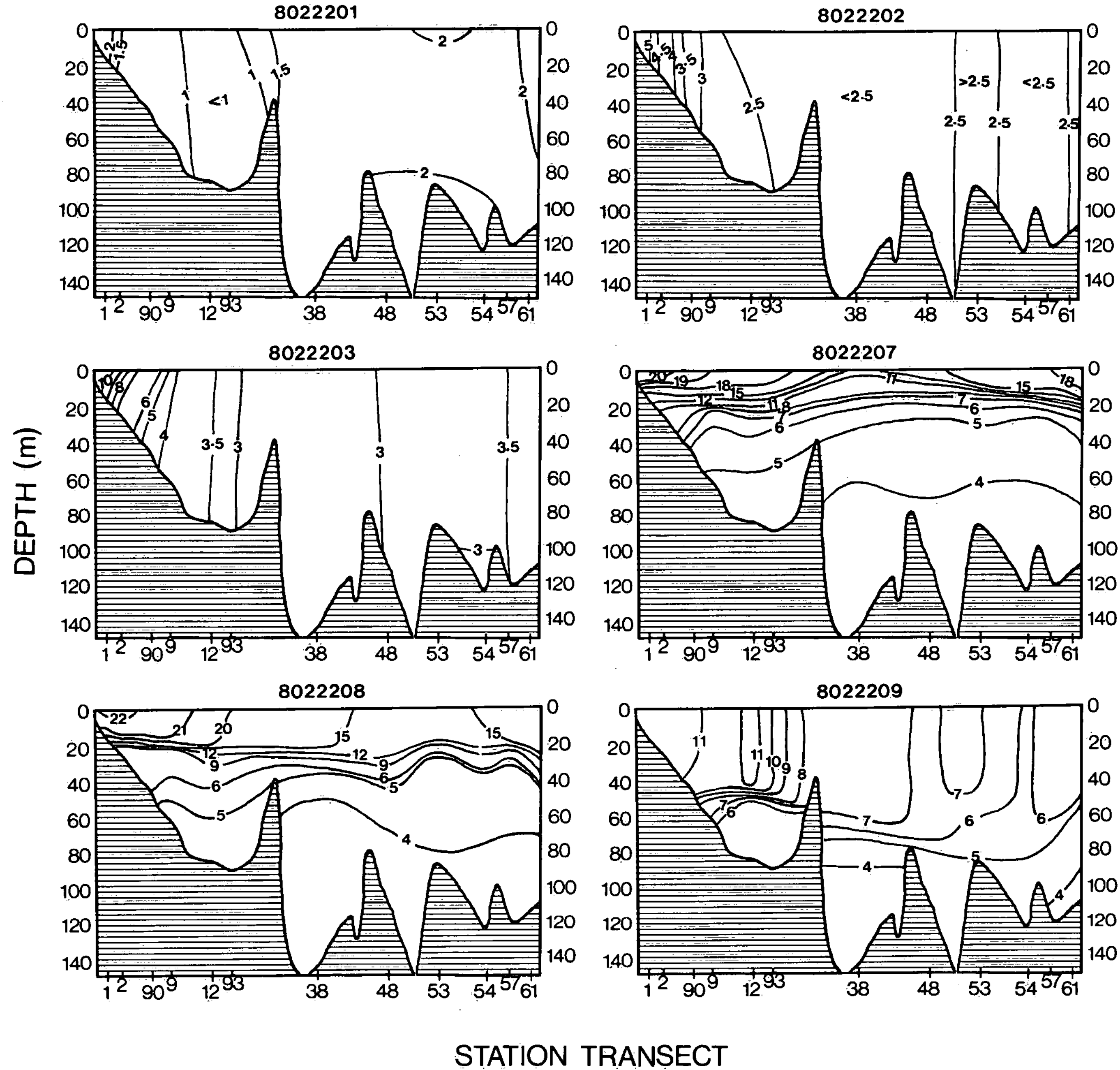


Figure 20. Cross-sectional temperature profile of Lake Huron.

The highest ammonia concentrations were observed in zone 17 of the North Channel, where a maximum area-weighted value of 14 µg/L N was reached during the first cruise. These elevated levels could be attributed to industrial discharge from Algoma Steel Corporation and municipal discharge from both sewage treatment plants in Sault Ste. Marie, Ontario, and Sault Ste. Marie, Michigan. Considerable improvement in ammonia levels, relative to those reported in 1974 (Warry, 1978b), has been noted in the North Channel. According to Warry (1978b), an average concentration of 13.0 µg/L N was observed in zone 17 from May to October 1974. During a similar period in 1980, concentrations averaged 3.7 µg/L N, representing a 72% decrease.

Total Kjeldahl nitrogen is made up of dissolved organic nitrogen (DON), particulate organic nitrogen (PON) and ammonia and consequently can be related to both incidences of organic pollution and the dynamics of the plankton biomass. In most instances, ammonia contributed less than 2% to TKN, except in the vicinity of the St. Marys River, where it contributed up to 18%, again highlighting the degree of contamination in the river. Correcting for ammonia gives total organic nitrogen (TON) of which, for average lake conditions, DON usually constitutes approximately 80% (Wetzel, 1975). The ratio of DON to PON was investigated in this study by subtracting total particulate nitrogen (TPN) from TKN (corrected for ammonia). This can only be considered an approximation, as TPN samples were collected using a 20-m integrating sampler, while TKN samples were collected using a discrete sampler.

Lake Huron results were consistent with the average conditions reported by Wetzel (1975), with DON constituting, on the average, 79% to 82% of TON during all but the June cruise. During this particular cruise, the DON fraction decreased to 69% of TON. The relatively small ratio of PON to DON is indicative of oligotrophic conditions (Wetzel, 1975). Several stations did show values characteristic of eutrophic conditions, with PON to DON ratios approaching 1:1, specifically those stations in zones 6, 8, 11, 12 and 13.

Results were similar in Georgian Bay, with DON contributing 79% to 86% of TON during all cruises. Again, several stations showed values indicative of more eutrophic conditions, although not as severe as in Lake Huron. Stations indicative of the most eutrophic conditions were usually in the shallowest nearshore zones, specifically 1, 7, 8 and 9.

While the ratio of particulate organic nitrogen to dissolved organic nitrogen gives a general index of trophic status, absolute concentrations of TKN are useful in identifying areas receiving excessive organic pollution. Total Kjeldahl nitrogen concentrations exhibited a consistent seasonal trend, with maxima in the early spring and fall and a distinct minimum in late spring. In most instances, zones reporting the largest PON:DON ratios exhibited the highest TKN values, with surface station values being more than twice the lake-wide area-weighted mean values. Specific areas in Lake Huron and the North Channel reporting high TKN values were stations directly offshore of Grand Bend, Goderich, Bayfield and Southampton in Ontario, and Lexington, Harbour Beach/Saginaw Bay and Alpena in Michigan, as well as in the vicinity of the Straits of Mackinac, the St. Marys River and the Serpent and Spanish rivers. In Georgian Bay, stations reporting elevated TKN values were at the Lake Huron/Georgian Bay interface, offshore of the French River, the southwest portion of Nottawasaga Bay and in the area of Penetanguishene and Midland. Most of these areas are proximate to the most developed regions of the basin and, as such, reflect increased municipal and industrial discharges.

Silica

Diatoms are the dominant phytoplankton taxa in Lake Huron (Munawar and Munawar, 1979), often accounting for more than 90% of the species (Lin and Schelske, 1981). This algal group is unique in its requirement for silica as a cell wall constituent (Happey, 1970a,b) and consequently can effect pronounced changes on the dissolved silica distribution in the trophogenic zone of Lake Huron and Georgian Bay.

Table 12 summarizes the area-weighted mean surface values of soluble reactive silica (SRS) for Lake Huron, the North Channel and Georgian Bay. Lake Superior, via the St. Marys River, was by far the principal source of soluble reactive silica at levels in excess of 2 mg/L SiO_2 throughout the study period. In contrast, SRS concentrations in the remaining surface waters of Lake Huron, while exhibiting large spatial and temporal variation, were generally less than 1.6 mg/L SiO_2. As discussed previously, SRS was the only nutrient, in the presence of the thermal bar, to be consistently and significantly depleted in the nearshore regions of Lake Huron. This depletion occurs in response to rapid phytoplankton growth in the warmer waters. By July, area-weighted mean surface levels of SRS in the open waters of the lake had decreased by 20%, from 1.5 mg/L SiO_2 to 1.2 mg/L SiO_2, but were still elevated relative to the nearshore. This nearshore-offshore gradient appeared largely as a result of the anticyclonic circulation pattern of the epilimnion, which maintains a separation of the two water masses.

Zone 12 in Lake Huron reported the lowest area-weighted mean surface value (0.671 mg/L SiO_2) of all the zones. However, the minimum single station values were found at stations 63 and 64, in the vicinity of the Straits of Mackinac, where concentrations at 1 m were 0.360 and 0.340 mg/L SiO_2. Levels of silica less than 0.5 mg/L are generally considered limiting to diatom growth (Wetzel, 1975). These low concentrations are due to inputs from Lake Michigan, where summer epilimnetic values fall within this range (Rockwell *et al.*, 1980).

The September (8022208) whole lake area-weighted surface silica values decreased 39% from the maximum levels observed in the spring, owing to both widespread horizontal mixing and an increase in phytoplankton standing crop associated with the onset of fall turnover. Continued inputs from Lake Superior and, in particular, entrainment of enriched hypolimnetic waters were responsible for the increasing levels observed during the next cruise (8022209).

As expected, the concentrations of SRS in the North Channel were considerably greater than in Lake

TABLE 12. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON PARAMETER: SOLUBLE REACTIVE SILICA (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	1.5254	1.5102	1.5194	1.1595	.8879	1.3431
2	1.5368	1.4724	1.4730	1.1973	.9097	1.2128
4	1.4956	1.4107	1.3841	1.0024	.9036	1.0841
5	1.6273	1.6335	1.7304	1.0164	1.1131	1.4896
6	1.5198	1.2186	1.4564	.7502	1.0245	1.3282
7	1.5566	1.4250	1.5639	1.1567	.7345	1.4239
8	1.4731	1.2847	1.1720	.9376	.7878	1.0158
10	1.4798	1.4856	1.2488	1.0602	.8810	1.1499
11	1.2935	1.1618	1.0318	.8938	.8805	1.0042
12	1.3989	1.2987	.9541	.6707	.8769	1.1380
13	1.4481	1.1091	.9085	.7902	1.0004	1.2039
14	1.4788	1.2596	1.1533	.9052	1.0016	1.1813
15	1.4229	1.3579	1.2977	.9272	.9744	1.2093
16	1.5281	1.5158	1.4351	1.1270	.9988	1.4688
25	1.5069	1.4301	1.3967	1.0705	.9170	1.2398

1980 NORTH CHANNEL PARAMETER: SOLUBLE REACTIVE SILICA (MG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	2.1210	2.0745	1.9625	1.7501	1.724	1.7402
18	1.8818	2.1241	2.0577	1.5801	1.4693	1.7428
19	ICE	1.7908	1.5389	1.4520	1.5606	1.9418
25	2.0014	2.0669	1.9632	1.6154	1.5580	1.7672

1980 GEORGIAN BAY PARAMETER: SOLUBLE REACTIVE SILICA (MG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	1.4059	1.2976	1.2038	1.0929	1.0287	1.4413
2	1.1889	1.2100	1.0901	.9632	.9541	1.3127
3	1.2295	1.2147	1.1282	.9187	.9280	1.2715
4	1.2365	1.1906	1.1508	.9545	.8942	1.1732
5	1.1877	1.1612	1.0781	.9715	.8558	1.0745
6	1.2104	1.1536	.9948	.8659	.8261	1.0531
7	1.1960	1.2893	1.1040	.7838	.8648	1.0483
8	1.1941	1.2046	1.0982	.7438	.8828	1.1197
9	1.5243	1.4854	1.3866	.8712	.9438	1.2753
10	1.2239	1.1902	1.1351	.9111	.8523	1.1584
25	1.2532	1.2271	1.1387	.8909	.8854	1.1765

Huron, owing to inputs from Lake Superior. A summer minimum of SRS was observed caused by phytoplankton utilization and water mass exchange with Lake Huron but was never less than 1.3 mg/L SiO_2.

Spring levels of SRS in Georgian Bay were 17% less than in Lake Huron and exhibited considerably less spatial variation. The only apparent inputs were from the North Channel (zone 1) and the French River (zone 9). Epilimnetic depletion of SRS, while evident, was not as pronounced as that observed for Lake Huron. Based on area-weighted surface (1 m) values, the largest summer decrease in Georgian Bay was observed in zone 9 (43%), reflecting both biological utilization and reduced summer discharge from the French River. Over the whole lake, however, the summer minimum represented only a 29% depletion.

The increasing concentrations of soluble reactive silica observed during the final cruise throughout Lake Huron and Georgian Bay were within 18% of spring levels, yet the water column was not entirely isochemical. These results corroborate those of other workers who report that most of the biogenic silica is recycled annually both in the hypolimnion and at the sediment-water interface (Conway *et al.*, 1977; Marmorino *et al.*, 1980).

Oxygen

Oxygen exhibited an orthograde distribution in Lake Huron and Georgian Bay indicative of oligotrophic lakes (Wetzel, 1975). Concentrations were high throughout the study period, ranging from 7.9 to 15.5 μg/L. In general, oxygen saturation levels were in excess of 90%. Samples that had lower saturation levels were, for the most part, confined to the (bottom -2 m) sampling depth during the stratified period.

The hypolimnetic oxygen deficit is related to phytoplankton productivity, suggesting that it can be used as an indication of lake trophic status (Hutchinson, 1957). Further, the linear development of this deficit indicates that, while hypolimnetic oxygen consumption may not be sensitive to brief changes in productivity, it does serve to integrate the total impact of allochthonous and autochthonous inputs from the epilimnion (Lasenby, 1975). Hutchinson (1957) originally considered that expression of the deficit on an areal basis (Areal Hypolimnetic Oxygen Deficit, AHOD) would largely eliminate morphometric effects. However, Charlton (1980) found both areal and volumetric expressions of the hypolimnetic oxygen deficit in the Great Lakes to be related to lake morphology by a dependence on hypolimnion thickness. He concluded that the AHOD depends upon mean hypolimnion thickness, temperature and productivity. Based on this, a predictive equation for AHOD was derived from available Great Lakes data that would permit interlake and interbasin comparisons:

$$\text{AHOD} = 4.09\left(\text{fChla}\,\frac{\bar{\bar{Z}}}{50+\bar{\bar{Z}}}\,2^{((\bar{\bar{T}}-4)/10)}\right) + 0.07$$

where $\bar{\bar{Z}}$ = mean hypolimnion thickness,
$\bar{\bar{T}}$ = mean hypolimnion temperature, and
Chla = chlorophyll *a* concentration.

$$\text{fChla} = \frac{1.15 \times \text{Chla}^{1.33}}{9 + 1.15\ \text{Chla}^{1.33}}$$

Both calculated and observed AHODs were determined on Lake Huron and Georgian Bay to evaluate the effects of productivity.

Prior to deriving the AHOD for Lake Huron, it was necessary to investigate the influence of the major basins on hypolimnetic development. For this purpose, a mid-lake transect (Fig. 19) was selected and the vertical temperature distribution at these stations was plotted for each cruise. Figure 20 shows the temperature isobars during the first three cruises to be mostly vertical, indicating nonstratified conditions. However, by the fourth cruise (July), thermal stratification was established and an apparent separation of the hypolimnion into basins occurred. This phenomenon continued throughout the two subsequent cruises, dividing the hypolimnion into at least three relatively distinct basins.

Derivation of the AHOD for each of the three basins (arbitrarily named the northern, central and southern basins) was based on a representative station within each basin for which detailed oxygen measurements were available. Georgian Bay was treated as one single basin. The observed and calculated AHODs ($g/m^2 \cdot d$) for these three basins and Georgian Bay are presented below:

	Lake Huron basins			
	South	Central	North	Georgian Bay
Observed	0.38	0.27	0.35	0.22
Calculated	0.36	0.34	0.51	0.27

Using Charlton's formula, the calculated AHOD values for the southern and central basin were similar, as would be expected, since these regions reported similar seasonal phytoplankton biomass levels (1.75 and 1.74 μg/L chlorophyll *a*, respectively). The calculated values were also similar to the observed values. In contrast, the calculated

AHOD (0.51 $g/m^2 \cdot d$) for the northern basin was much higher than the observed value (0.35 $g/m^2 \cdot d$). This shift to a more eutrophic value is unexpected, as this area exhibited even lower chlorophyll concentrations (1.59 $\mu g/L$) than the other two regions. It is possible that the proposed formula does not sufficiently compensate for the large hypolimnion thickness of the northern basin which, at 62 m, is roughly three times greater than that of the other basins. The calculated AHOD for Georgian Bay was the lowest at 0.27 $g/m^2 \cdot d$, in accordance with the chlorophyll results which, at 1.23 $\mu g/L$, were the lowest of all the basins.

There are two widely accepted scales which utilize AHOD as a measure of trophic status, i.e., those of Hutchinson (1967) and Mortimer (1941). According to Hutchinson, 0.17 $g/m^2 \cdot d$ is the upper limit of oligotrophy, and 0.33 $g/m^2 \cdot d$ is the lower limit of eutrophy. Mortimer offered a slightly different scale with 0.25 $g/m^2 \cdot d$ as the upper limit of oligotrophy and 0.55 $g/m^2 \cdot d$ as the lower limit of eutrophy. Based on these two scales, it would appear that Lake Huron is mesotrophic to mesotrophic/eutrophic, while Georgian Bay is in the oligotrophic/mesotrophic range.

Phytoplankton Indicators

Ultimately, the management of water quality requires an ability to evaluate phytoplankton biomass in relation to nutrient concentrations. Three indicators of phytoplankton biomass were included as part of the 1980 Lake Huron surveillance program: chlorophyll *a*, corrected and uncorrected, particulate organic carbon (POC) and total particulate nitrogen (TPN). The area-weighted mean values for uncorrected and corrected chlorophyll *a*, summarized by zone, are presented in Tables 13 and 14, respectively. Chlorophyll *a* (uncorrected) measures both phytoplankton and detrital chlorophyll *a*. Correcting for phaeopigment removes much of this detrital component, thereby providing an estimate of phytoplankton standing crop. Interpretation of corrected chlorophyll *a* concentrations is complicated by fluctuations in cellular chlorophyll content, owing to different species composition with differing growth rates, as well as nutritional state and seasonal differences in cellular chlorophyll content within a species (Lin and Schelske, 1981; Hunter and Laws, 1981). Both POC and TPN provide estimates of total seston, including phytoplankton, zooplankton, bacteria and detritus. Consequently, high percentages of non-living material can be included in their measurements. Evaluating phytoplankton biomass therefore becomes a question of assessing the interrelationships of these parameters.

The seasonal cycles of chlorophyll *a*, POC and TPN in the North Channel and most nearshore zones of Lake Huron and Georgian Bay were bimodal, with maxima occurring in spring and fall. The open lake zones of Lake Huron (zones 1 and 2) and Georgian Bay (zone 10), however, exhibited a unimodal distribution with a maximum in late spring or summer.

The timing and magnitude of the maxima and minima of the biomass indicators may be attributed to a combination of factors including light, temperature, nutrient availability and physical regime (e.g. turbulence) (Happey, 1970a,b; Tilzer and Goldman, 1978). Spring blooms of diatoms, as found in Lake Huron (Munawar and Munawar, 1979; Lin and Schelske, 1981), are common in oligotrophic dimictic lakes and usually occur immediately upon cessation of spring turnover, when nutrient availability is high and vertical mixing is reduced (Wetzel, 1975; Happey, 1970a,b). Due to differences in the rate of seasonal development, a pronounced nearshore-offshore gradient was observed in both Georgian Bay and, in particular, Lake Huron during the first three cruises (Figs. 24 to 27).

The magnitude of this gradient between the nearshore and offshore areas in Lake Huron was investigated in the presence of the thermal bar, using the same technique as that applied to the nutrient data except that data were log-transformed to produce a normal distribution. Results of this analysis demonstrated that chlorophyll *a* concentrations, both corrected and uncorrected, were significantly greater ($p < 0.05$) in the nearshore during the first and second spring cruises, but by June (cruise 8022203), offshore chlorophyll levels had increased to the extent that there was no significant difference across the thermal bar. In contrast, POC and TPN concentrations in the nearshore were significantly greater than offshore during the first and third cruises, but not during the second. The lack of a significant difference during the second cruise was due to decreasing levels in the nearshore, coupled with greater variability in the offshore samples, thereby reducing the ability to detect a real difference.

The lack of agreement between the chlorophyll results and those of POC and TPN occurred because the relationship between the three parameters, as exemplified in Figure 21, was not consistent during the study period. Correlation analysis of POC and TPN revealed a significant ($p < 0.01$) relationship between the two parameters throughout the year, indicating a relatively constant carbon to nitrogen ratio in the total particulate fraction. Neither parameter, however, showed a consistent relationship with chlorophyll *a*. The highest correlations ($r > 0.7$) were observed during the first and last cruises, when nutrient availability was high and the temperature structure was isothermal. This coincides with the period when deep mixing populations are both of larger species types and

TABLE 13. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON

PARAMETER: CHLOROPHYLL A UNCORRECTED (μG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	1.64	1.62	2.13	1.61	1.42	1.29
2	1.78	1.80	2.28	1.44	1.38	1.39
4	2.07	2.29	2.40	1.00	1.60	1.57
5	2.18	1.62	2.20	1.38	1.66	1.55
6	2.35	2.11	2.35	.93	1.76	2.24
7	1.99	1.75	2.32	1.09	1.72	1.69
8	1.82	2.09	2.07	1.45	2.06	2.52
10	1.86	2.08	2.12	2.08	1.29	1.78
11	3.27	2.57	2.32	1.58	1.69	3.01
12	2.60	4.25	2.18	.73	1.42	1.86
13	2.86	3.78	3.23	.68	1.64	2.13
14	2.27	2.30	2.57	.93	1.42	1.47
15	1.55	1.77	2.22	.83	1.20	1.40
16	1.98	1.67	2.08	1.37	1.49	1.29
25	1.97	2.02	2.27	1.36	1.49	1.58

1980 NORTH CHANNEL

PARAMETER: CHLOROPHYLL A UNCORRECTED (μG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	1.82	1.88	2.34	1.90	1.54	2.21
18	1.31	1.58	2.10	1.22	1.37	1.82
19	ICE	1.89	2.29	1.12	1.73	2.06
25	1.57	1.71	2.20	1.41	1.47	1.97

1980 GEORGIAN BAY

PARAMETER: CHLOROPHYLL A UNCORRECTED (μG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	1.26	1.79	2.03	1.15	1.47	1.52
2	1.19	.98	1.11	.85	1.31	.80
3	1.15	1.09	1.17	.93	1.21	1.09
4	.94	1.03	1.25	.93	1.15	1.27
5	.90	1.02	1.28	1.14	1.21	1.24
6	1.11	1.23	1.59	.80	1.36	1.13
7	1.28	1.88	2.08	.93	1.74	1.85
8	1.45	1.53	1.73	1.27	1.34	1.53
9	1.46	1.65	1.94	1.20	1.40	1.32
10	1.20	1.18	1.32	.99	1.24	1.23
25	1.23	1.33	1.52	1.04	1.31	1.31

TABLE 14. AREA-WEIGHTED MEAN VALUES (1m) SUMMARIZED BY ZONE

1980 LAKE HURON PARAMETER: CHLOROPHYLL A CORRECTED (μG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
1	1.27	1.55	2.02	1.59	1.31	1.16
2	1.57	1.74	2.15	1.38	1.35	1.24
4	1.88	2.11	2.24	.98	1.63	1.36
5	1.57	1.50	2.13	1.39	1.52	1.41
6	1.96	1.92	2.22	.84	1.59	2.04
7	1.58	1.64	2.28	1.03	1.64	1.57
8	1.76	1.98	1.99	1.40	2.00	2.22
10	1.75	2.00	2.04	1.92	1.30	1.63
11	3.06	2.41	2.17	1.53	1.67	2.58
12	2.35	3.77	2.00	.95	1.41	1.59
13	2.67	3.56	2.91	.72	1.66	1.87
14	2.01	2.11	2.47	.93	1.39	1.31
15	1.41	1.77	2.17	.81	1.12	1.19
16	1.31	1.55	1.96	1.35	1.39	1.11
25	1.69	1.90	2.15	1.33	1.43	1.41

1980 NORTH CHANNEL PARAMETER: CHLOROPHYLL A CORRECTED (μG/L)
DEPTH: 1.0

CRUISE	8022201	8022202	8022203	8022207	8022208	8022209
CRUISE DATES	80/04/13. TO 80/04/23.	80/05/09. TO 80/05/17.	80/05/27. TO 80/06/05.	80/07/18. TO 80/07/27.	80/09/08. TO 80/09/24.	80/10/22. TO 80/11/01.
17	1.40	1.82	2.26	1.81	1.43	1.96
18	1.15	1.50	2.02	1.22	1.30	1.68
19	ICE	1.90	2.36	1.00	1.64	2.00
25	1.28	1.65	2.13	1.37	1.38	1.81

1980 GEORGIAN BAY PARAMETER: CHLOROPHYLL A CORRECTED (μG/L)
DEPTH: 1.0

CRUISE	8022501	8022502	8022503	8022506	8022507	8022508
CRUISE DATES	80/04/24. TO 80/04/27.	80/05/18. TO 80/05/21.	80/06/05. TO 80/06/07.	80/07/27. TO 80/07/30.	80/09/16. TO 80/09/21.	80/11/02. TO 80/11/04.
1	1.22	1.81	1.97	1.14	1.27	1.41
2	1.17	1.02	.93	1.02	1.08	.69
3	1.10	1.16	1.10	.98	1.08	.89
4	.88	1.01	1.20	.94	1.08	1.05
5	.87	1.00	1.21	1.06	1.16	1.10
6	1.05	1.28	1.56	.99	1.17	1.03
7	1.27	1.71	1.96	.95	1.55	1.34
8	1.33	1.49	1.70	1.18	1.27	1.42
9	1.44	1.75	1.86	1.21	1.31	1.23
10	1.12	1.15	1.24	.99	1.13	1.11
25	1.16	1.32	1.45	1.05	1.19	1.16

generally have an increased cellular chlorophyll content (D. Lean, personal communication). As the extent of stratification increased, the strength of the relationship between chlorophyll and either TPN or POC decreased, suggesting changes in the detrital and bacterial fractions and/or the cellular chlorophyll content.

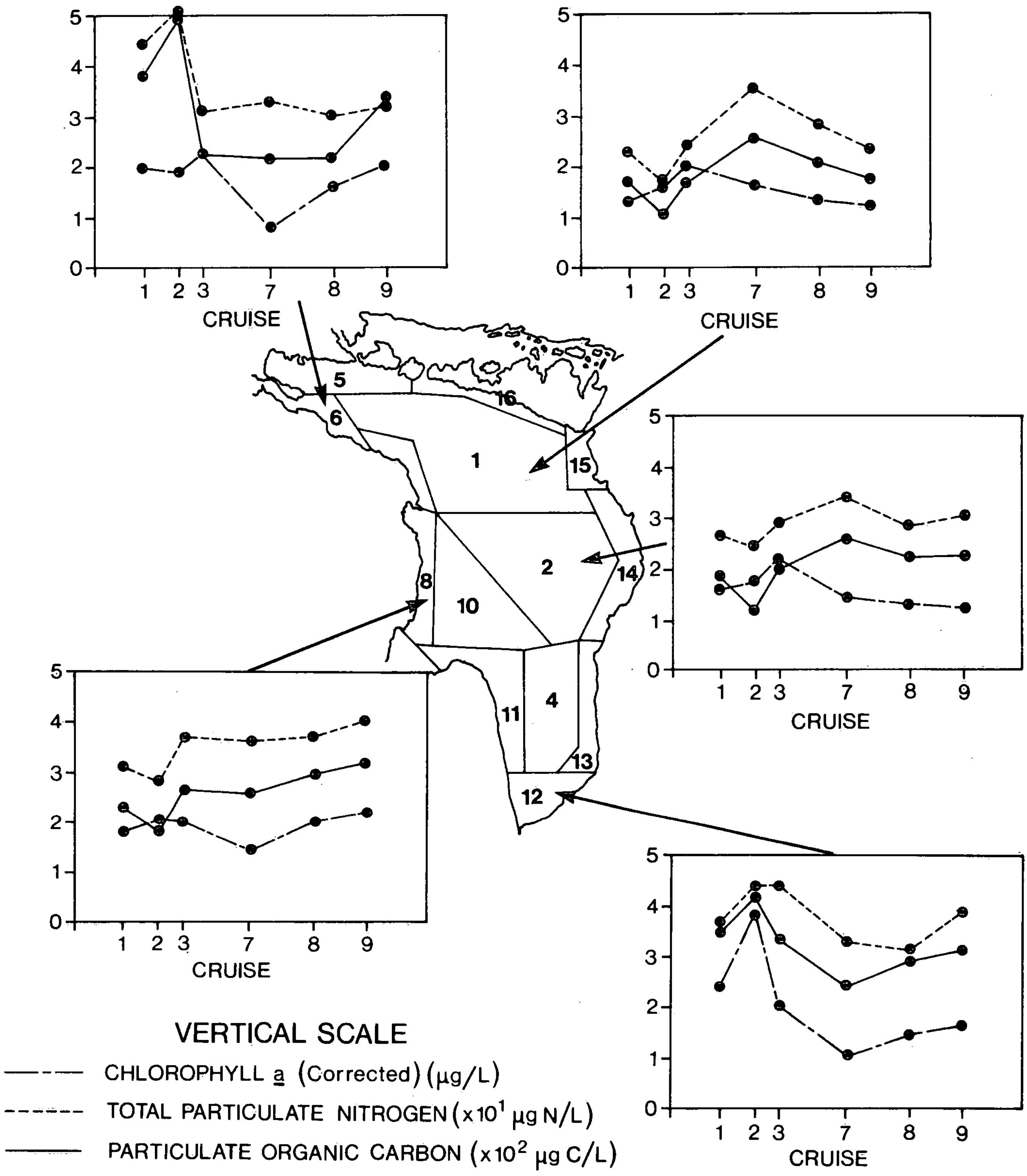


Figure 21. Phytoplankton biomass indicators.

To investigate these changes, the F-ratio (after Strickland, 1960) was calculated for each cruise. The F-ratio is calculated by performing a linear regression with POC as the dependent variable and chlorophyll *a* (corrected) as the independent variable. The slope of the regression is equivalent to the carbon to chlorophyll ratio in the phytoplankton, where a larger ratio is characteristic of a more rapidly growing population. The y-intercept represents that fraction of the POC found in the detritus.

Despite a variety of complicating factors in determining the F-ratio (cf. Banse, 1977), a consistent pattern in the data emerged in both Lake Huron and Georgian Bay. The ratio was maximal in the spring and fall when diatom populations were increasing (Munawar and Munawar, 1979). The ratio during cruise 8022501 on Georgian Bay was 122, decreasing rapidly to 63, then 45, during the subsequent two cruises. By cruise 8022507, the ratio had increased to 100 in conjunction with the fall phytoplankton bloom. The pattern was similar in Lake Huron with maximum ratios of 129 and 96 in the spring and fall and a summer minimum of 60 during cruise 8022207. When this procedure was repeated with TPN, a similar pattern was observed. Maximum ratios in Lake Huron and Georgian Bay were 14.3 and 15.8, respectively, in the spring and 12.7 and 17.2 in the fall, which corresponded to average carbon to nitrogen ratios in the phytoplankton of 9 and 8 in the spring and fall in Lake Huron, and 8 and 6 in Georgian Bay.

That fraction of the total particulate matter comprised of detritus, as determined by the F-ratio intercept, is shown in Figure 22 for both Lake Huron and Georgian Bay. While the concentration of particulate matter, as either POC or TPN, did not vary markedly throughout the year, the detrital fraction, expressed as a percentage, increased dramatically during the summer, rising from a spring minimum of roughly 14% in Lake Huron and 25% in Georgian Bay to approximately 70% in both during the fourth cruise. By the final cruise, detritus still constituted approximately 30% of the total particulate matter in Lake Huron, and 55% in Georgian Bay. When this detrital particulate matter was substracted from the total particulate matter, a much closer correspondence between chlorophyll *a* and both POC and TPN was observed (Fig. 23). It is only during the first two spring cruises, when phytoplankton development was extremely rapid, that the relationship broke down.

Due to the difficulties in relating POC and TPN concentrations strictly to phytoplankton biomass, chlorophyll *a* concentrations are most suitable for determining areas of elevated biomass in the lake. These results, summarized by zone, are presented in Tables 13 and 14. During the study period, average levels in Georgian Bay (1.23 µg/L) were less than those in Lake Huron (1.65 µg/L) and the North Channel (1.60 µg/L) over the whole lake. In general, concentrations were low (<2 µg/L) throughout the entire system, with offshore values in central and northern Lake Huron and central Georgian Bay being indicative of oligotrophic conditions (Wetzel, 1975).

The highest concentrations (>5 µg/L) were found only in the nearshore areas of southern Lake Huron, specifically offshore from Lexington, Grand Bend and Goderich, during the first two spring cruises. These levels are indicative of mesotrophic conditions (Dobson *et al.*, 1974). Moderate concentrations, ranging from 2 to 5 µg/L, were reported in the vicinity of the Straits of Mackinac, Saginaw Bay, Alpena, and the offshore waters of southern Lake Huron. In Georgian Bay, concentrations in this range were found in the vicinity of the North Channel/Georgian Bay interface, offshore of the French River and in the eastern reaches of the bay near Penetanguishene and Midland.

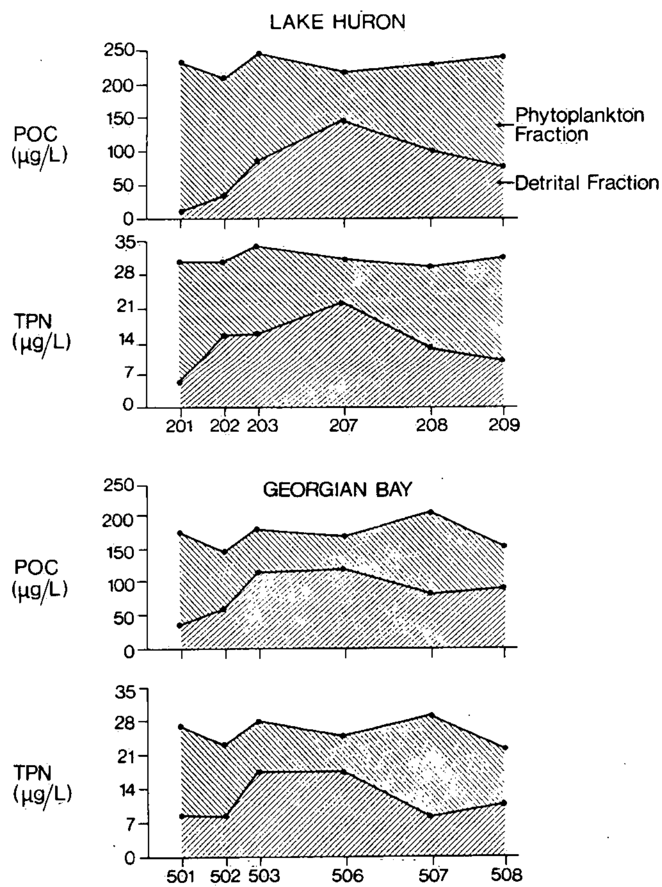


Figure 22. Seasonal changes in particulate organic carbon and total particulate nitrogen in phytoplankton and detrital fractions.

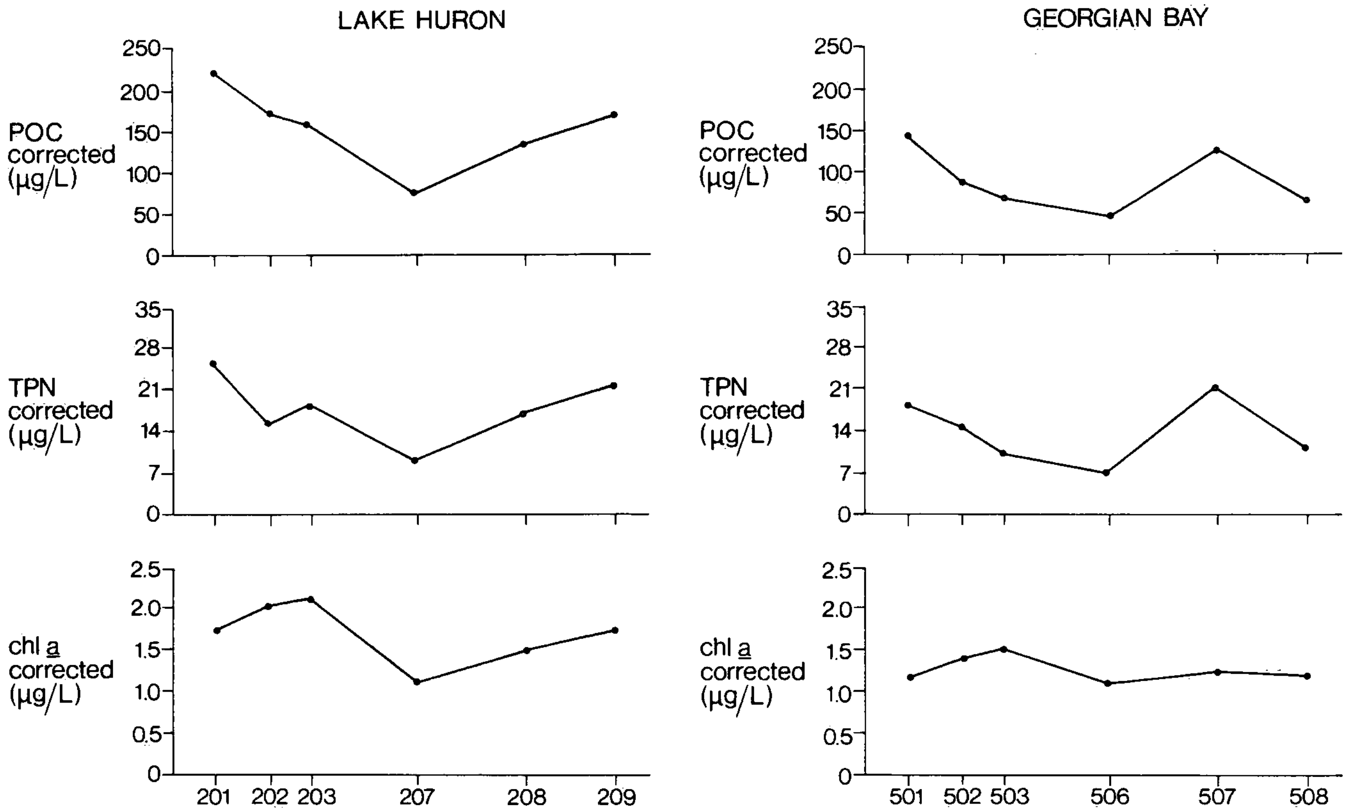


Figure 23. Seasonal pattern of corrected particulate organic carbon, total particulate nitrogen and chlorophyll *a*.

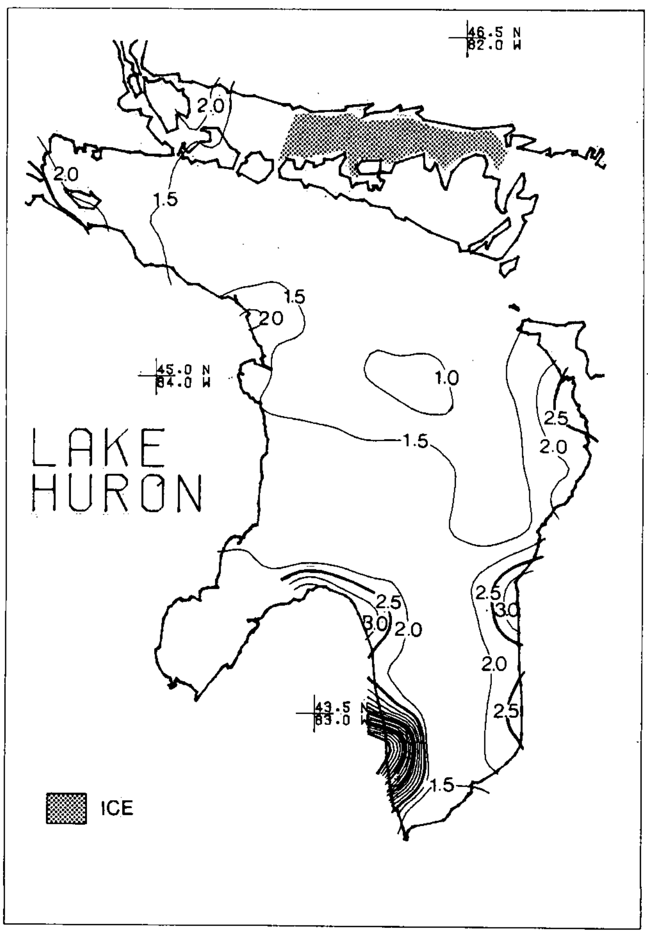


Figure 24. Isopleths of corrected chlorophyll *a* (µg/L) integrated to 20 m, cruise 8022201.

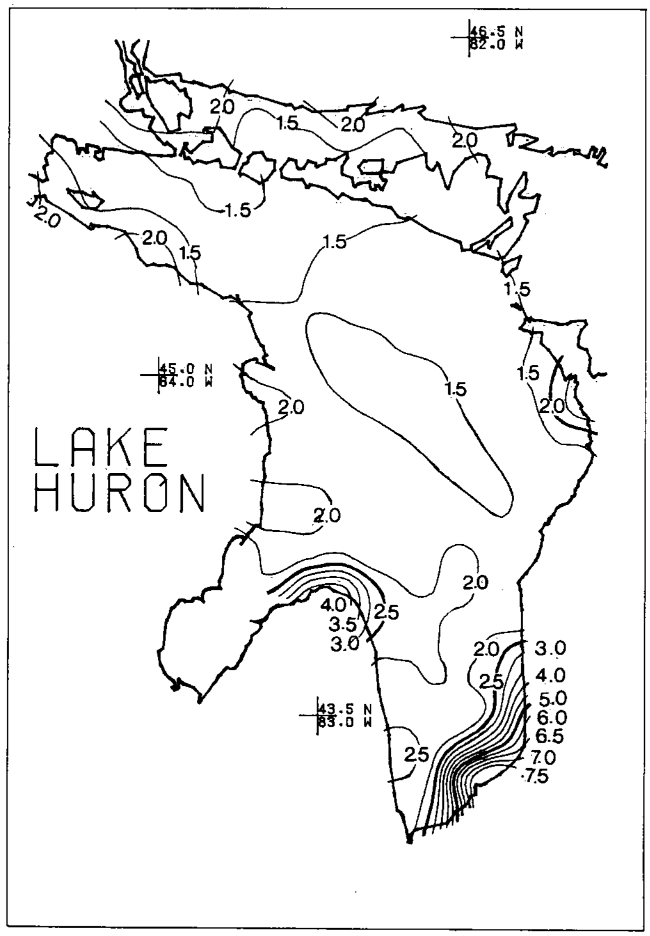


Figure 25. Isopleths of corrected chlorophyll *a* (µg/L) integrated to 20 m, cruise 8022202.

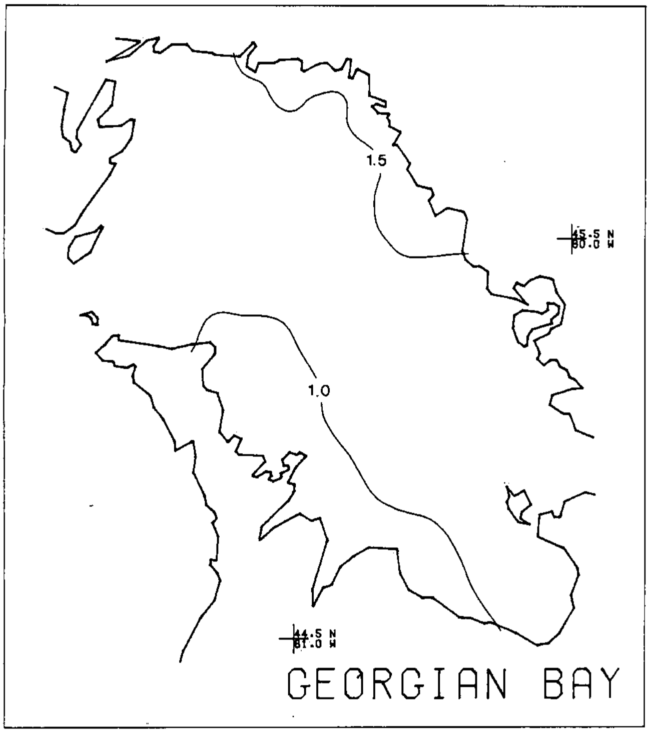


Figure 26. Isopleths of corrected chlorophyll *a* (µg/L) integrated to 20 m, cruise 8022501.

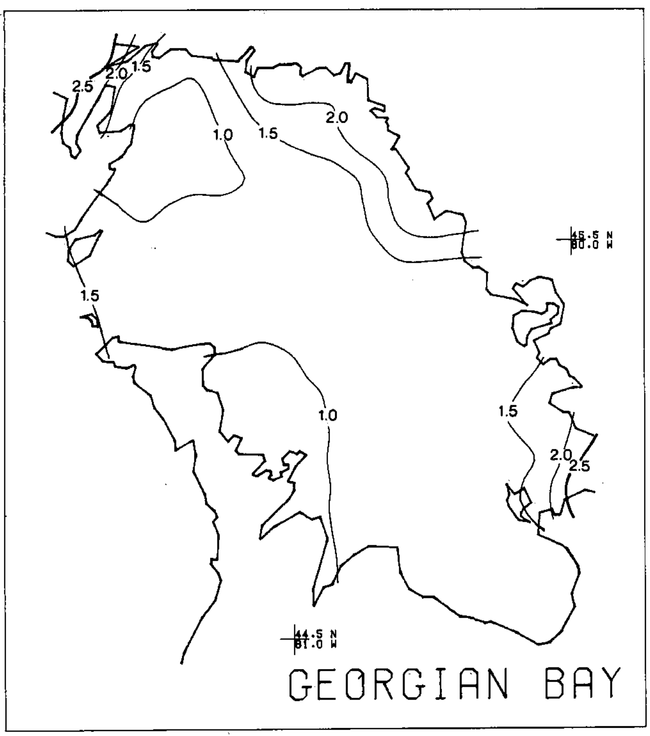


Figure 27. Isopleths of corrected chlorophyll *a* (µg/L) integrated to 20 m, cruise 8022502.

INTER-YEAR COMPARISONS

A principal objective of the 1980 Lake Huron intensive surveillance program was to document any change in water quality by comparing current results with the baseline data sets of 1971 and 1974. For the purpose of this comparison, only stations equally represented in both years were used to eliminate any bias associated with station locations. In total, 59 stations in Lake Huron and 44 in Georgian Bay were comparable. To eliminate bias further, statistical comparisons were performed on 1-m results on spring cruises, when conditions were isochemical.

Several confounding factors must be considered in the interpretation of trends or changes in spring water quality data. Principal among these are the characteristics of the thaw period, such as its timing and magnitude, which can greatly influence ambient concentrations in the near-shore waters. Other factors that can influence ambient concentrations between years are sediment-water exchange, such as resuspension due to wind-induced wave action, and intensity of incident solar radiation, which, as a determinant of phytoplankton growth, can indirectly influence nutrient concentrations. Complicating this interpretation are the improved analytical capabilities applied to the 1980 nutrient data. The varying influences of these factors necessitate that some subjective interpretation be applied to any statistical treatment of data. The mean and standard deviation for total phosphorus, nitrate + nitrite and soluble reactive silica for the 1971 and 1980 spring cruises on Lake Huron and 1974 and 1980 spring cruises on Georgian Bay are presented in Table 15. Comparisons for chlorophyll *a* were not included, as the sampling methodology changed between the years, with 1971 and 1974 data being based on discrete samples and 1980 data based on integrated samples.

When a t-test was performed comparing means of similar stations from cruises 7122201 (April 20–28, 1971) and 8022201 (April 13–23, 1980) in Lake Huron, total phosphorus demonstrated no significant ($p < 0.05$) change. However, an important difference between the total phosphorus data of 1980 and that of the baseline years was the variability associated with the mean. A large variability is indicative of elevated concentrations of phosphorus in the nearshore due to point source discharges and tributary inputs. The coefficient of variation, which expresses the standard deviation as a percentage of the mean, was 153% for total phosphorus for cruise 7122201, whereas for cruise 8022201 it was 52%. This indicates a marked decline in localized nearshore inputs of phosphorus, although improved analytical capability possibly contributed to this change.

TABLE 15. INTER-YEAR COMPARISONS

STUDY AREA	PARAMETER	YEAR	MEAN ± STANDARD DEVIATION	COEFFICIENT OF VARIABILITY (%)
LAKE HURON	TOTAL PHOSPHORUS (μG/L)	1980	4.62 ± 0.71 N.S.	14.4
		1971	4.13 ± 1.50	35.5
	NITRATE + NITRITE (μG/L)	1980	283.8 ± 10.01 **	3.5
		1971	235.0 ± 18.62	7.9
	SOLUBLE REACTIVE SILICA (MG/L)	1980	1.497 ± 0.096 **	6.4
		1971	1.395 ± 0.058	4.2
GEORGIAN BAY	TOTAL PHOSPHORUS (μG/L)	1980	5.08 ± 2.03 N.S.	40.0
		1974	4.66 ± 3.02	64.7
	NITRATE + NITRITE (μG/L)	1980	267.1 ± 26.82 **	10.0
		1974	240.3 ± 20.39	8.5
	SOLUBLE REACTIVE SILICA (MG/L)	1980	1.248 ± 0.176 **	14.1
		1974	1.444 ± 0.184	12.7

** – SIGNIFICANT DIFFERENCE (5% LEVEL).
N.S. – NO SIGNIFICANT DIFFERENCE (5% LEVEL).

Interpretation of the Georgian Bay data is more complicated owing to the complex seasonal pattern exhibited by total phosphorus in 1974 relative to 1980. During cruise 7422501 (April 28-May 2, 1974), mean surface concentrations averaged 9.2 μg/L, but decreased sharply to 4.7 μg/L by the second cruise (May 18-23, 1974) (7422503). The reason for this marked decline over a three-week period is not clear, as a similar pattern was not observed in 1980. However, both cruises were completed during isothermal, and presumably isochemical, conditions. When a t-test was performed comparing the mean of cruise 7422501 with that of 8022501, a statistically significant ($p < 0.05$) difference was determined, representing a 49% decrease from 1974 to 1980. When the mean total phosphorus concentration of cruise 7455503 was compared with that of cruise 8022502 (May 18-21, 1980), no significant difference was noted. Furthermore, as observed in Lake Huron, the coefficient of variation decreased markedly between 1974 and 1980, from 32% and 65% for cruises 7422501 and 7422503 to 19% and 41% for cruises 8022501 and 8022502. Therefore, although the results of the comparison for Georgian Bay are not as conclusive as for Lake Huron, it appears that total phosphorus has demonstrated a noticeable decline between 1974 and 1980.

Soluble reactive silica showed a significant ($p < 0.05$) increase of 12% from 1971 to 1980 in Lake Huron. With only two years of data available for comparison, it is difficult to determine if this increase represents an annual incremental increase or simply reflects the natural year-to-year fluctuations in the silica cycle. However, as this increase was consistent throughout the respective study periods (Fig. 28), it suggests that it is a real increase. The SRS levels in Georgian Bay exhibited a significant ($p < 0.05$) decrease of 13.5% from 1974 to 1980. While this decrease is in apparent contrast to that of Lake Huron, the fact that there was a 17% difference between ambient concentrations of Georgian Bay and Lake Huron in 1980 indicates a marked degree of separation between the two water masses.

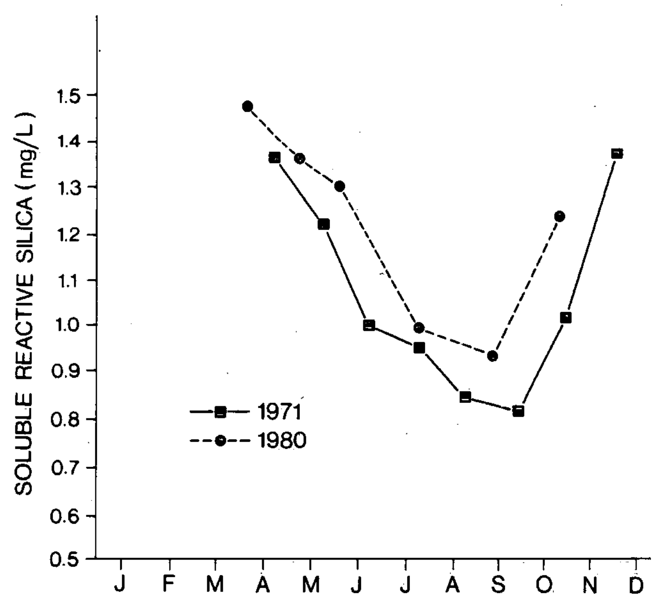


Figure 28. Seasonal changes of soluble reactive silica (mg/L SiO_2) in surface waters of Lake Huron.

Consequently, a change in SRS level in Lake Huron does not necessitate a corresponding change in Georgian Bay. Owing to the limited data available, it is difficult to attribute these changes to any specific cause. However, as inputs from Lake Superior are the principal allochthonous source of silica to Lake Huron, these changes may be related to either altered loadings from the St. Marys River or to differing circulation and exchange patterns during the two years.

Like silica, nitrate + nitrite was consistently higher throughout the study period (Fig. 29) and demonstrated a significant ($p < 0.05$) increase in both Lake Huron and Georgian Bay. If a constant annual loading rate is assumed, then (NO_3+NO_2) increased at approximately 5.4 μg/L$\cdot$yr N or 15 000 metric tons/yr in Lake Huron and 4.5 μg/L$\cdot$yr N or 3000 metric tons/yr in Georgian Bay (lake volumes from ULRG, 1977). A similar increase since 1969 has been reported for Lake Ontario which has an annual rate of increase of 8.8 μg/L$\cdot$yr N, based on annual spring surface measurements (Neilson, 1983). Unlike silica, much of the nitrogen input is derived from atmospheric sources. The Great Lakes region receives a larger input of nitrogen (1 g/m$^2\cdot$yr N) from precipitation and bulk fallout than all the continental United States (Chapin and Uttormark, 1973). Furthermore, high inputs of inorganic nitrogen are received from runoff through sedimentary formations, such as in the southern Lake Huron and Georgian Bay watersheds (Wetzel, 1975). That the combined inputs of these sources account for more than 50% of the water budget of Lake Huron and Georgian Bay (ULRG, 1977), and that both basins exhibit similar increases, suggests a common source of increased loading, such as atmospheric inputs. Again, as with silica, without more frequent data on which to assess these changes, it is difficult to determine the causes of this increase.

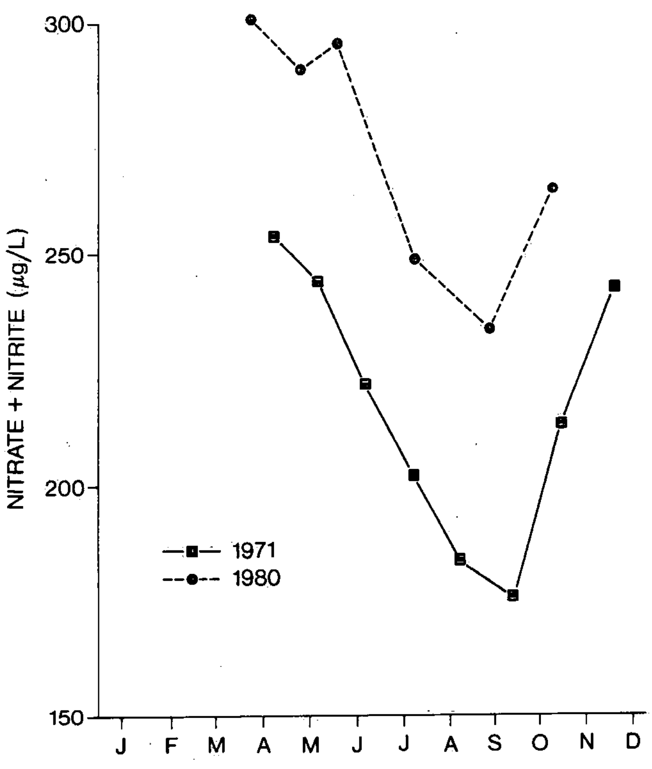


Figure 29. Seasonal changes of nitrate + nitrite (μg/L N) in surface waters of Lake Huron.

The ability to detect a real difference between the 1980 data and those of the baseline years depends on the variability associated with the mean parameter value. Over the whole lake, variability was extensive, reflecting the influence of tributary inputs on the nearshore stations. To reduce this variability, the nearshore stations were eliminated from the analysis and the comparisons repeated. Substantial reduction in variability was noted but, in all cases, the tests of significance remained unaltered.

SUMMARY AND RECOMMENDATIONS

Lake Huron and Georgian Bay exhibit thermal characteristics typical of northern temperate dimictic lakes, with spring turnover persisting throughout April and May and fall turnover beginning in late October. Lakewide thermal stratification was established by July and was accompanied by a marked increase in the areal distribution of inputs throughout the system.

The chemical limnology of Lake Huron, the North Channel and Georgian Bay varied markedly with geographic region. Inputs of low salinity from Lake Superior via the St. Marys River, and high salinity from Lake Michigan via the Straits of Mackinac exerted the most pronounced influence on the water quality of Lake Huron proper. Based on the ambient concentrations of phosphorus, nitrogen and chlorophyll *a*, the water quality of Lake Huron is largely indicative of oligotrophic conditions. As with the conditions reported by the Upper Lakes Reference Group in 1977, incidences of more serious pollution problems were generally restricted to localized areas such as embayments and nearshore areas adjacent to point source inputs. The most impacted regions were the nearshore waters of southern Lake Huron, where nutrient and chlorophyll levels were indicative of mesotrophic to eutrophic conditions. Specific areas in Lake Huron demonstrating signs of nutrient enrichment were the following:

Ontario	Michigan
Port Albert	Cheboygan-Black River
Goderich-Maitland River	Alpena-Thunder Bay River
Bayfield-Bayfield River	Southeast shore of Saginaw Bay
Grand Bend	Harbor Beach
St. Marys River	Port Sanilac

In particular, the Ontario nearshore waters of southern Lake Huron were generally of poorer quality in 1980 than in 1971, based on spring (April-May) sampling. However, this may, to a large extent, reflect differences between the spring thaw periods, such as increased snowmelt or earlier ice breakup. Without more frequent annual sampling it is difficult to attribute this change to an increasing trend.

The nearshore water quality adjacent to the Michigan shoreline, although in many instances indicative of mesotrophic conditions, has shown a noticeable improvement since 1971. The waters at the Saginaw Bay-Lake Huron interface in particular have shown a decrease in total phosphorus, presumably in response to the remedial programs implemented by Michigan.

The water quality of the North Channel was highly variable owing to inputs from the St. Marys, the Spanish and Serpent rivers, as well as exchange with Lake Huron and Georgian Bay, all of which exhibited a pronounced seasonal variation in their extent of impact. In general, the water quality was indicative of oligotrophic conditions. Elevated levels of phosphorus and nitrogen were evident in the vicinity of the St. Marys River, presumably from industrial and municipal discharges into the river at Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan. Elevated levels of ammonia were also detected, but were considerably reduced from 1974.

The ambient water quality of the open waters of Georgian Bay was slightly superior to that of Lake Huron. Those areas demonstrating degradation of water quality were the waters offshore of the French River, Midland and Owen Sound and the waters proximate to the northeastern and eastern shoreline, including the areas adjacent to Penetanguishene. The impact from the French River was directly related to its flow and, consequently, exhibited a significant impact only during spring runoff. Discharges to Owen Sound were confined to the Sound itself and water quality offshore of this area and in Nottawasaga Bay showed no adverse change. The impact along the northeastern and eastern shorelines was also primarily related to spring runoff, showing the highest nutrient levels during May.

To assess the magnitude of the change in water quality between 1980 and the baseline years (1971 for Lake Huron, 1974 for Georgian Bay), the major nutrient data were compared using a t-test. The test was based on data from stations that were sampled in both years during spring turnover when conditions were isochemical. Based on this analysis, total phosphorus in the whole lake exhibited no statistically significant change between 1971 and 1980 in Lake Huron and a definite, but possibly not significant, decline between 1974 and 1980 in Georgian Bay. These results were in keeping with the requirements of non-degradation identified in the Great Lakes Water Quality Agreement (1978). Interpretation was difficult because of the complicated seasonal pattern followed by phosphorus during the baseline years, but the large decrease in variability associated with the mean suggests that, in general, phosphorus loadings to the nearshore waters have decreased.

Nitrate + nitrite has shown a significant increase in both Lake Huron and Georgian Bay between 1980 and the baseline years. The increase of 5.4 $\mu g/L \cdot yr$ N in nitrate in Lake Huron, equivalent to 15 000 metric tons/yr, is far in excess of the 2800 metric tons/yr loading of total N to the lake predicted by the ULRG (1977). The increase in Georgian Bay is equivalent to 4.5 $\mu g/L \cdot yr$ N or 3000 metric tons/yr. With only two years of spring data available for comparison, it is difficult to determine if this change represents a real trend, such as increased atmospheric loading.

Soluble reactive silica demonstrated a statistically significant ($p < 0.05$) increase of 102 $\mu g/L$ SiO_2 between 1971 and 1980 in Lake Huron or roughly 31 000 metric tons/yr. Despite the magnitude of this change, it represents only 7% of the total SRS loading to Lake Huron and 21% of the SRS loading via the St. Marys River (ULRG, 1977). Georgian Bay, in contrast, showed a statistically significant decline of 196 $\mu g/L$ SiO_2 since 1974 or 21 000 metric tons/yr. Georgian Bay does not show a change corresponding to that in Lake Huron. This may be because inflow from Lake Superior, which is the principal source of silica to Lake Huron, has little influence on Georgian Bay.

The paucity of data with which to assess the real significance of these trends is a serious restriction. Consequently, it is recommended that an annual spring surveillance program be carried out on Lake Huron, the North Channel and Georgian Bay to verify these findings. Secondly, increased effort must be devoted to determining the causes of these increases, with specific attention being given to the determination of atmospheric and tributary inputs.

The apparent decline of water quality in the nearshore waters of southern Lake Huron, as evidenced by elevated levels of phosphorus and nitrogen, should be verified through an annual surveillance program and, where feasible, a nearshore monitoring program. Effort should also be directed at determining sources of inputs. Where significant inputs of nutrients are verified, appropriate remedial programs should be implemented to ensure that no further degradation of ambient water quality, relative to that of 1980, occurs. Should nutrient levels be shown to impair water use, quantifiable objectives should be established.

ACKNOWLEDGMENTS

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APPENDIX

Table A-1. Parameter List

Parameter	Agency	Cruises
Sounding depth (m)	On ship	All
Secchi disk depth (m)	On ship	All
Temperature (°C)	On ship	All
Turbidity (JTU)	United States Environmental Protection Agency	I, II, IV
Colour	Environment Canada	III, V, VI
Percent transmission	On ship	All
pH	On ship	All
Alkalinity	Both	All
Conductivity	On ship	All
Dissolved oxygen	Both	All
Total phosphorus	Environment Canada	All
Total filtered phosphorus	Environment Canada	All
Soluble reactive phosphorus	Environment Canada	All
Total Kjeldahl nitrogen (unfiltered)	Environment Canada	All
Nitrate + nitrite (filtered)	Environment Canada	All
Ammonia (filtered)	Environment Canada	All
Soluble reactive silica	Environment Canada	All
Particulate organic carbon	Environment Canada	All
Total particulate nitrogen	Environment Canada	All
Chlorophyll *a* (uncorrected)	Environment Canada	All
Chlorophyll *a* (corrected)	Environment Canada	All
Calcium (total)	United States Environmental Protection Agency	I
Magnesium (total)	United States Environmental Protection Agency	I
Sodium (total)	United States Environmental Protection Agency	I
Potassium (total)	United States Environmental Protection Agency	I
Chloride (total)	United States Environmental Protection Agency	II-VI
Sulphate (total)	United States Environmental Protection Agency	II-VI