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(Résumé en français)

INLAND WATERS DIRECTORATE, ONTARIO REGION, WATER QUALITY BRANCH, BURLINGTON, ONTARIO, 1978.

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Cat. No. En36-502/92

ISBN 0-662-10155-3

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Abstract

Analysis of North Channel water collected on seven surveys between April and December 1974 permitted a comprehensive chemical definition of this water body. Using these data, it was possible to define three distinct areas of water in the North Channel. It also was found that the chemical quality of the North Channel is determined mostly by the water quality of the St. Marys River.

An estimate of water exchange between the North Channel and Lake Huron was calculated using the chemical data. It indicated that 17 % of the total volume of the North Channel may be exchanged during a one-year period.

The North Channel is small enough that man's impact on the water chemistry can be seen. This is best demonstrated by its elevated ammonia concentrations. Soluble trace metal concentrations exhibit a seasonal variation in the North Channel, very similar to that observed in Georgian Bay.

Résumé

L'analyse d'eaux du chenal Nord recueillies entre avril et décembre 1974 à l'occasion de sept relevés a rendu possible une étude chimique globale de cette étendue d'eau. À l'aide de ces données, il a été possible de définir trois zones distinctes dans les eaux du chenal Nord. On a également constaté que la qualité chimique du chenal Nord est déterminée principalement par la qualité des eaux de la rivière St. Marys.

À l'aide des données chimiques, on a évalué l'échange d'eaux entre le chenal Nord et le lac Huron. On a constaté que 17% du volume total du chenal Nord peut être échangé pendant une période d'un an.

Le chenal Nord est suffisamment petit pour qu'on puisse y observer les répercussions des activités humaines sur la chimie de l'eau, comme le montrent assez bien les concentrations élevées d'ammoniac qu'on y trouve. Les concentrations des métaux solubles à l'état de traces présentent dans le chenal Nord une variation saisonnière qui est très semblable à celle qu'on a observée dans la baie Georgienne.

Chemical Limnology of the North Channel, 1974

N.D. Warry

INTRODUCTION

The North Channel is a small body of water connecting the St. Marys River, Georgian Bay and Lake Huron. It has a surface area of only 3950 km^2 and a volume of only 8.81×10^{10} m^3. Its mean depth is 22.3 m.

The water quality of the North Channel is determined almost entirely by the large quantity of water flowing into it from its primary tributaries, especially the St. Marys River. This large exchange of water results in a short residence time of about 2 years (Schertzer and Bennett, 1977) and in a highly variable water chemistry. As a result, there exists no single area in the North Channel which is representative of its chemistry as a whole, and thus no single "baseline" chemical description of the North Channel is possible, as it is for the other Great Lakes (Weiler, 1976; Shiomi and Chawla, 1970; Warry, 1978; Crawford, 1976).

This communication will present a detailed description of the chemical character of the North Channel and will provide some insight into its major control mechanisms.

SAMPLING AND DATA PROCESSING METHODS

The details of sample collection, analytical procedures, data handling, interpretation and errors are discussed in another paper (Warry, 1978). Sample locations are identified in Figure 1 and the sampling dates and parameters sampled are summarized in Table 1.

Table 1. Chemical Parameters Measured During Each 1974 Cruise on North Channel

Chemical measurement	Cruise dates						
	Apr. 22–27	May 14–18	June 22–28	July 22–28	Aug. 26–Sept. 1	Sept. 30–Oct. 5	Dec. 4–10
TP ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
TDP ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
DRP ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
Diss. $NO_3^- + NO_2^-$ ($mg\ l^{-1}$)	Y	X	X	X	X	X	X
Diss. NH_3 ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	
SRS ($mg\ SiO_2\ l^{-1}$)	Y	X	X	X	X	X	X
Diss. O_2 ($mg\ l^{-1}$)	Y	X	X	X	X	X	X
pH	Y	X	X	X	X	X	X
Ca ($mg\ l^{-1}$)	Y	X			X		
Mg ($mg\ l^{-1}$)	Y	X			X		
Na ($mg\ l^{-1}$)	Y	X			X		
K ($mg\ l^{-1}$)	Y	X			X		
Alkalinity ($mg\ l^{-1}$)	Y	X	X	X	X	X	X
Cl^- ($mg\ l^{-1}$)	Y	X	X	X	X	X	X
SO_4^{2-} ($mg\ l^{-1}$)	Y	X	X	X	X	X	X
Spec. cond. ($\mu mhos\ cm^{-1}$)	Y	X	X	X	X	X	X
Cd ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
Cr ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
Cu ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
Fe ($\mu g\ l^{-1}$)			X	X	X	X	X
Pb ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
Mn ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
Ni ($\mu g\ l^{-1}$)	Y	X	X	X	X	X	X
Zn ($\mu g\ l^{-1}$)	Z	Z	X	X	X	X	X

X – Samples collected during cruise.
Y – Samples collected only on segment 1, ice cover.
Z – Samples contaminated.

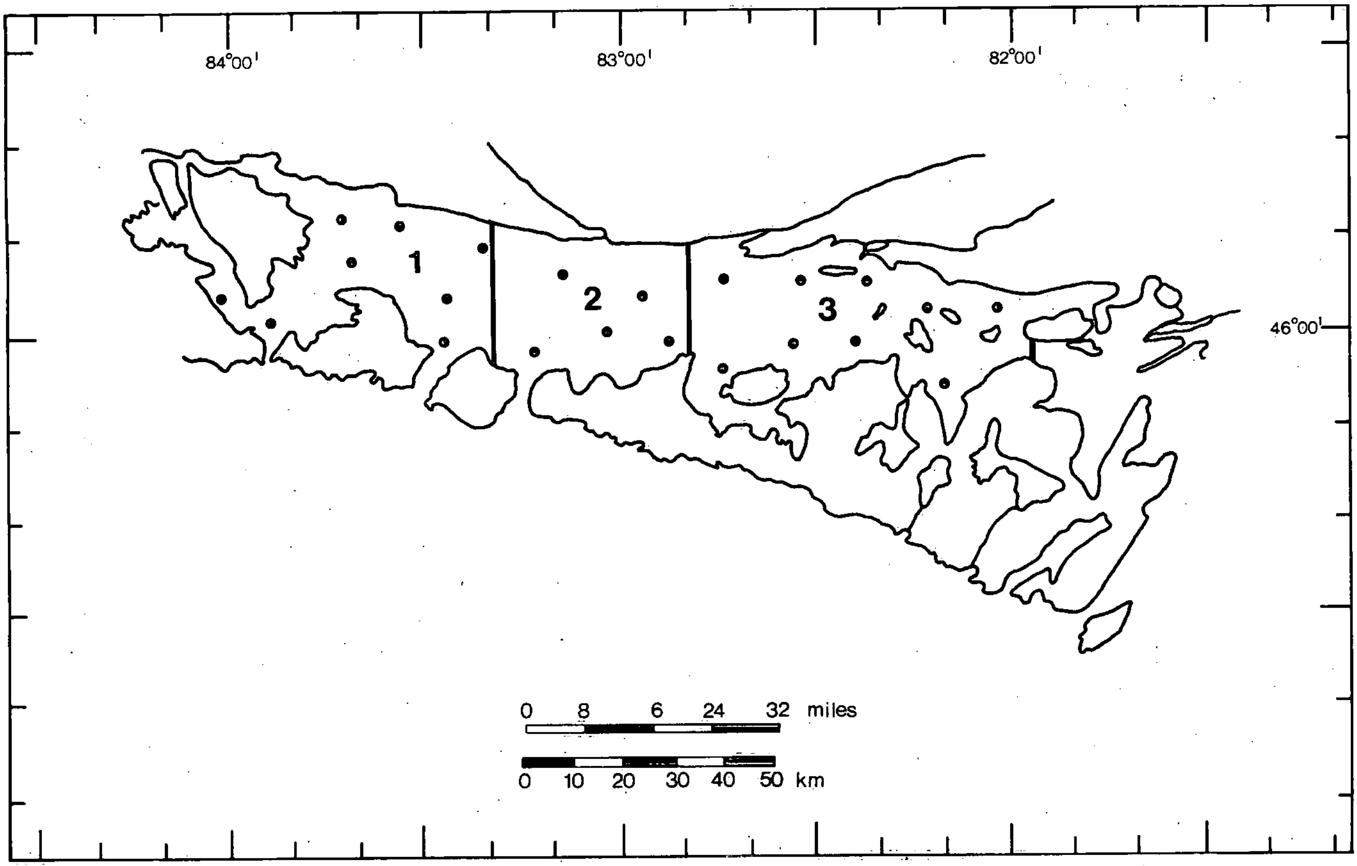

Figure 1. Map of the North Channel showing station locations and zones. The numbers represent the zones into which the channel was divided.

RESULTS AND DISCUSSIONS

Major Ions

The distributions of the major ions in the surface waters of the North Channel during May are depicted in Figure 3. Obviously, significant concentration gradients exist for all major ions with the exception of potassium.

The largest concentration gradient in percentage terms is observed for sulphate. Its volume–weighted mean concentration in the top 1 m of the water column increases more than 100% from 6.4 mg l^{-1} in segment 1, to 14.7 mg l^{-1} in segment 3. Other increases include a doubling in chloride concentration from 2.3 to 4.7 mg l^{-1}, and increases of 28 to 67% in the concentrations of calcium, magnesium, sodium and alkalinity.

Large concentration differences are observed between the surface (<10 m) and deep (>25 m) waters of segment 1 as well. In this case, the differences are not as large, ranging from a minimum increase of 17% (48.5–56.8 mg l^{-1}) for alkalinity to a maximum increase of 55% for sulphate (6.4–9.9 mg l^{-1}).

These large differences exist because of the overwhelming influence of the St. Marys River on the surface waters of this segment. The major ion chemistry of the surface water in this segment is more characteristic of the St. Marys River than of the North Channel, simply because so much water from the St. Marys River flows into this area. The water flow into this region through the St. Joseph Channel averages 722 m^3 s^{-1} (Schertzer and Bennett, 1977).

In the North Channel, the total quantities of all dissolved ions, except alkalinity, increase between May and October. In Table 2, for example, it is seen that the quantity of chloride increases 10%, from a low of 3.7 x 10^5 kg in May to a maximum of 4.1 x 10^5 kg in October, calculated on the basis of a constant volume of 8.809 x 10^{10} m^3 for the channel. Since the volume of the channel actually declines 1-2% during this time (Schertzer, personal communication), the increase in chloride content measured in Table 2 is conservative.

The excess chloride comes from two sources. About 43% of the increase is derived from the increased chloride concentration in the St. Marys River and is found in the top 20 m of segment 1. The other 57% of the increase is found

Table 2. **Concentration* of Major Ions in Epilimnion and Hypolimnion of Segments 1-3 of the North Channel**

Parameter	May	June	July	Aug.	Oct.	Dec.
		SEGMENT 1				
Filtered Ca (mg l^{-1})	16.6 18.1			19.5 25.1		
Filtered Mg (mg l^{-1})	3.8 4.3			4.4 6.3		
Filtered Na (mg l^{-1})	1.9 2.1			2.2 3.0		
Filtered K (mg l^{-1})	0.6 0.7			0.7 0.8		
Filtered alkalinity (mg $CaCO_3$ l^{-1})	51.5 58.4	53.5 66.1	53.9 68.0	53.1 73.8	59.5 76.3	64.4 67.5
Filtered Cl^- (mg l^{-1})	2.7 4.2	3.1 4.5	3.0 4.6	3.1 5.2	3.7 5.4	3.4 5.0
Filtered SO_4^{2-} (mg l^{-1})	8.0 12.0	8.9 12.4	9.0 14.0	9.8 15.1	10.9 15.1	10.2 14.0
Spec. cond. ($\mu S \cdot cm^{-1}$)	135 151	138 172	133 171	140 191	151 190	146 178
Filtered Zn (μg l^{-1})		4.5 4.0	3.3 4.7	2.8 3.4	2.1 3.0	1.8 1.2
Filtered Ni (μg l^{-1})	9.4 6.8	1.2 1.0	1.0 1.1	1.1 1.0	1.4 1.0	1.0 1.0
Filtered Mn (μg l^{-1})	2.5 2.2	1.9 2.3	0.4 N.D.	0.6 0.2	0.3 0.2	0.2 0.2
Filtered Pb (μg l^{-1})	0.2 0.3	0.3 0.6	0.2 N.D.	N.D. N.D.	N.D. 0.1	N.D. N.D.
Filtered Fe (μg l^{-1})		4.3 2.0	4.2 3.3	4.2 1.3	2.8 2.5	1.3 1.0
Filtered Cu (μg l^{-1})	3.8 3.6	2.3 2.0	1.6 1.6	1.1 1.5	0.9 0.5	1.0 1.0
TP (μg l^{-1})	6.5 5.2	6.2 6.8	5.7 7.8	7.2 8.9	7.1 7.1	6.5 5.1
TDP (μg l^{-1})	2.3 2.3	2.7 2.5	2.9 3.2	3.5 2.8	4.1 4.6	3.1 3.0
DRP (μg l^{-1})	0.8 0.4	0.6 0.7	0.5 1.0	0.7 0.9	1.3 0.7	0.8 0.5
Diss. $NO_3^- + NO_2^-$ (mg N l^{-1})	0.30 0.30	0.28 0.30	0.25 0.32	0.25 0.31	0.26 0.31	0.30 0.30
Diss. NH_3 (μg N l^{-1})	32.3 24.9	10.1 14.8	8.6 8.0	8.0 4.8	6.2 2.0	
SRS (mg SiO_2 l^{-1})	2.38 2.24	2.01 2.34	1.87 2.61	2.01 2.17	2.07 2.15	2.05 1.98
Diss. O_2 (mg l^{-1})	13.0 13.4	11.2 12.6	9.7 12.0	9.6 11.8	10.9 11.6	13.0 12.1

Table 2. (cont'd)

Parameter	May	June	July	Aug.	Oct.	Dec.
		SEGMENT 2				
Filtered Ca (mg l^{-1})	20.7 21.7			21.0 26.0		
Filtered Mg (mg l^{-1})	5.1 5.4			5.3 7.0		
Filtered Na (mg l^{-1})	2.7 2.9			2.9 3.2		
Filtered K (mg l^{-1})	0.7 0.7			0.8 0.9		
Filtered alkalinity (mg $CaCO_3$ l^{-1})	60.0 67.0	58.8 72.4	57.7 75.0	58.7 75.7	63.7 74.9	57.9 67.5
Filtered Cl^- (mg l^{-1})	4.5 4.8	4.4 5.1	4.2 5.5	4.4 5.5	4.7 5.4	4.5 4.6
Filtered SO_4^{2-} (mg l^{-1})	14.0 14.1	14.0 13.9	13.7 15.3	14.4 15.5	14.3 15.5	14.1 13.7
Spec. cond. ($\mu S \cdot cm^{-1}$)	167 181	164 187	155 194	158 198	172 191	170 177
TP (μg l^{-1})	4.0 3.5	5.3 6.4	4.8 6.0	5.1 5.8	5.9 6.3	6.6 5.0
TDP (μg l^{-1})	1.6 1.3	2.6 2.5	2.8 2.2	3.3 2.8	3.5 2.7	3.6 3.0
DRP (μg l^{-1})	0.6 0.5	0.7 1.1	0.7 0.3	0.6 0.6	0.7 0.7	1.0 0.5
Diss. $NO_3^- + NO_2^-$ (mg N l^{-1})	0.22 0.23	0.27 0.29	0.26 0.28	0.24 0.29	0.26 0.29	0.28 0.30
Diss. NH_3 (μg N l^{-1})	7.3 3.0	8.2 15.0	6.3 7.0	4.2 9.0	2.6 1.0	
SRS (mg SiO_2 l^{-1})	2.46 2.12	2.09 1.96	1.84 1.72	1.56 1.60	1.81 2.11	2.26 1.98
Diss. O_2 (mg l^{-1})	13.4 13.7	11.4 12.9	9.6 13.0	9.3 12.6	10.7 11.8	12.4 12.1
Filtered Zn (μg l^{-1})		2.7 3.0	1.7 5.0	2.2 2.4	1.7 2.0	1.8 1.0
Filtered Ni (μg l^{-1})	9.1 6.7	4.3 1.0	4.0 1.0	3.5 1.0	2.6 1.0	2.5 2.2
Filtered Mn (μg l^{-1})	0.3 2.0	0.9 0.9	0.3 0.5	0.2 0.2	0.2 0.2	0.2 0.2
Filtered Pb (μg l^{-1})	0.6 0.6	0.1 N.D.	0.1 N.D.	N.D. N.D.	N.D. N.D.	N.D. N.D.
Filtered Fe (μg l^{-1})		5.1 1.0	3.1 3.5	1.2 1.1	1.4 1.5	1.3 1.2
Filtered Cu (μg l^{-1})	4.3 4.2	2.4 1.5	1.6 1.5	1.1 1.1	0.9 1.0	0.9 1.0

Table 2. (cont'd)

Parameter	May	June	July	Aug.	Oct.	Dec.
		SEGMENT 3				
Filtered Ca (mg l^{-1})	21.2			21.1		
	21.5			21.5		
Filtered Mg (mg l^{-1})	5.2			5.5		
	5.1			5.6		
Filtered Na (mg l^{-1})	2.7			3.0		
	2.7			3.0		
Filtered K (mg l^{-1})	0.7			0.9		
	0.7			0.9		
Filtered alkalinity (mg $CaCO_3$ l^{-1})	61.2	61.1	62.6	60.4	60.7	64.5
	62.7	63.6	64.5	62.6	60.9	64.8
Filtered Cl^- (mg l^{-1})	4.5	4.4	4.5	4.6	4.5	4.6
	4.6	4.6	4.5	4.8	4.6	4.6
Filtered SO_4^{2-} (mg l^{-1})	14.8	14.8	15.1	15.3	15.0	14.3
	14.7	14.8	14.9	15.6	15.0	14.2
Spec. cond. ($\mu S \cdot cm^{-1}$)	174	166	164	164	165	171
	181	168	166	164	164	171
TP (μg l^{-1})	5.0	4.7	5.4	5.4	6.5	7.5
	6.3	7.2	6.7	6.6	5.9	6.4
TDP (μg l^{-1})	1.9	2.5	2.6	3.7	3.4	4.4
	1.8	2.5	2.9	3.8	3.4	3.5
DRP (μg l^{-1})	0.3	0.6	0.9	0.8	1.2	1.3
	0.5	0.8	1.0	0.9	1.0	1.1
Diss. NO_3^- + NO_2^- (mg N l^{-1})	0.28	0.18	0.18	0.18	0.19	0.27
	0.29	0.22	0.21	0.28	0.21	0.28
Diss. NH_3 (μg N l^{-1})	3.5	5.5	6.0	4.0	4.5	
	3.9	15.8	7.3	2.2	2.5	
SRS (mg SiO_2 l^{-1})	2.04	1.67	1.47	1.45	1.99	2.10
	2.12	2.06	2.24	2.57	1.98	2.11
Diss. O_2 (mg l^{-1})	13.3	11.0	9.4	8.9	9.9	12.3
	13.4	11.8	10.8	9.3	10.0	12.3
Filtered Zn (μg l^{-1})		3.3	2.2	1.3	2.3	1.8
		2.6	3.7	1.8	2.1	1.0
Filtered Ni (μg l^{-1})	3.9	3.4	2.3	3.4	3.2	2.9
	3.3	3.1	3.0	3.2	3.8	2.3
Filtered Mn (μg l^{-1})	0.2	0.3	0.3	0.5	0.1	0.5
	0.6	0.1	0.1	0.2	0.1	0.7
Filtered Pb (μg l^{-1})	0.3	N.D.	N.D.	0.7	N.D.	N.D.
	0.8	N.D.	N.D.	0 1	N.D.	N.D.
Filtered Fe (μg l^{-1})		2.9	2.8	1.2	1.1	1.3
		1.2	2.4	1.0	1.0	1.1
Filtered Cu (μg l^{-1})	4.6	2.1	1.6	1.0	1.0	1.0
	5.6	2.1	1.9	1.0	1.0	1.0

N.D.—Below detection limit.
* First row of figures for each parameter is concentration in the epilimnion; second row is for hypolimnion.

in the deeper waters of the North Channel in segments 1 and 2. This increase results from the exchange of North Channel water with Lake Huron water.

The volume of water containing increased chloride in the hypolimnion of segments 1 and 2 is 4.94×10^{10} m^3. The total increase in chloride content of this volume of water is approximately 2.09×10^{10} g. To increase the chloride content this much, there would be required an influx of 1.5×10^{10} m^3 of Lake Huron water into the North Channel, having a mean chloride concentration of 5.5 mg l^{-1}, coupled with the outflow of the same quantity of North Channel water having a chloride concentration of 4.1 mg l^{-1}.

As support for this calculation, if one assumes that 1.5×10^{10} m^3 of Lake Huron water is exchanged and then uses the measured difference in the quantity of sulphate of 3.6×10^{10} g, one obtains a sulphate concentration difference between the inflowing Lake Huron water and the outflowing North Channel water of 2.4 mg l^{-1}. The observed differences in sulphate concentration in the hypolimnion between May and October are 2.6 mg l^{-1} in segment 2 and 2.7 mg l^{-1} in segment 1.

Nutrients

Soluble Reactive Silica

The distribution of soluble reactive silica (SRS) in the surface waters of the North Channel during May is typical for most parameters in the North Channel. As in the case of the major ions, the primary concentration gradient runs east from the St. Marys River inflow; however, in this case it is a decreasing gradient as opposed to an increasing one. In segments 2 and 3, silica depletion in the surface waters averages 0.9 and 0.6 mg l^{-1}, respectively, and the depletion rates are about 8.0 μg l^{-1} day^{-1} in segment 2 and 5.5 μg l^{-1} day^{-1} in segment 3. This difference is a result of low May SRS concentrations in segment 3 (2.0 mg l^{-1} vs 2.4 mg l^{-1}) because of the low silica Georgian Bay water which flows into this segment in May.

The depletion rate in segment 2 is 15% higher than the depletion rates calculated for Georgian Bay (Warry, 1978) and for Lake Huron (Crawford, 1977). This may reflect the species composition of the North Channel biomass, in which diatoms compose a larger percentage of its phytoplankton population than they do in either Lake Huron or Georgian Bay (Watson, personal communication).

The total SRS depletion in segment 1 is less than in the other segments, averaging only 0.5 mg l^{-1}; however, the depletion rate of 6.9 μg l^{-1} day^{-1} is intermediate between that of segments 2 and 3. Segment 1 is different from the others because its silica is depleted only during the spring diatom bloom. Once this ends in mid-July, the constant supply of silica from the St. Marys River overcomes any further uptake; thus the time to maximum depletion is only two-thirds as long as in the other zones. As a result, the depletion rate is high even though total depletion is low.

Phosphorus

Because of ice cover, the three forms of phosphorus (total (TP), total dissolved (TDP), dissolved reactive (DRP)) were measured at only three stations in segment 1 of the North Channel in April. From these data the volume-weighted mean TP concentration was 11.4 μg l^{-1}, while the concentrations of TDP and DRP were 7.1 μg l^{-1} and 1.2 μg l^{-1}, respectively. When these data are compared with the May data in Table 2, it is seen that a very large drop in concentration occurs for all three phosphorus forms during the three weeks between cruises. A similar large drop in concentration of all three phosphorus forms has been reported for Georgian Bay by Warry (1978).

Table 3 shows that the ratio of total particulate P (TPP) to TP is at its minimum in April and its maximum in May, indicating that much of the phosphorus has been converted from soluble to particulate form. It also shows that the concentration of chlorophyll *a* increases 27% during this time.

Table 3. Relation of Total Particulate P to Total P and Chlorophyll *a* Concentration in the North Channel

		Apr.	May	June	July	Aug.	Oct.	Dec.
Segment	1	0.38	0.65	0.50	0.46	0.50	0.46	0.56
	2	N.M.*	0.60	0.49	0.43	0.34	0.39	0.44
	3	N.M.	0.62	0.46	0.63	0.31	0.43	0.41
Chlor. *a*		1.6	2.2	1.7	1.3	1.3	1.5	1.9

*N.M., not measured.

Together, these three observations suggest that excess phosphorus, mostly in soluble form (DRP), is added to the Channel during spring runoff, and some of it is then converted quickly to biomass. The disappearance of the remainder (44% of the total quantity in segment 1) between April and May is presumably the result of sedimentation.

Throughout the rest of the year, the spatial distribution of all three forms of phosphorus in the surface waters of the North Channel does not vary significantly from that depicted for May (Fig. 2). Generally, the highest concentrations are found in the areas of the major inputs; St. Marys River, and to a lesser extent, Georgian Bay.

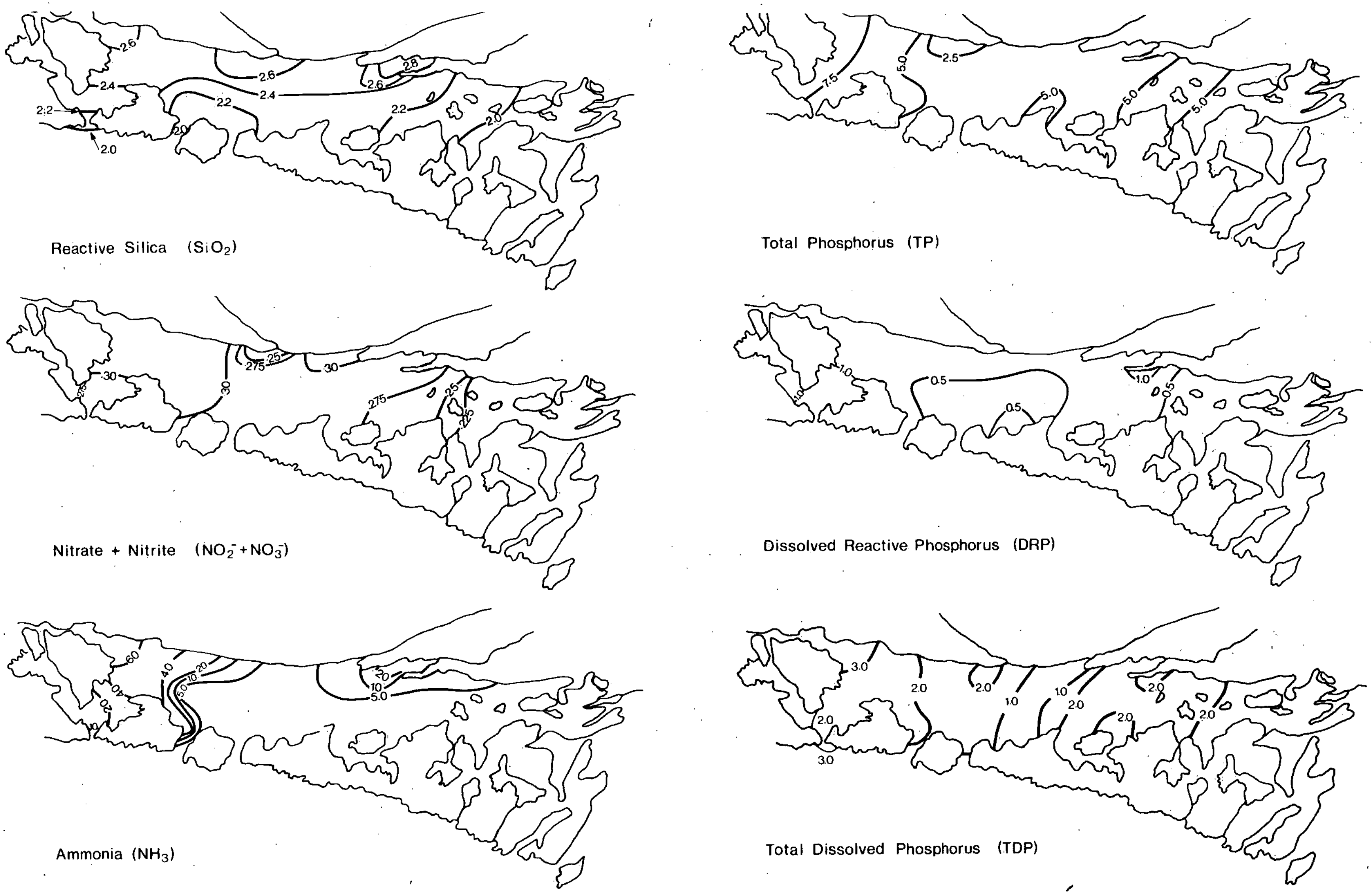

Figure 2. Distribution of the nutrients TP, DRP, TDP, NO_2^- + NO_3^-, NH_3 and SRS in the surface waters of the North Channel during May 1974. Concentrations of SRS and NO_3^- + NO_2^- are in mg l^{-1}; all others are in $\mu g\ l^{-1}$.

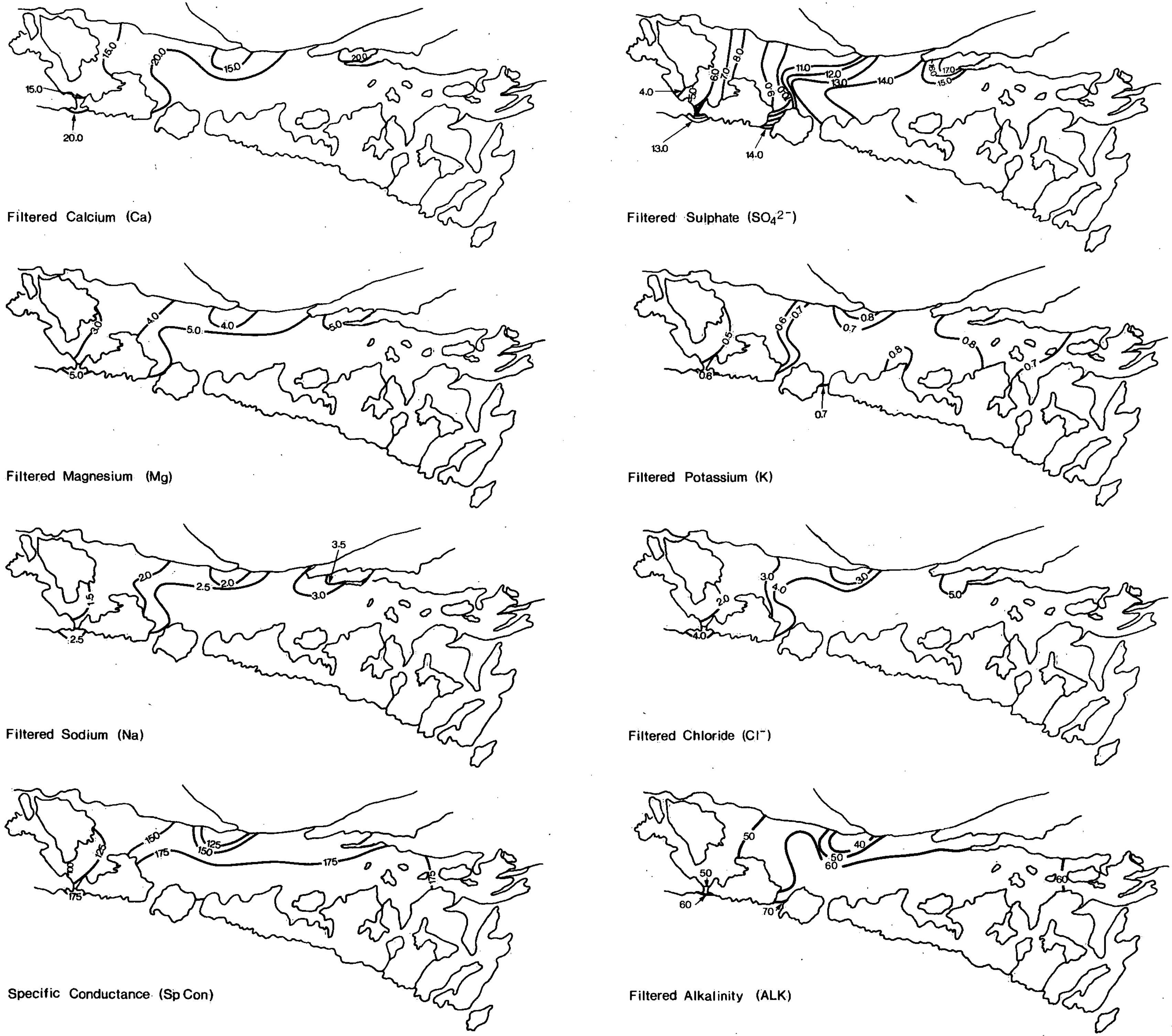

Figure 3. Distribution of major ions in the surface waters of the North Channel during May 1974. Concentrations are all in mg l^{-1}; conductance is reported in $\mu S\ cm^{-1}$.

Nitrogen

There is a gradual decrease in the concentration of nitrate + nitrite in the surface waters of the North Channel as one moves from west to east. The concentration drop is 27%, from 0.30 mg N l^{-1} in segment 1 to 0.22 mg N l^{-1} in segment 3. This gradient again is the result of the influx of water high in nitrogen into the west end from the St. Marys River and water low in nitrogen flowing into the east end from Georgian Bay.

The effects of the water inflows also are manifested as different total depletions and depletion rates in each zone. These are listed in Table 4. In segment 2, the only area not affected by water exchange, the total N depletion and its depletion rates are comparable to those reported in Georgian Bay (Warry, 1978) and Lake Huron (Crawford, 1976).

Table 4. Depletion Rates and Total Depletion of $NO_3^- + NO_2^-$ in the Surface Waters of the North Channel

	Segment No.		
	1	2	3
Depletion rate (μg N l^{-1} day^{-1})	0.86	0.50	1.33
Total depletion (μg N l^{-1})	60	50	40

Unlike any other water body in the Great Lakes, the North Channel exhibits an extremely varied and interesting ammonia chemistry. Figure 2 illustrates the large concentration gradients for ammonia found in the North Channel. These result from industrial discharges of ammonia, particularly from Algoma Steel Corp. in Sault Ste. Marie, Ontario. These discharges were decreased significantly at the end of 1976 and the problem has improved noticeably (Kinkead, Ontario Ministry of Environment, personal communication).

The status of the two other anthropogenic discharges of ammonia, the Spanish and Serpent Rivers, has also improved since the field program was conducted in 1974 (Kinkead, Ontario M.O.E., personal communication).

As discussed elsewhere (Warry and Schertzer, in press), anthropogenic discharges of ammonia are large enough to affect the nitrogen budget of the North Channel significantly.

Oxygen and pH

There is no evidence for serious oxygen depletion in any part of the North Channel at any time of the year. However, in segment 3, September oxygen concentrations in the hypolimnion are as low as 9.2 mg l^{-1}, or 93% saturation. The low concentration probably results from the oxidation of phenols being discharged from the Spanish River rather than from an oxygen demand required by decaying phytoplankton (U.L.R.G., 1977, Vol. II).

Over most of the North Channel, pH is within the range 7.8–8.2. A summer maximum of 8.4 is found in the epilimnion in August, while a minimum of 7.6 is found in the hypolimnion in July.

Trace Metals

In the North Channel, trace metal data are divisible into two groupings: (1) those elements present in concentrations at or near their detection limits, and (2) those detectable in quantifiable amounts. Cadmium, chromium, cobalt and selenium are seldom detectable in the North Channel. The group displaying measurable variation in concentration consists of lead, manganese, copper, nickel, iron and zinc. The May distributions of these elements in the surface waters of the North Channel are illustrated in Figure 4.

Without exception, the highest mean concentration for each metal occurs in the May–June period, suggesting that the concentration of these metals is related to input from surface runoff. This is supported by the fact that the highest concentrations of Fe, Mn and Ni are found near the mouths of the major rivers.

In contrast, lead concentrations (1.0–1.5 μg l^{-1}) are at a maximum in the area of Barrie Island, and zinc is present at its greatest concentration (6.0–7.0 μg l^{-1}) in the area of Cockburn Island. The zinc appears to be coming from Lake Huron, but there is no apparent source for the lead. The copper concentration is fairly uniform over the entire North Channel at this time, averaging 4.0–5.0 μg l^{-1}.

Filtered iron exhibits interesting annual variations in concentration. June (the first month data were collected) iron concentrations are the highest of the year, ranging from 2.5 μg l^{-1} in segments 2 and 3 to 6.6 μg l^{-1} in segment 1. The concentrations in segment 1 are highest because of the high concentrations of dissolved iron (up to 20 μg l^{-1}) in the St. Marys River (Chan, personal communication). The elevated concentrations in the river likely reflect input from Algoma Steel Corp. and the town of Sault Ste. Marie, Ontario.

Filtered iron concentrations generally decrease from June to December, to an early December concentration

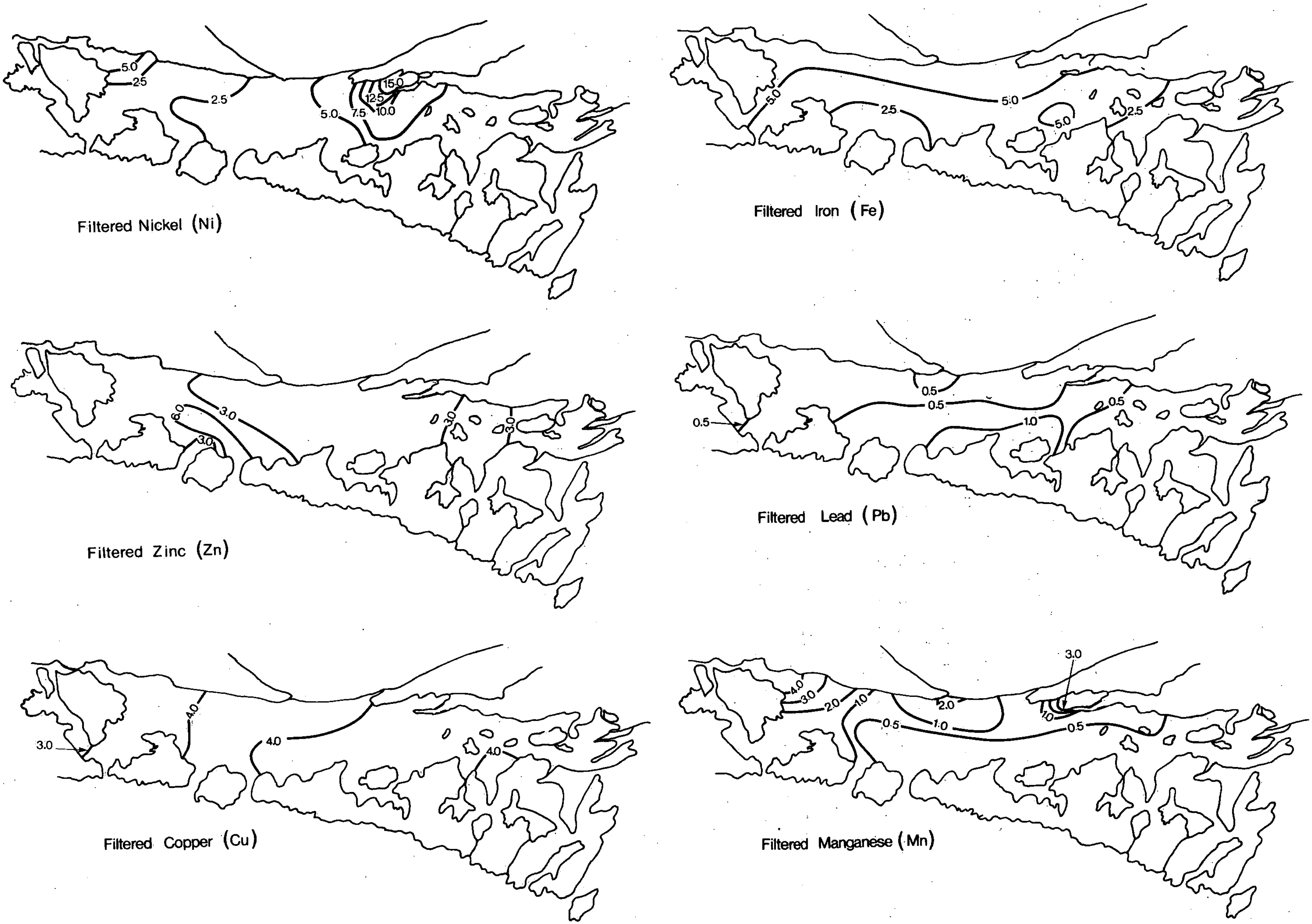

Figure 4. Distribution of Ni, Zn, Cu, Fe, Pb and Mn in the surface waters of the North Channel during May 1974. Concentrations are in $\mu g\ l^{-1}$.

near 1 $\mu g\ l^{-1}$ over the entire North Channel. Iron is converted from dissolved to particulate form during the growth season (McMahon, 1969) and this results in the overall decrease in dissolved iron concentration during the stratified period.

Another curious feature of dissolved iron in the North Channel involves the sudden and dramatic seasonal changes in the concentration observed in segment 1. In July, concentrations as high as 12 $\mu g\ l^{-1}$ were recorded in the St. Marys River stations, but by the next cruise, values had returned to 2 $\mu g\ l^{-1}$. Again in October, concentrations up to 4 $\mu g\ l^{-1}$ had been recorded in this area, but by December the mean concentration was 1 $\mu g\ l^{-1}$. Though it cannot be confirmed by this study, these pulses may reflect episodes of waste discharge into the St. Marys River, or resuspension of bottom sediments into the water column.

Manganese, copper and nickel exhibit similar concentration cycles in North Channel waters. Each is present at its maximum concentration of 4, 9 and 1 $\mu g\ l^{-1}$, respectively, in May. Five weeks later the concentrations have decreased to 2.3, 3.3 and 0.4 $\mu g\ l^{-1}$. Throughout the rest of the year the concentration of manganese remains stable, while copper and nickel concentrations slowly decrease to 50% of the May values. A similar phenomenon has been reported to occur in Georgian Bay during the same time period (Warry, 1978).

It should be noted that the concentrations of filtered nickel in the North Channel are the highest in the Great Lakes. Nowhere else in the Great Lakes is dissolved nickel present all year in quantities above its detection limit of 1 $\mu g\ l^{-1}$ except in the North Channel, where the mean concentration is never less than 2 $\mu g\ l^{-1}$ in 1974 and 4 $\mu g\ l^{-1}$ in 1976. These nickel concentrations probably are attributable to input from the Spanish River and the atmosphere. They are also much less than the IJC objective for nickel, which is 25 $\mu g\ l^{-1}$ in unfiltered Great Lakes water.

SUMMARY

The chemical character of the North Channel responds to three major influences: (i) the major tributaries, (ii) anthropogenic discharges, and (iii) exchange with Lake Huron.

More than any other factor, the St. Marys River determines the chemical limnology of the North Channel. The river sets the residence time of the North Channel at two years, it is responsible for most major chemical concentration gradients, and it controls the chemical differences between the surface and deep waters in over 50% of the North Channel basin. In addition, it is the carrying of manmade waste products in this river that results in the high and variable concentrations of ammonia and possibly dissolved iron observed in North Channel, even though the Channel receives only that 32% of the St. Marys River flow travelling down the St. Joseph Channel. The other 68% of the flow proceeds through the Neebish Channel directly into Lake Huron.

The effects on the North Channel chemistry of the other major tributaries (Georgian Bay, Serpent, Spanish and Mississagi rivers) are more localized as is apparent from Figures 2, 3 and 4. The parameters responding to the Spanish, Serpent and Mississagi river inputs include nitrate and nitrite, ammonia, reactive silicate and a number of major ions and trace metals. Those responding to Georgian Bay inflow include chloride, alkalinity, soluble reactive silica and nitrate + nitrite.

Effects of man's activities are most noticeable in regard to ammonia and filtered iron, as discussed above. The elevated concentrations of dissolved nickel found in the North Channel presumably are the result of human activity as well.

It is apparent after examination of the major ion data that a significant exchange of water between the North Channel and Lake Huron exists. A preliminary calculation of the magnitude of this exchange indicates that 17% of the total quantity of water in the North Channel may be involved in this exchange. The accuracy of this exchange estimate can not be determined at this time, since the necessary flow data are not yet available. It will be interesting to compare the water exchange computed in this report with the measured exchange when it becomes available.

ACKNOWLEDGMENTS

I wish to thank the officers and crew of the *Martin Karlsen*, who guided the ship through difficult areas to collect the samples, and the Water Quality Branch Laboratory at the Canada Centre for Inland Waters for analyzing the samples. Special thanks goes to F.C. Elder for his comments and criticisms of the manuscript.

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