H.F.H. Dobson

Lakes Research Branch
National Water Research Institute
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario L7R 4A6
Canada

SOME OBSERVATIONS OF (NON-TOXIC) CHEMICALS IN WATER SAMPLES FROM THE ST. LAWRENCE RIVER FROM KINGSTON TO QUÉBEC

NWRI Contribution No. 90-19

MANAGEMENT PERSPECTIVE

St. Lawrence River water quality data collected in the 1970's and 1980's, were evaluated to provide knowledge on the fundamental chemical and physical forces influencing the river from Kingston, Ontario to Québec City.

This present report displays and discusses data for the dissolved and particulate nutrients, planktonic biomass, clarity, dissolved oxygen, and other "classical" parameters. This approach will amplify our knowledge and understanding of the St. Lawrence River and Estuary, and provides an ecological context for contamination research.

PERSPECTIVES DE LA DIRECTION

On a évalué les données relatives à la qualité de l'eau du fleuve Saint-Laurent, obtenues dans les années 1970 et 1980, pour déterminer les forces chimiques et physiques fondamentales, qui s'exercent sur le fleuve à partir de Kingston en Ontario jusqu'à la ville de Québec.

Le présent rapport présente et étudie les données relatives aux éléments suivants : agents nutritifs dissous et particulaires, biomasse planctonique, turbidité, oxygène dissous et autres paramètres classiques. Cette démarche augmentera nos connaissances sur le fleuve Saint-Laurent et son estuaire et fournira un contexte écologique pour la recherche dans le domaine de la contamination.

ABSTRACT

This paper is an interpretive study of non-toxic constituents of St. Lawrence River water, to provide a "water quality" perspective for research by others on toxic contaminants now polluting this great river.

Two sets of data are used: (1) Janson and Sloterdijk's data record published in 1982, and (2) data from recent surveys using the C.S.S. Limnos, the research flagship of the Canada Centre for Inland Waters. Here, the parameters are plotted versus longitude, as a substitute for distance downstream, and some pairs of parameters are plotted versus each other - strong relations are found.

In terms of the parameters studied in this paper, the St. Lawrence River is "healthy": (1) it has moderate amounts of phytoplankton, turbidity, suspended sediments, dissolved oxygen, pH, and major ions; (2) the nitrogen-to-phosphorus ratio is increasing (this is inferred from Lake Ontario data) and this prevents the occurrence of harmful blue-green algae; and finally, (3) four parameters are directly proportional to each other (approximately). These are: turbidity, total iron, total manganese, and total phosphorus. This suggests that iron colloids may play an important role in the St. Lawrence River and perhaps also in the upstream Great Lakes.

RÉSUMÉ

La présente communication est une étude interprétative sur les constituants non toxiques du fleuve Saint-Laurent, destinée à fournir un cadre de recherche sur la "qualité de l'eau" pour d'autres chercheurs étudiant les contaminants toxiques qui polluent aujourd'hui ce grand fleuve.

On fait appel à deux ensembles de données : 1) les données de Janson et Sloterdijk publiées en 1982; 2) les données récentes obtenues grâce au NSC Limnos, le navire-major de recherche du Centre canadien des eaux intérieures. Ici, les paramètres sont représentés en fonction de la longitude, à la place de la distance en aval, et certaines paires de paramètres sont représentées les unes par rapport aux autres; on trouve ainsi des relations très étroites.

D'après les paramètres étudiés dans cette communication, on peut dire que le fleuve Saint-Laurent est en "bonne santé" : 1) les valeurs sont modérées en ce qui concerne le phytoplancton, la turbidité, les sédiments en suspension, l'oxygène dissous, l'acidité et les principaux ions; 2) le rapport azote/phosphore est en hausse (d'après les données du lac Ontario), ce qui empêche la croissance d'algues bleu-vert; 3) quatre paramètres sont directement proportionnels l'un à l'autre (approximativement), à savoir la turbidité, le fer total, le manganèse total et le phosphore total. Cela laisse supposer que les colloïdes de fer pourraient jouer un rôle important dans le fleuve Saint-Laurent et peut-être aussi dans les Grands Lacs supérieurs.

LIST OF FIGURES

Figure 7. St. Lawrence River, Cornwall to Québec City: total phosphorus in water samples from 29 stations, median values in the 1970's, versus longitude. Data from Janson and Sloterdijk (1982).

Figure 8. Lake Ontario, nitrate + nitrite in offshore, near-surface waters in the years 1968 to 1981, cruise mean values. The seasonal minimum was poorly defined in the years 1977 to 1980 which lacked data for August. From Dobson (1984).

Figure 9. St. Lawrence River, Cornwall to Québec City: total iron in water samples at 31 stations, median values in the 1970's, versus longitude. Data from Janson and Sloterdijk (1982).

Figure 10. St. Lawrence River, Cornwall to Québec City: total manganese versus total iron in water samples from 30 stations, median values in the 1970's. Data from Janson and Sloterdijk (1982).

Figure 11. St. Lawrence River, Cornwall to Québec City: total phosphorus versus total iron in water samples from 27 stations, median values in the 1970's. Data from Janson and Sloterdijk (1982).

Figure 12. St. Lawrence River, Cornwall to Québec City: total iron versus turbidity in water samples from 30 stations, median values in the 1970's. Data from Janson and Sloterdijk (1982).

I. INTRODUCTORY INFORMATION

A main concern about the St. Lawrence River is the presence of toxic trace organic chemicals and metals in the biota, the suspended particles, the sediments, and perhaps in the drinking water. This paper provides a preliminary ecological context for the important studies of contamination.

"The St. Lawrence River discharges about 400 km^3 of water annually at Québec City, 44% more than leaves Lake Ontario. The discharge is highest in the spring (April-May), decreases during the summer, increases in late fall (November-December), and is least in winter (January-February) when the river is often frozen" (Pocklington and Tan, 1987). About 6% of Lake Ontario's incoming suspended sediment is exported to the St. Lawrence River (Lum et al., 1987).

II. MATERIALS AND METHODS

II.A. Sampling and Measurements

The earliest of the two data sets used in this paper was published by Janson and Sloterdijk (1982) of the Inland Waters Directorate, Quebec Region, Environment Canada. Analytical methods are given by a code number in the data record, and descriptions of the methods are found in their "Naquadat Dictionary". Depths of sampling seem not to be specified in Janson and Sloterdijk (1982), and also the boats (or ships) for their surveys seem not to be mentioned.

The second data set is that of the National Water Research Institute (NWRI) of Burlington, Ontario. The sampling platforms were the research vessel C.S.S. Limnos, and occasionally the

C.S.S. Advent. Analytical methods are given by a parameter code number and documented in the NWRI/CCIW "STAR Dictionary". Further references for the NWRI methods are to be found in Dobson (1984, 1985). In this present paper, the Appendix is a statistical summary of the NWRI data.

II.B. Data Development

Janson and Sloterdijk (1982) correctly stated (p. xiii): "... experience has shown the median to be a useful estimate of overall conditions. It is noteworthy that the median is less affected by extremes than is the arithmetic average." Their listed median values for a number of stations in the 1970's are considered here.

In some of the diagrams herein, the longitude of each observational station is used for plotting, approximately but efficiently, the concentrations along an upstream-to-downstream profile of the St. Lawrence River. For future workers, it might be useful and more accurate to establish, for the river profile plotting, one carefully constructed standard table of midstream distances, using the many nautical charts of the entire river.

The approach of this paper is oceanographical/geographical rather than statistical. Major gaps are obvious: there are no transverse sections or maps of plumes.

III. DATA DISPLAYS AND INTERPRETATIONS

III.A. Appearance of the Waters, Algal Abundance, and "Trophic" Classification

III.A.1. Turbidity

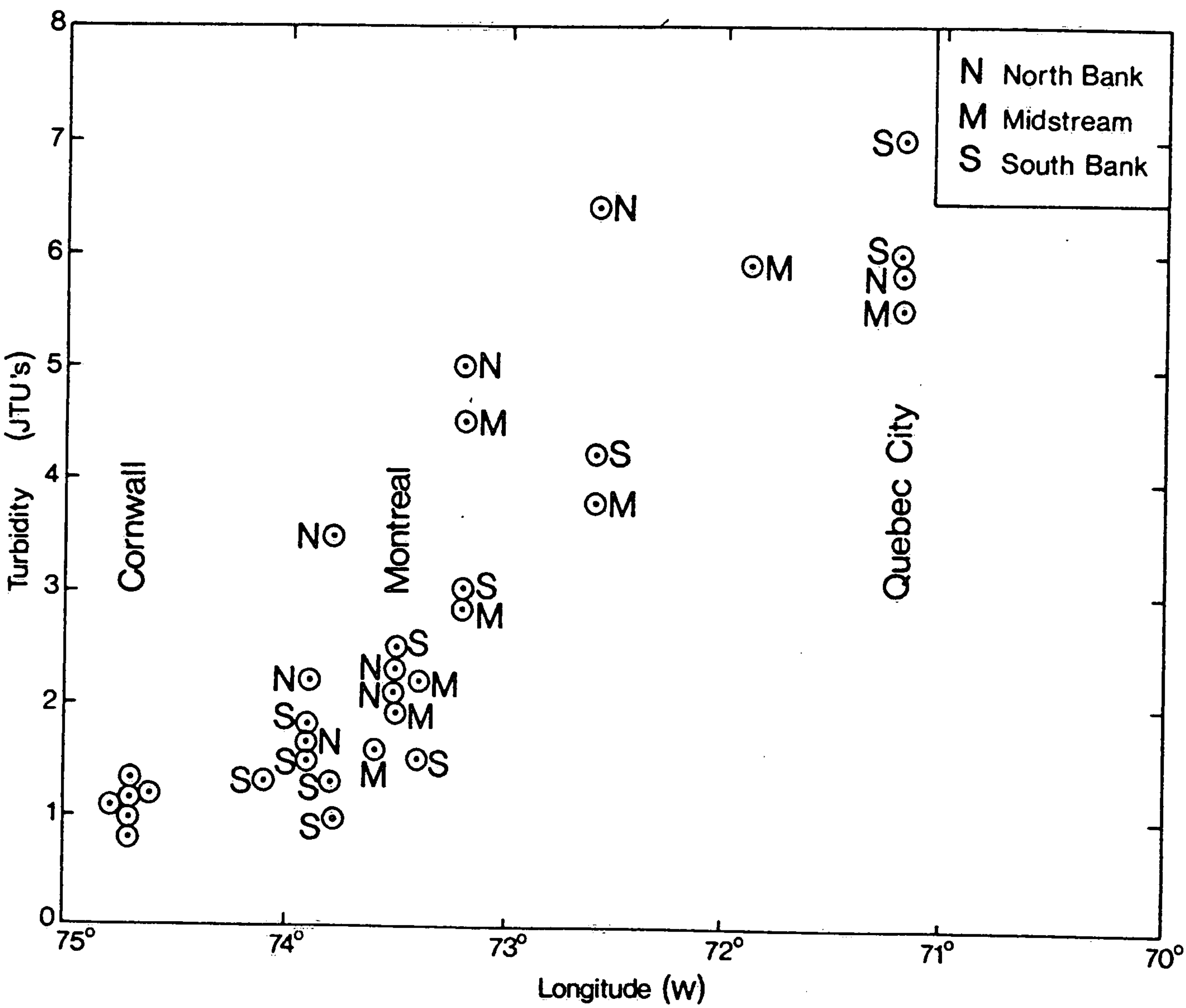
"Turbidity" measures suspended particles of many kinds. Particle size (as well as concentration of particles) influences turbidity readings. "Finished" drinking water should be less than five or one Jackson Turbidity Unit (JTU) (McNeely et al. 1979).

Removal of particles that have collected some chemical contaminants is an important process in the treatment of water for drinking.

Figure 1 is a turbidity profile for the St. Lawrence from Cornwall to Québec City, showing median values in the 1970's. These medians increase quite regularly from 1 JTU at Cornwall to about 6 JTU's at Québec City. No doubt the individual readings would show much more "scatter". An interpretation of this figure is attempted in the Discussion section of the paper, below.

III.A.2. Secchi Transparency

As is well known, Secchi depth is the depth of disappearance of a white disc lowered on a line and viewed from the survey vessel. Readings less than 5 m should be recorded to the nearest 0.1 m. Very approximately, 3 m is a healthy value - not too much phytoplankton and suspended sediment, but not too little either, for collecting contaminants. The Secchi reciprocal values are proportional to particle concentration, so mean values should be calculated via reciprocals (Postma 1961).



St. Lawrence River, Cornwall to Quebec City: Turbidity at 34 stations, median values in the 1970's, vs. longitude.
Data from Janson and Sloterdijk (1982).

FIGURE 1

Since 1970, Lake Ontario offshore waters in summer had mean Secchi values of 2.1 to 3.4 m in the different years (Dobson 1984, 1985). On the recent St. Lawrence River cruises of the "Limnos", Secchi depths were measured on the June/July 1987 cruise only: $n = 27$, $\bar{x} = 4.2$ m; SD = ±0.5 m; min = 2.5 m; max = 5.0 m. Here n is the number of samples, $\bar{x}$ is the mean value, and SD is the standard deviation. (One would expect the St. Lawrence riverine lakes to be more turbid on windy days.)

III.A.3. Colour of the Water

On the "Limnos" surveys of water quality, the observations of colour used the Forel-Ule 22 grade scale (Hutchinson 1957, page 416) applied by viewing at the Secchi end-point. Such observations are called "apparent colour" because suspended particles are not removed. The scale is:

Colour Number	Colour Name
1	Blue
5	Blue-green
9	Green
13	Yellow-green
18	Yellow
22	Brown

The "Limnos" survey of June and July 1987 included 17 colour measurements with a range of 12 (yellow-green) to 20 (yellow-brown). Streaks of white appeared in some satellite pictures in summer, apparently due to suspended calcite (Bruton et al. 1988), which is known to occur in the surface waters of Lake Ontario (Strong and Eadie 1978). Our scale cannot cope with such a colour, or the colours of some industrial waste discharges.

[Aerial photography would be a useful tool for studying water quality in these and other waters.]

III.A.4. Chlorophyll a and "Trophic" Classification

The concentration of chlorophyll a (total or active) is an approximate measure of phytoplankton amount or concentration in a water sample (Tolstoy 1979), and is much more efficiently measured than total phytoplankton volume (Jones and Lee 1982).

Many workers studying eutrophication of water have suggested quantification of the "trophic" lake-type system, using total phosphorus, chlorophyll a, and sometimes Secchi transparency. But no single assignment of type ranges has been generally accepted. Type boundaries should probably be related to each other by factors of one-third and three (R.A. Vollenweider, personal communication). It has previously been shown how dissolved oxygen measurements could be classified (Chapra and Dobson 1981) and, following Vollenweider's suggestion, how type ranges for total chlorophyll a could be derived from: (a) an observed relationship of chlorophyll to total phosphorus in Great Lakes data, and (b) a total phosphorus "mesotrophic" range of 10 to 30 μg P/L (Dobson 1981):

Trophic Classification	Measured Total Chlorophyll a value (μg/L)
Hypertrophic	Greater than 18.
Eutrophic	6.0 to 18.
Mesotrophic	2.0 to 6.0
Oligotrophic	0.7 to 2.0
Ultra-Oligotrophic	0.0 to 0.7

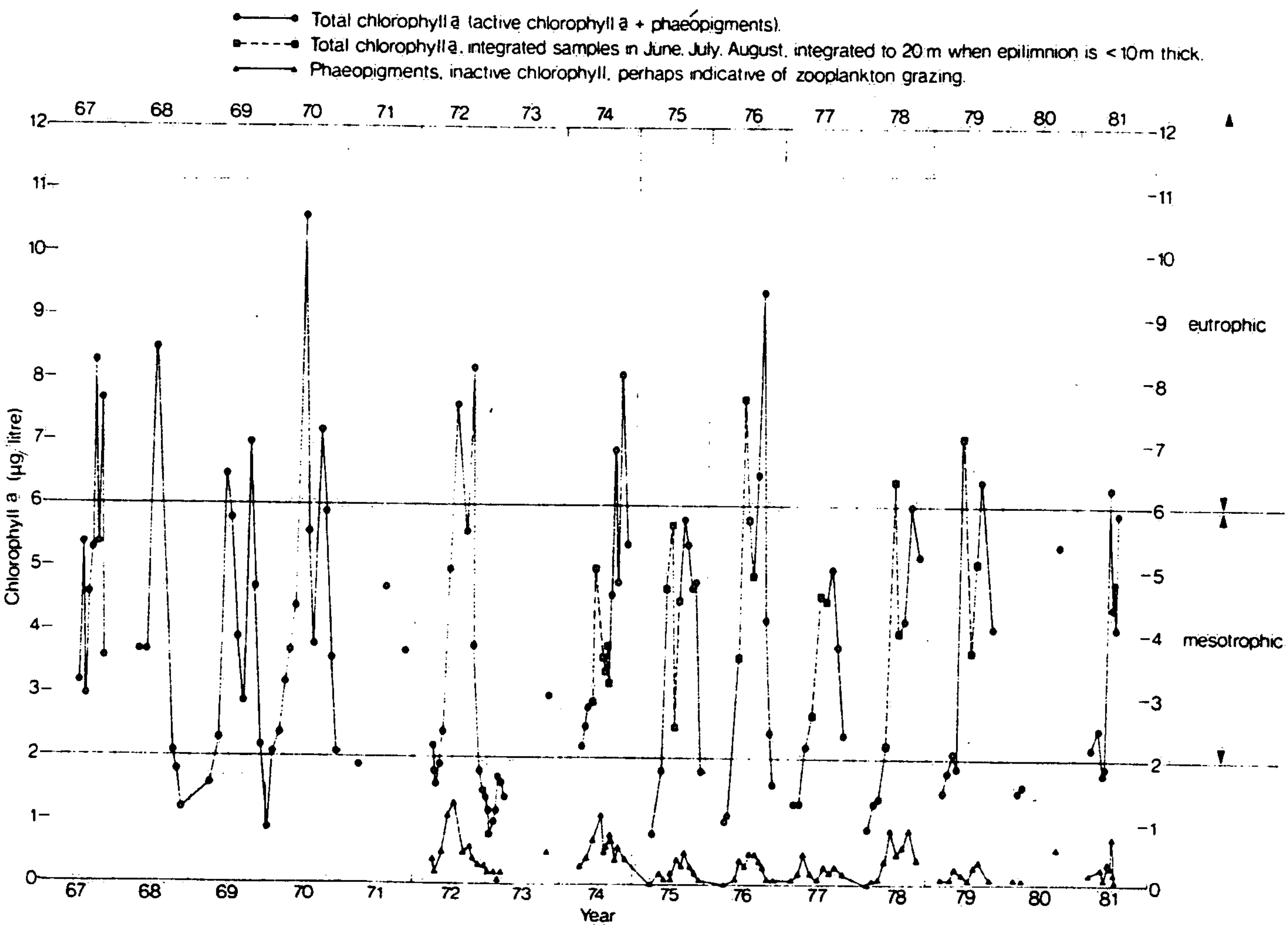
Lake Ontario (the principal source for the St. Lawrence River) has a long-term chlorophyll data set (Figure 2, from Dobson 1984, 1985). Seasonal fluctuations are large but usually there are higher values in summer in the offshore part of Lake Ontario. The classification of these values falls in three type-ranges: oligotrophic in winter; often mesotrophic; and sometimes eutrophic, especially in summer. The author advocates assigning the classification system to individual results, as well as having a single classification for a major water body, so that its variability will be known.

An upstream to downstream profile of chlorophyll in the river shows slightly eutrophic values (Figure 3, June 16 to July 6, 1987) between Montreal and Québec City, and some hypertrophic values (below Québec) where the "Limnos" occupied an "anchor station" on June 27. Table 1, showing anchor station data, indicates great variability and high percentages of "dead" chlorophyll (= pheopigment) - this latter evidence suggests much resuspended dead phytoplankton or "detritus".

III.B. Dissolved Oxygen

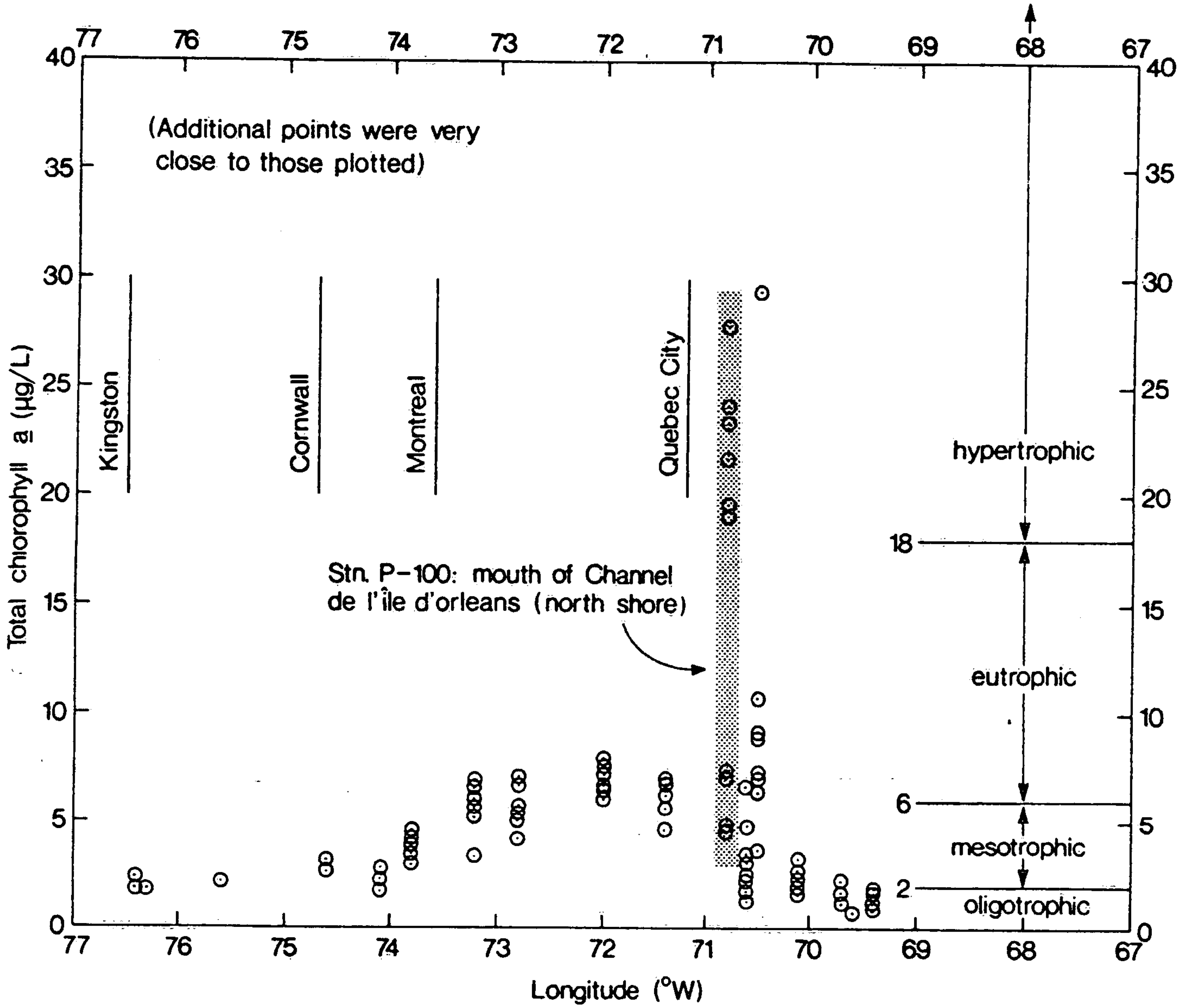
Winkler's oxygen method measures oxygen concentration, whereas electrode methods sense the percent saturation. The percent saturation can also be calculated from mg O_2/L, in situ temperature, and salinity. The recent "Limnos" data, only for October 1985, were obtained by the Winkler method. The consistently high values indicated healthy waters. For simplicity here, percent saturation was not calculated.

A river, as is well known, may have a downstream oxygen "sag" and recovery, below a sewage outfall. These data for the St. Lawrence, summarized below, do not exhibit a sag below



Lake Ontario, chlorophyll a and phaeopigments in offshore, near-surface waters, cruise-mean values in the years 1967 to 1981

FIGURE 2



Total chlorophyll a in near-surface waters of the St. Lawrence River, vs. longitude, June 16 to July 6, 1987, cruise of the Limnos".

FIGURE 3

TABLE 1: Chlorophyll a at station P-100 in the St. Lawrence River below Québec City and near the north shore. Latitude 47°02'30" north, Longitude 70°48'31" west, June 27, 1987, the vessel "Limnos". (Samples from a depth of 5 m.)

	Chlorophyll a (µg/L)		
Time	Total	Active	Pheopigment
0000	4.6	1.4 (30%)	3.2 (70%)
0200	7.0	2.2 (31%)	4.8 (69%)
0400	19.6	4.6 (23%)	15.0 (77%)
0600	23.4	8.5 (36%)	14.9 (64%)
0800	19.1	6.8 (36%)	12.3 (64%)
1000	27.8	13.0 (47%)	14.8 (53%)
1200	4.7	1.4 (30%)	3.3 (70%)
1400	7.3	2.0 (27%)	5.3 (73%)
1600	21.7	10.3 (47%)	11.4 (53%)
1800	24.1	11.8 (49%)	12.3 (51%)
		Mean %: 36.	Mean %: 64.

Montreal or Québec City: either there were no sags, or the sampling was too sparse to detect them.

The oxygen data base is very small: October 1 to 17, 1985; Limnos; $n = 87$; $\bar{x} = 9.37$ mg O_2/L; SD = ±0.28; min. 8.43; max. 9.83.

III.C. pH

The pH is temperature dependent: $\Delta pH/^\circ C \approx -0.010$. Therefore a standard reference temperature is needed for accurate pH values. The electrodes work best at room temperature, yet apparently in these data the pH was measured quickly before much warming. We do not know how the electrodes behaved with rapid temperature changes from sample to sample.

In the Appendix are shown some simple pH statistics. Because of the pH scale, ordinary averaging is not appropriate; medians would be better, although not shown here.

The values are uncertain even at tenths of a pH unit, yet the table shows pH ≈8.1, similar to Lake Ontario and the world ocean, and typical for bicarbonate waters. "Acid rain" apparently has "little" effect on the pH of this river.

III.D. Electrical Conductance and Major Dissolved Salts

Parameters in this group are excellent tracers of different source waters entering a lake or river.

Certain salts are beneficial to human health. For example, drinking waters containing moderately high concentrations of calcium and bicarbonate are claimed to reduce heart diseases (McNeely *et al.* 1979).

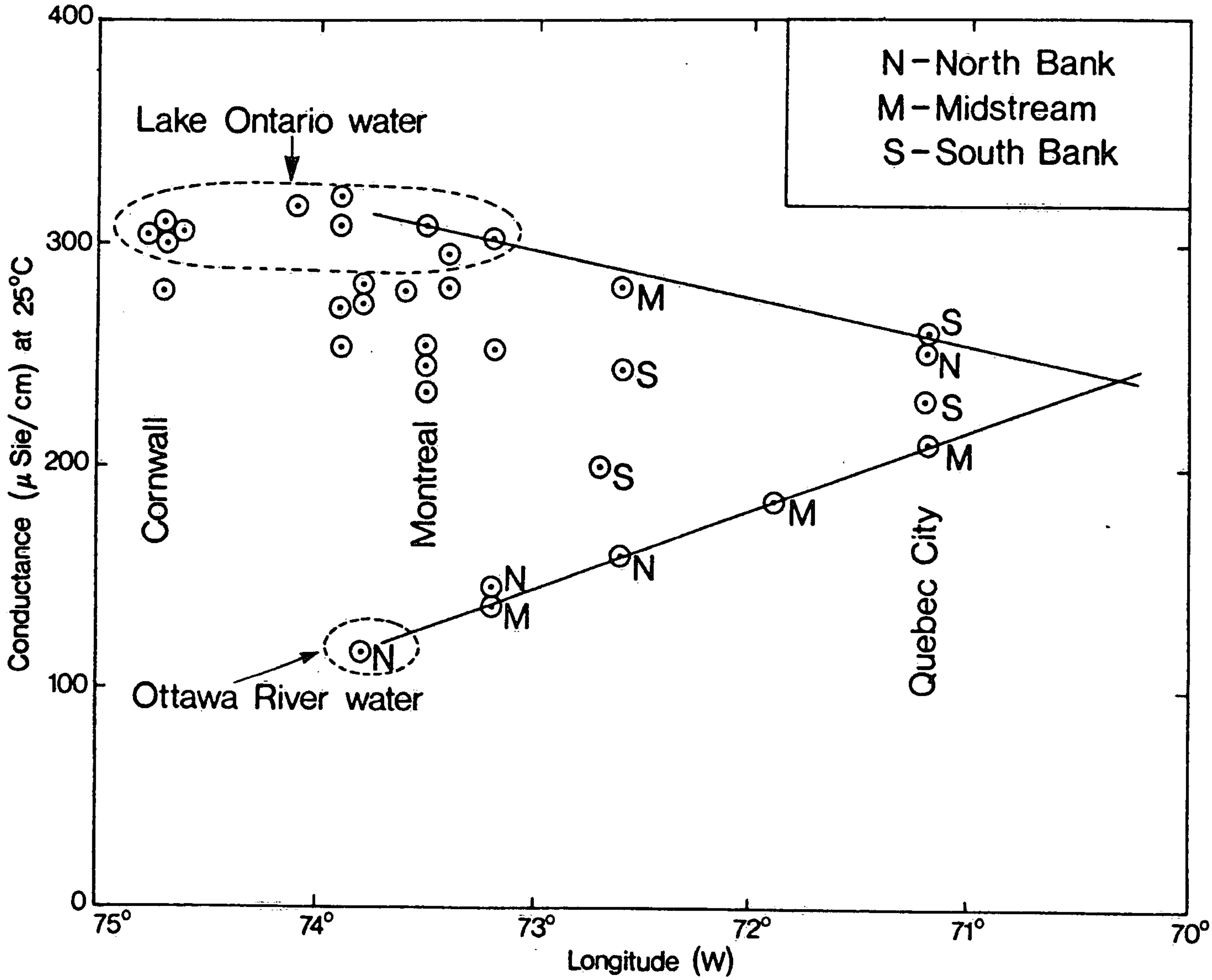
Figure 4 shows median values of conductance (25°C) at stations throughout the St. Lawrence River in the 1970's, from Janson and Sloterdijk (1982), plotted versus longitude. There was gradual mixing of Lake Ontario water and Ottawa River water as the main river flowed downstream from Montreal to Québec City.

Conductance values from three recent "Limnos" cruises (1985, 1987, 1988) had an overall range of 59 to 49,500 µS (25°C); their geographical distributions could be studied on station maps, but that would perhaps be unrewarding if the station networks do not resolve the distributions.

Figure 5 (Dobson 1984), displays long-term trends of principal ions dissolved in Lake Ontario waters. That lake is usually well mixed for these parameters, except for a slight stratification of calcium and bicarbonate (alkalinity) in summer. The three ions, bicarbonate, magnesium, and potassium, have remained constant in this century, but the four ions, calcium, sulphate, chloride, and sodium, have increased. Possible long-term data sets for major ions at drinking water intakes in the St. Lawrence River, if they exist, could allow the construction of long-term trend graphs for a few locations in the river itself.

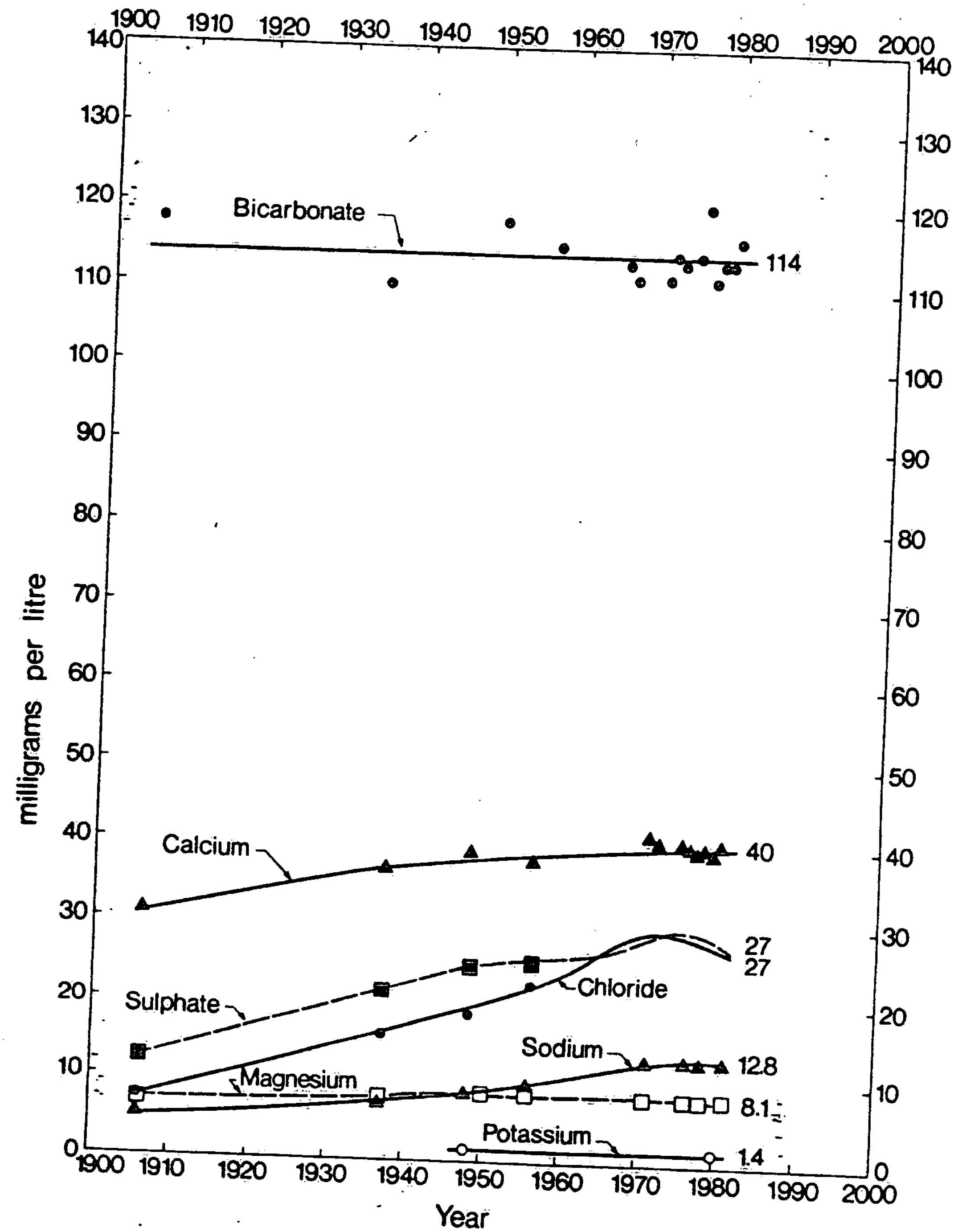
III.E. Major Nutrient Elements: P, N, C; and Silica for Diatoms

Often in near surface waters, one or more of these elements becomes depleted (assimilated by the phytoplankton) and becomes a "limiting factor" preventing further increase of the biomass. In this sense, light and grazing by zooplankton are also common limiting factors. Lake Ontario seems to have phosphorus limitation in August and September each year. Nitrate has increased in recent years in all the Great Lakes, probably due, to some extent, to acid rain (Dobson 1981, 1984; Bennett 1986).



St. Lawrence River, Cornwall to Quebec City: Conductance at 34 stations, median values in the 1970's, vs. longitude. Data from Janson and Sloterdijk (1982).

FIGURE 4



Lake Ontario: trends in the concentrations of seven major ions, 1906 to 1981.

FIGURE 5

III.E.1. Phosphorus

Total phosphorus, in a small (?) water sample, has been given water quality management significance for the Great Lakes: it is the main parameter to assess the result of phosphorus external loading control. Lake Ontario's target is 10 µg P/L. Figure 6 shows a smoothed trend curve and indicates a steady decline from 21.0 µg P/L in 1973 to 10 µg P/L in 1987. According to the data of Janson and Sloterdijk (1982), total phosphorus values in the St. Lawrence are higher downstream than upstream, but with large variability between Montreal and Québec City (Figure 7): this distribution is perhaps due to tributary and outfall contributions and/or resuspension of particles in the river.

Phosphorus fractions can be approximately measured by using or not using filters and acid digestion. Our phosphorus analyses are for total phosphorus, total dissolved phosphorus, and soluble reactive phosphorus. We have had no quantification of the mineral apatite in water samples. A small example is now given for the St. Lawrence River, October 1985, n = 22 only:

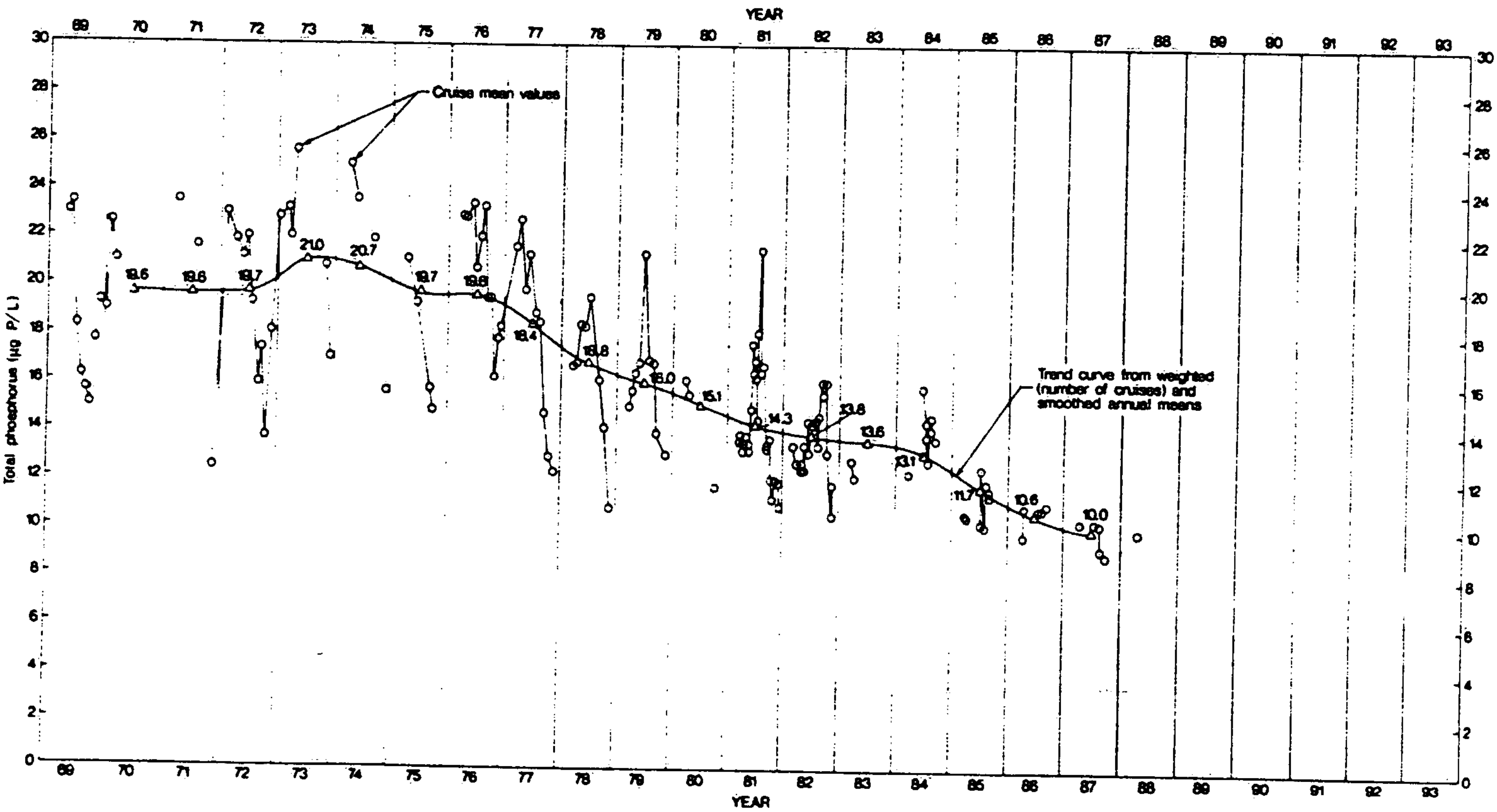
Total P minus total dissolved P = particulate P.

	$\bar{x}$
Total P	22.4
- TDP	13.5
= Particulate P	8.9 µg P/L

Total dissolved P minus soluble reactive P = dissolved organic P.

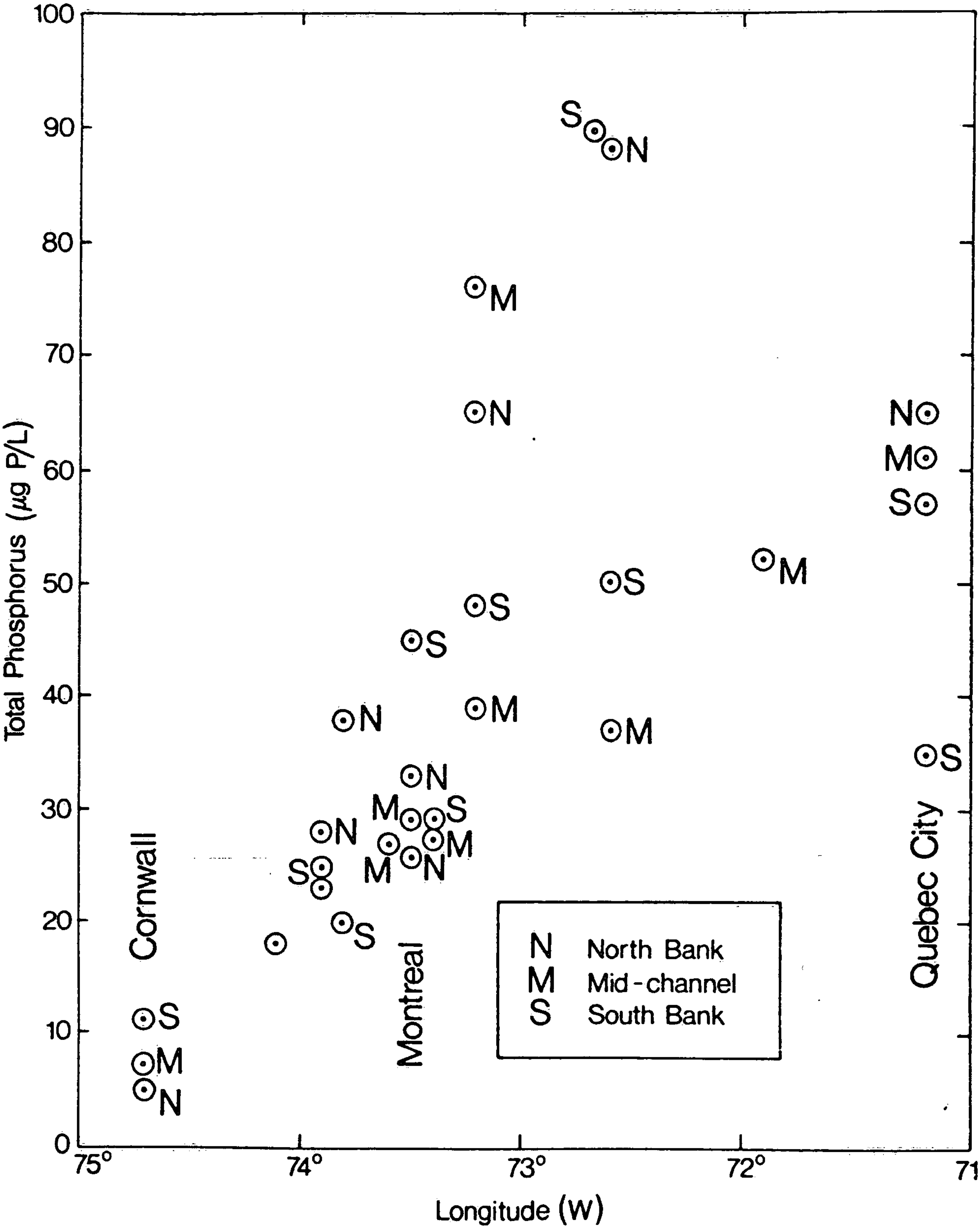
	$\bar{x}$
TDP	13.5
- SRP	4.3
= Dissolved organic P	9.2 µg P/L

The measured parameter "total dissolved P" has no meaning in itself.



Total phosphorus in Lake Ontario, offshore surface waters: CCIW data, cruise-mean values; and a trend curve from weighted (number of cruises) and smoothed annual means.

FIGURE 6



St. Lawrence River, Cornwall to Quebec City: Total phosphorus in water samples from 29 stations, median values in the 1970's, vs. longitude. Data from Janson and Sloterdijk (1982).

FIGURE 7

III.E.2. Nitrogen

The main fractions of the element nitrogen in surface waters are nitrate, urea, ammonia, nitrite, dissolved organic N, particulate N, and dissolved nitrogen gas (N_2). Here, the three underlined fractions have been measured on some of the NWRI surveys of water quality.

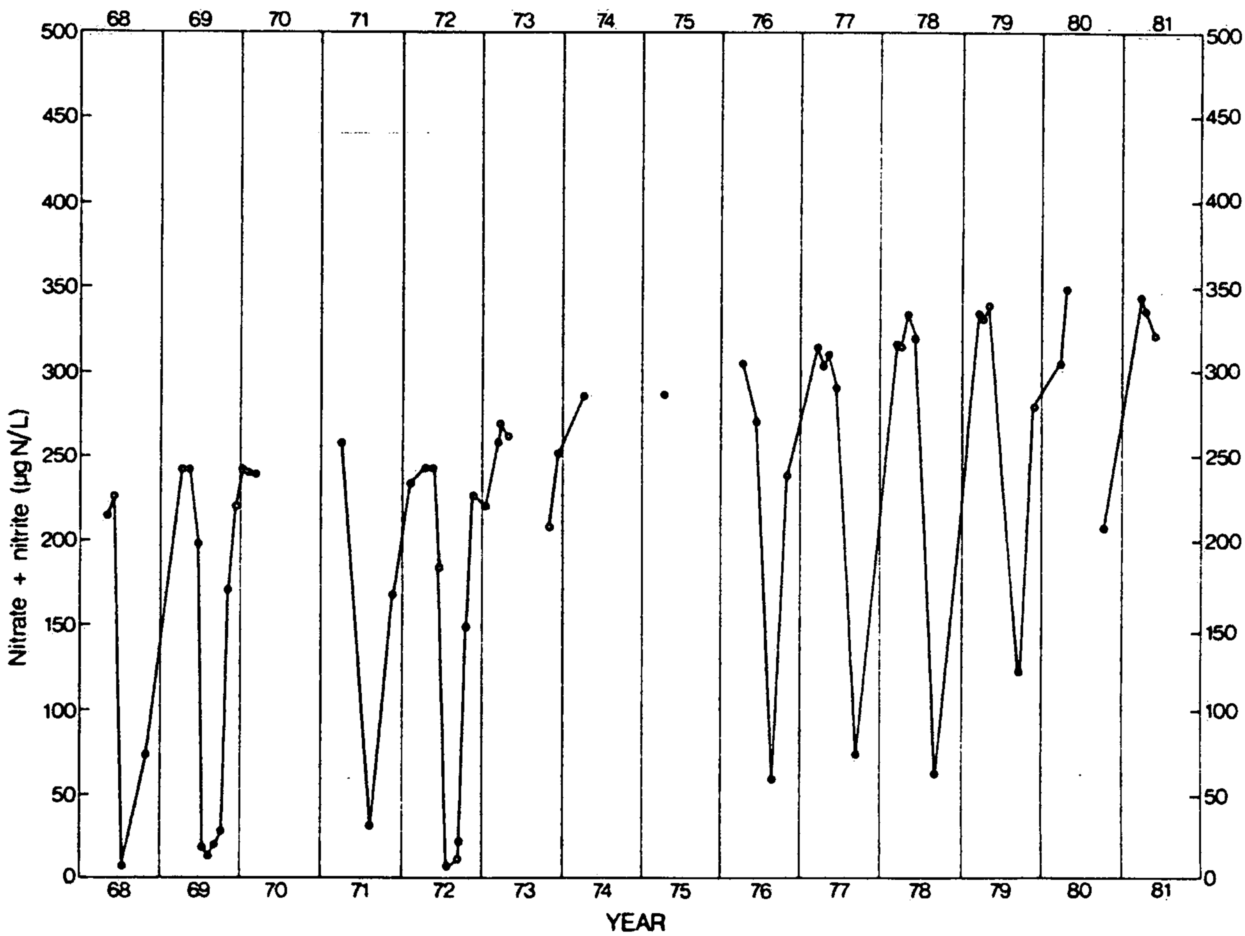
All the Great Lakes now have excess nitrate. This does not have a large effect on algal biomass because phosphorus remains the main limiting factor in the offshore waters. A high ratio of N/P, which we now have, will suppress nitrogen-fixing species of blue-green algae that could produce scums on the surface of waters. So excess nitrate is beneficial if external loadings of phosphorus to the lakes and rivers are controlled and kept low. But with excess nitrogen, phosphorus control in detergents and sewage effluents must continue indefinitely, or else the lakes and rivers will "bloom".

Ammonia is usually low, less than 30 µg N/L, in Lake Ontario (Dobson 1984). If oxygen becomes depleted in lakes or rivers, the nitrate transforms to ammonia, but this has not occurred in the Great Lakes except occasionally in the central bottom water of Lake Erie.

Figure 8 shows (nitrate + nitrite) [mostly nitrate] in Lake Ontario, 1968 to 1981. Late winter values are rising steadily, and August levels became "in excess" in the 1970's.

A few nitrate and ammonia data for the St. Lawrence River were obtained on one of our recent surveys (see the Appendix of this paper). Interpretation would require more data and should include measurements in the various tributaries and outfalls of the river.

Particulate nitrogen was measured on three "Limnos" surveys (see Appendix). The approximate "mesotrophic" range for particulate nitrogen in small water samples is 50 to 150 µg N/L (Dobson,



Lake Ontario, nitrate + nitrite in offshore, near-surface waters in the years 1968 to 1981, cruise-mean values. The seasonal minimum was poorly-defined in the years 1977 to 1980 which lacked data for August.

FIGURE 8

1981). Particulate nitrogen is probably a valuable measure of total (plankton + detritus). Particulate phosphorus is a smaller fraction of the mass of the particles. Particulate carbon may or may not include calcium carbonate crystals. In the St. Lawrence River waters in early summer, particulate nitrogen averaged 155 µg N/L in 1986, and 89 µg N/L in 1987. Then the classification would be mesotrophic/eutrophic in 1986 and mesotrophic in 1987.

For more advanced research, particulate nitrogen measured in various size fractions might be related to the abundance of phytoplankton, zooplankton, and ichthyoplankton, but the size boundaries of these groups may be "blurred".

III.E.3. Carbon

The main forms of carbon in these waters are: bicarbonate (≈alkalinity) (Figure 5), particulate organic carbon (POC), calcite (in surface waters in summer) and dissolved organic carbon. A few data for POC in the St. Lawrence River are in the Appendix. An approximate eutrophic range for POC is 750 to 2250 µg C/L (Dobson, unpublished work). In the river in early summer, the mean values were 1490 µg C/L in 1986 (eutrophic) and 820 µg C/L in 1987 (mesotrophic/eutrophic).

III.E.4. Silica

Aquatic forms of silica are: soluble reactive silica; particulate biogenic silica (diatom frustules), and fine sands.

In Lake Ontario surface waters (1968 to 1982), late winter values of soluble reactive silica were about 300 to 600 µg SiO_2/L and late summer values were about 100 µg/L, indicating silica limitation of diatoms in summer (Dobson 1984). In the recent "Limnos" surveys of the river, there were very few measurements of soluble reactive silica. We did not measure particulate biogenic silica yet. Methods of its analysis are given in Krausse et al. (1983).

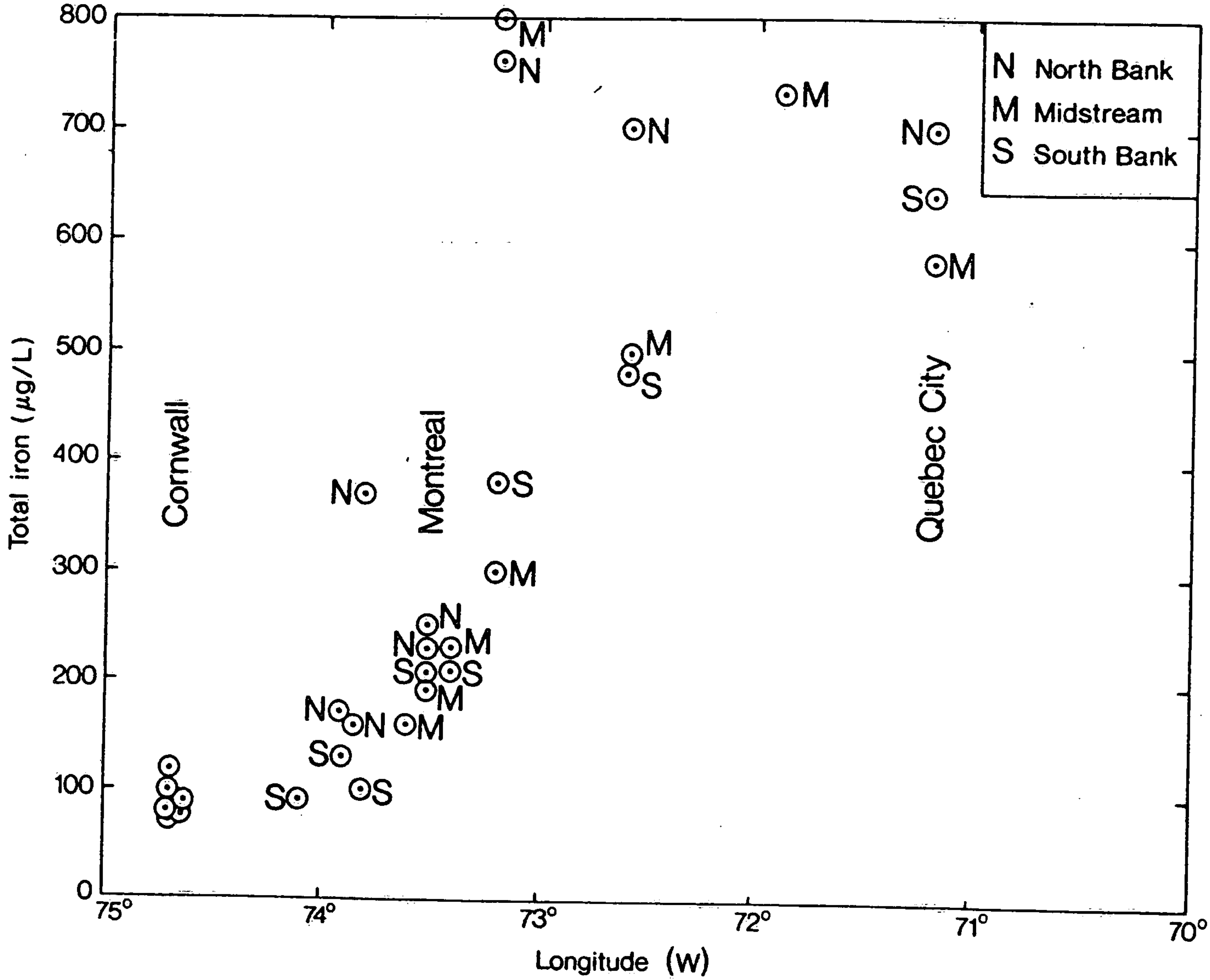
III.F. The Element Iron and Its Relationships With Other Parameters

III.F.1. Iron: A Longitudinal Profile, Median Values in the 1970's (Figure 9)

These data are measurements of total iron in unfiltered water samples. Upstream, near Cornwall, the values are near 100 µg/L. Downstream of Montreal, the median values at different stations are highly scattered in the range 200 to 800 µg/L. No doubt the individual values would show even more extreme variability. There seems to be no regularity of higher values on one side or the other side in the river.

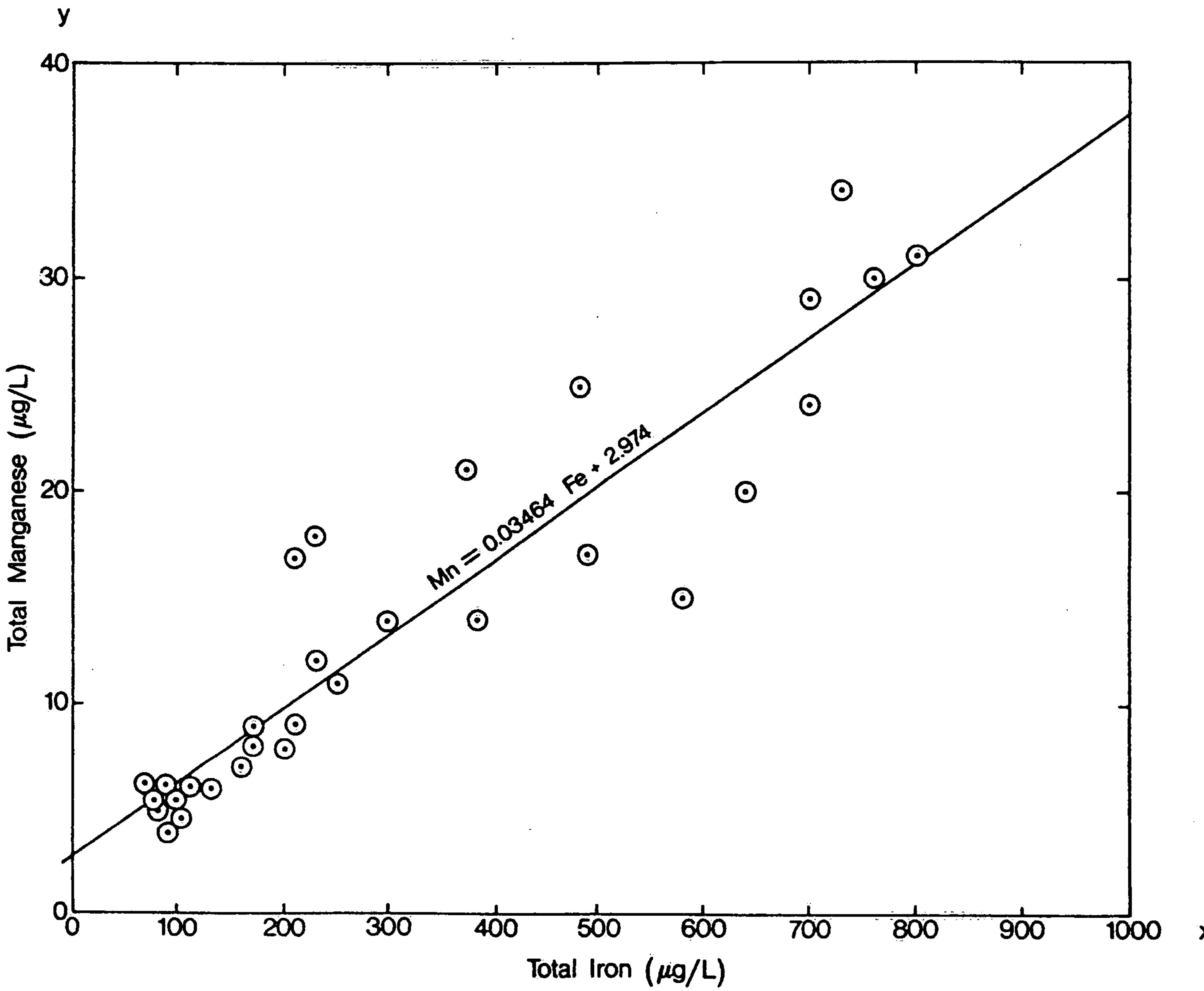
III.F.2. Iron Versus Manganese (Figure 10)

For the same stations shown in Figure 9, this next graph indicates a nearly constant ratio of total iron to total manganese. Are they associated in dissolved or particulate forms, or perhaps colloidal sized particles? The straight line was fitted by least squares regression.



St. Lawrence River, Cornwall to Quebec City: Total iron at 31 stations, median values in the 1970's (water samples), vs. longitude. Data from Janson and Sloterdijk (1982).

FIGURE 9



St. Lawrence River, Cornwall to Quebec City: Total manganese vs. total iron in water samples from 30 stations, median values in the 1970's. Data from Janson and Sloterdijk (1982).

FIGURE 10

III.F.3. Iron Versus Phosphorus (Figure 11)

Total phosphorus and total iron are also closely proportional to each other at the same set of stations (approximately). How much of the total phosphorus is associated with iron colloids in the St. Lawrence River, or even at upstream locations in the Great Lakes and their connecting channels? The answer would require new research. Also, this association of phosphorus with iron might require a deeper understanding of phosphorus/"eutrophication" relationships, in whose context iron has been usually neglected.

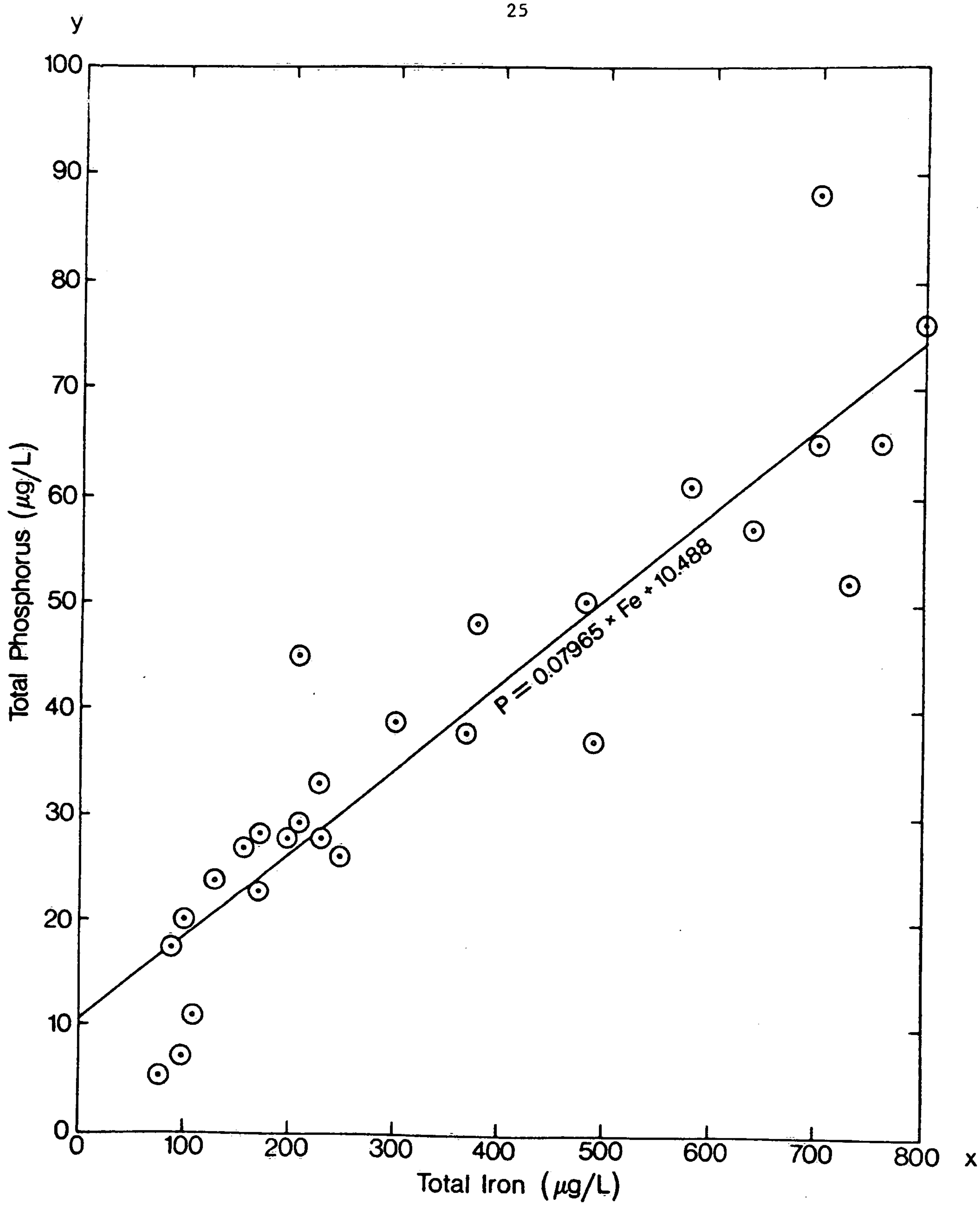
III.F.4. Total Iron Versus Turbidity (Figure 12)

Again there is a close relationship. Probably particles affecting "turbidity" data would be small particles, possibly of colloidal size.

IV. DISCUSSION

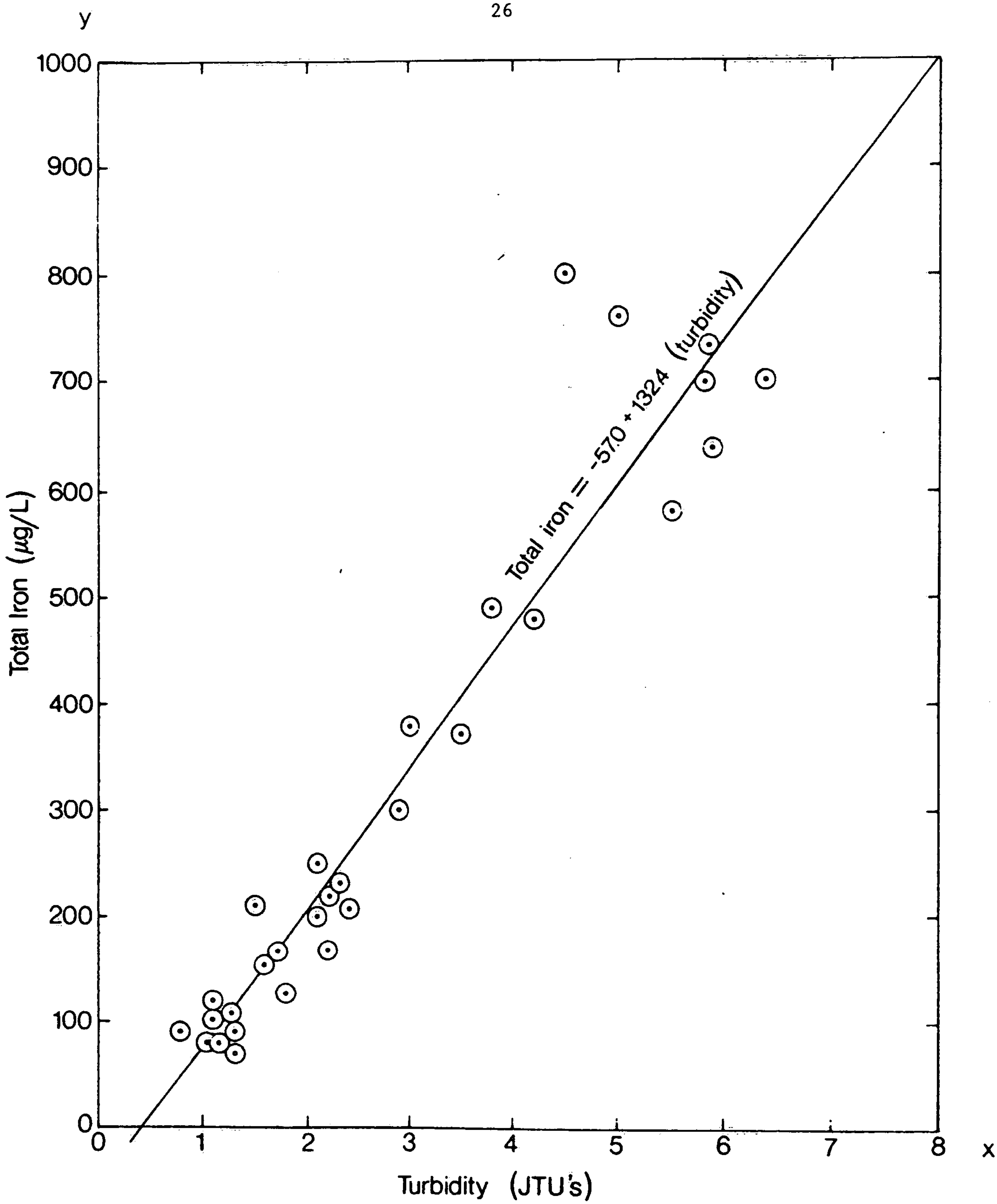
IV.A. Lake Ontario as a Source of Particles

In Lake Ontario in summer, there is a turbid layer, about 30 m thick, in the deeper parts of the lake, composed of diatoms, calcite, quartz, and clay minerals (Sandilands and Mudroch 1983). In autumn and winter, these particles may be dispersed throughout the lake and some, therefore, carried into the St. Lawrence River via the Kingston Basin of Lake Ontario. The particles are probably transported intermittently downstream with some temporary sedimentation in the riverine lakes of the St. Lawrence River, eventually reaching the Gulf of St. Lawrence. Within-river sedimentation and



St. Lawrence River, Cornwall to Quebec City: Total phosphorus vs. total iron in water samples, 27 stations, median values at each station in the 1970's. Data from Janson and Sloterdijk (1982).

FIGURE 11



St. Lawrence River, Cornwall to Quebec City: Total iron vs. turbidity in water samples, 30 stations, median values at each station in the 1970's. Data from Janson and Sloterdijk (1982).

FIGURE 12

transport of particles would have to be studied throughout the year to understand the complex transport and "wash-out" characteristics. To understand the upstream/downstream turbidity profiles (e.g., Figure 1) would require data for different months.

IV.B. Suggestions for Future Monitoring

Studies of water quality and biotic health in the St. Lawrence River, its source waters, and tributaries, will probably continue in the decades ahead. Strategies for such surveys and studies are discussed in Likens (1988).

Here the long experience of oceanography can also offer some wisdom. We must resolve distributions in space-and-time or risk arriving at erroneous results (Defant 1950). The design of station patterns and sampling depths is a scientific art that requires competence and gradually advancing local knowledge of the water body being studied (Stommel 1963).

Monthly cruises by a major vessel in the ice-free period will give knowledge of spatial distributions. In spatial surveys, stations close in space must be close in time also, or erroneous spatial distribution maps will be obtained. Such "quasi-synoptic" surveys, if continued, will also give some knowledge of long-term trends (Dobson 1984, 1985). This plan of monthly surveys would require a long-term commitment of staff, a research vessel, and shore facilities.

Analytical chemical analysis allows the production of major data sets with biological relevance. Size-fractionation plus analysis of chlorophyll, particulate nitrogen, and particulate carbon will give biomass measures of the phytoplankton, zooplankton and ichthyoplankton. Such work could be expanded to include contamination research by also measuring lipid and specific contaminants.

Individual outfall plumes should receive attention and be surveyed under different conditions of wind and current, especially if the outfalls are upstream from drinking water intakes. Smaller research vessels could be used for this plume sampling and mapping.

IV.C. Drinking Water Treatment Facilities and Their Importance

Removal of particles that have collected some chemical contaminants, at drinking water treatment facilities of towns and cities, is a valuable process already in place. Both the presence of particulate matter in the water, and the filtration/coagulation to remove them are conditions that can lower certain contaminant levels in processed drinking water. For some highly polluted source waters such as the Rhine River, activated carbon filtration is an added step to further treat water for human consumption.

V. CONCLUDING STATEMENT

For the parameters studied here, Lake Ontario is a healthy Great Lake and the St. Lawrence River a healthy river. Other biological and chemical studies show that these waters and biota contain certain toxic contaminants. Even if the drinking water is satisfactory as far as contaminant levels are concerned, the impact of these contaminants on biota (plankton; fish; whales) needs to be further assessed. The classical data provided here may help in such interpretations.

VI. ACKNOWLEDGEMENTS

I thank programmers Jackie Dowell and Joanne Hodson, and data manager Jim Byron for their effort in support of this work, and also my supervisor Dr. Klaus Kaiser for encouragement and some patience. Mr. Bill Finn and his staff did the final drafting of the figures. Drs. Paul Hamblin and Rod Allan kindly helped to improve the text.

VII. REFERENCES

Bennett, E.B., 1986, The nitrifying of Lake Superior; Ambio, volume 15, number 5, p.272-275.

Bruton, J.E., Jerome, J.H. and Bukata, R.P., 1988, Satellite observations of sediment transport patterns in the Lac Saint-Pierre region of the St. Lawrence River; Water Pollution Research Journal of Canada, volume 23, number 2, p.243-252.

Canada Centre for Inland Waters, 1982, STAR Dictionary of Parameter Codes and Methods; National Water Research Institute, Data Management Group, Burlington, Ontario.

Chapra, S.C. and Dobson, H.F.H., 1981, Quantification of the lake trophic typologies of Naumann (surface quality) and Thienemann (oxygen) with special reference to the Great Lakes; Journal of Great Lakes Research, volume 7, number 2, p.182-193.

Defant, A., 1950, Reality and illusion in oceanographic surveys; Journal of Marine Research, volume 9, number 2, p.120-138.

Dobson, H.F.H., 1981, Trophic conditions and trends in the Laurentian Great Lakes; World Health Organization Water Quality Bulletin, volume 6, number 4, p.146-151, 158 and 160.

Dobson, H.F.H., 1984, Lake Ontario Water Chemistry Atlas; Environment Canada, Inland Waters Directorate, Ottawa, Scientific Series Number 139, xiii + 59 p.

Dobson, H.F.H., 1985, Atlas de chimie de l'eau du lac Ontario. Environnement Canada, Direction Générale des Eaux Intérieures, Étude Numéro 139, Série Scientifique, xiv + 61 p.

Hutchinson, G.E., 1957, A Treatise on Limnology, Volume 1: Geography, Physics, and Chemistry; John Wiley & Sons, Inc., New York, 1015 p.

Janson, M. and Sloterdijk, H., 1982, Water Quality Data, St. Lawrence River, Québec, 1950-1980; Environment Canada, Inland Waters Directorate, Ottawa, xvii + 159 p.

Jones, R. Anne and Lee, G. Fred, 1982, Chlorophyll - a raw water quality parameter; Journal American Water Works Association, volume 74, number 9, p.490-494.

Krausse, G.L., Schelske, C.L. and Davis, C.O., 1983, Comparison of three wet alkaline methods of digestion of biogenic silica in water; Freshwater Biology, volume 13, number 1, p.73-81.

Likens, G.E. (Editor), 1988, Long-Term Studies in Ecology; Approaches and Alternatives; Springer-Verlag, New York, xvi + 214 p.

Lum, K.R., Kaiser, K.L.E. and Comba, M.E., 1987, Export of mirex from Lake Ontario to the St. Lawrence Estuary; The Science of the Total Environment, volume 67, p.41-51.

McNeely, R.N., Neimanis, V.D. and Dwyer, L., 1979, Water Quality Sourcebook: A Guide to Water Quality Parameters; Environment Canada, Inland Waters Directorate, Ottawa, ix + 88 p.

Pocklington, R. and Tan, F.C., 1987, Seasonal and annual variations in the organic matter contributed by the St. Lawrence River to the Gulf of St. Lawrence; Geochimica et Cosmochimica Acta, volume 51, p.2579-2586.

Postma, H., 1961, Suspended matter and Secchi disc visibility in coastal waters; Netherlands Journal of Sea Research, volume 1, number 3, p.359-390.

Sandilands, R.G. and Mudroch, A., 1983, Nepheloid layer in Lake Ontario; Journal of Great Lakes Research, volume 9, number 2, p.190-200.

Stommel, H., 1963, Varieties of oceanographic experience; Science, volume 139, number 3555; p.572-576.

Strong, A.E. and Eadie, B.J., 1978, Satellite observations of calcium carbonate precipitations in the Great Lakes; Limnology and Oceanography, volume 23, number 5, p.877-887.

Tolstoy, Anna, 1979, Chlorophyll a in relation to phytoplankton volume in some Swedish lakes; Archiv fur Hydrobiologie, volume 85, number 2, p.133-151.

APPENDIX

Statistical Summary of Canada Centre for Inland Waters/ National Water Research Insitute Data, Four Cruises of the "Limnos" on the St. Lawrence River

STAR Code	Name	Date	n	$\bar{x}$ ± S.D.*	Unit
30	Secchi depth	1987 Jun Jul	17	4.2 ± 0.5	m
31	Colour	1987 Jun Jul	17	16 ± 2	See text
160	Conductance	1985 Oct	96	262 ± 72	µS
160	Conductance	1986 Jun Jul	14	296 ± 29	µS
160	Conductance	1987 Jun Jul	168	10500 ± 16300	µS
160	Conductance	1988 Oct	80	22300 ± 19800	µS
213	pH	1985 Oct	91	8.08 ± 0.22	-
213	pH	1986 Jun Jul	147	8.10 ± 0.10	-
213	pH	1987 Jun Jul	169	8.33 ± 0.36	-
213	pH	1988 Oct	80	7.80 ± 0.19	-
223	Alkalinity	1985 Oct	20	8.02 ± 20.7	mg $CaCO_3$/L
227	Part. Org. C	1985 Oct	22	241 ± 67	µg C/L
227	Part. Org. C	1986 Jun Jul	126	1494 ± 2880	µg C/L
227	Part. Org. C	1987 Jun Jul	166	818 ± 1550	µg C/L
245	Diss. Oxygen	1985 Oct	87	9.37 ± 0.28	mg/L
260	Total Phosphorus	1985 Oct	22	22.4 ± 6.8	µg P/L
263	Sol. React. P	1985 Oct	20	4.3 ± 2.6	µg P/L
264	Total Dissolved P	1985 Oct	22	13.5 ± 4.1	µg P/L
268	Part. N	1985 Oct	22	30 ± 7	µg N/L
268	Part. N	1986 Jun Jul	123	155 ± 263	µg N/L
268	Part. N	1987 Jun Jul	159	89 ± 129	µg N/L
270	Ammonia	1985 Oct	18	20 ± 12	µg N/L
276	Nitrate Nitrite	1985 Oct	20	173 ± 14	µg N/L
283	Sulphate	1985 Oct	20	24.8 ± 5.2	mg SO_4/L
284	Chloride	1985 Oct	20	21.7 ± 6.0	mg/L
295	Sol. React. Silica	1985 Oct	20	997 ± 922	µg SiO_2/L
325	Calcium	1985 Oct	20	32.6 ± 8.1	mg/L
355	Magnesium	1985 Oct	20	7.1 ± 1.7	mg/L
373	Potassium	1985 Oct	20	1.4 ± 0.2	mg/L
389	Sodium	1985 Oct	20	11.0 ± 2.6	mg/L
610	Total Chloro. a	1985 Oct	22	1.7 ± 0.4	µg/L
610	Total Chloro. a	1987 Jun Jul	166	4.5 ± 4.7	µg/L
611	Active Chloro. a	1985 Oct	22	1.2 ± 0.3	µg/L
611	Active Chloro. a	1987 Jun Jul	166	2.2 ± 2.0	µg/L

* N is the number of samples; $\bar{x}$ is the mean value; S.D. is the standard deviation.