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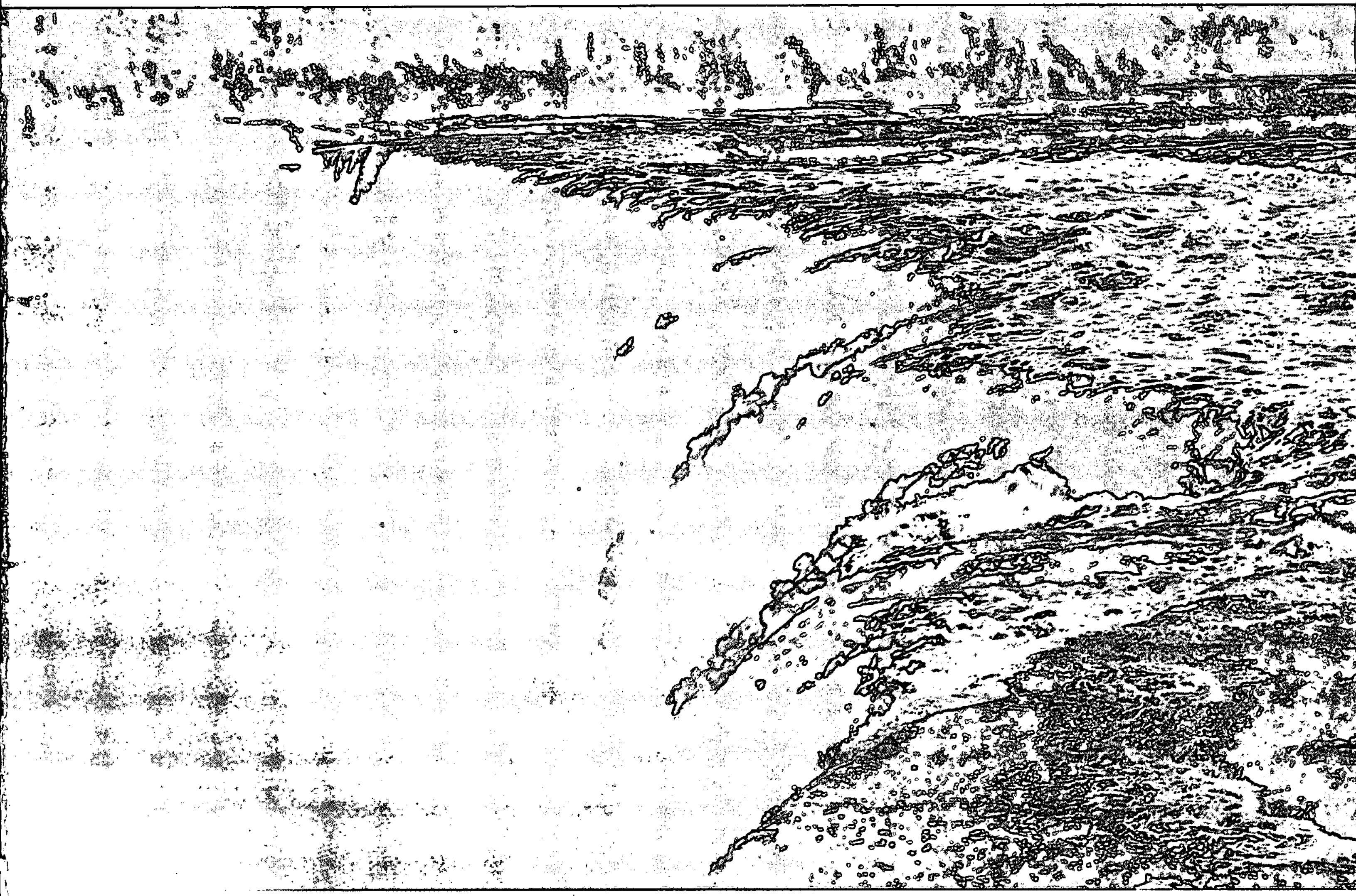
A. Sylvestre, K.W. Kuntz and N.D. Warry



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Abstract

Daily nutrients analyses and weekly major ions and trace metals analyses have been performed since 1977 on water samples collected in the south channel of the St. Lawrence River at Wolfe Island. This report presents the results of the first seven years of this program.

Data analysis showed that pH and total phosphorus were underestimated. Calcium carbonate precipitation is suspected to occur almost every year in August or September. Most of the major ions have decreased, especially chloride and sodium. All trace metal data were below the objectives of the International Joint Commission in 90% of the cases or more.

The Wolfe Island station was found to be a good tool for following the general trend of the main water quality parameters. More attention, however, should be focused on the problems of shipping delays and containers.

Résumé

Depuis 1977, des échantillons d'eau recueillis dans le chenal sud du fleuve Saint-Laurent, à l'île Wolfe, ont été analysés quotidiennement (éléments nutritifs) et hebdomadairement (principaux ions et métaux présents sous forme de traces). Les résultats des sept premières années de ce programme sont présentés.

L'analyse des données montre que les valeurs du pH et du phosphore total ont été sous-estimées. On croit qu'il se produit presque chaque année, en août ou en septembre, une précipitation de carbonate de calcium. La concentration de la plupart des principaux ions, notamment le chlorure et le sodium, a diminué. Dans 90 % des cas ou plus, les valeurs obtenues pour les métaux présents sous forme de traces étaient conformes aux objectifs de la Commission mixte internationale.

On a constaté que la station de l'île Wolfe constituait un bon moyen de surveillance de la tendance générale des principaux paramètres relatifs à la qualité de l'eau. Cependant, une plus grande attention devrait être accordée aux problèmes du retard dans l'expédition et à celui des contenants.

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INTRODUCTION

The St. Lawrence River is the second largest river in Canada in terms of its length and the area of its drainage basin, and has the largest daily discharge of any river in Canada. It is a major transportation corridor to the Canadian and U.S. interiors and is also used for power generation, commercial fishing, recreation, and tourism. The Laurentian Great Lakes, as the source of the St. Lawrence River system, constitute the largest freshwater reservoir in the world.

It has been recognized for some time that the water quality of the Great Lakes has been degraded. In response to the obvious need to control pollution and improve the quality of water in the Great Lakes system, the Great Lakes Water Quality Agreement between Canada and the United States was signed in 1972 and renewed in 1978.

As part of their commitment to the Great Lakes Water Quality Agreement, Canada and the United States carry out surveillance and monitoring activities on the Great Lakes system. This monitoring program was designed to identify instances where environmental water quality objectives were violated, to evaluate water quality trends, and to estimate loadings. As part of this monitoring strategy, the Water Quality Branch, Ontario Region, established a station in 1976 for the daily monitoring of water quality at Banford Point on the south shore of Wolfe Island in the south channel of the St. Lawrence River.

This report presents the first comprehensive assessment of water quality data collected at this station. The data are compared with the data produced from a series of surveys, including transects, conducted around Wolfe Island, as well as eastern Lake Ontario surveillance cruise data. Also, seasonal variation and long-term trends of the major water quality variables are characterized, and loading estimates for the St. Lawrence River are presented. Recommendations regarding future sampling activities at this station are also included.

METHODS

Sampling and Shipping

Surveys around Wolfe Island

In 1973, 1974, 1975, and 1977, the Water Quality Branch, Ontario Region (WQB/OR), undertook a series of comparative surveys along the St. Lawrence River from Kingston to Cornwall. During the first three years, two transects were sampled in the north and south channels around Wolfe Island at mile 185 north and south at approximately equal distances from Longueuil (the zero point). In 1977 a new transect was added at mile 179 off Banford Point (south channel) to evaluate the similarity between this cross section of the river and the Wolfe Island station. Figure 1 shows the location of these transects. Dates, transects, and parameters sampled are summarized in Table 1.

In all cases, water was sampled from a depth of about 1 m, except on June 12, 1977, when a sample was collected from a depth of 15 m at stations 185 north and south to check for thermal and chemical stratification. Field analyses were carried out in a laboratory trailer located at Kingston. The methods used are described in the *Analytical Methods Manual* (Environment Canada, 1979).

Wolfe Island Permanent Station

Description of Sampling Area

The Wolfe Island station sampling area is located between Banford Point and the U.S. shore at latitude 44°12′24″ N and longitude 76°14′18″ W (Fig. 1). The river is about 2.5 km wide at this point. The intake is located 122 m from shore in 13.5 m of water and 5.5 m off the bottom.

Wolfe Island divides the St. Lawrence River into two channels. The south channel receives about 60% of the flow from Lake Ontario, and the north channel the remaining 40% (Casey and Salbach, 1974).

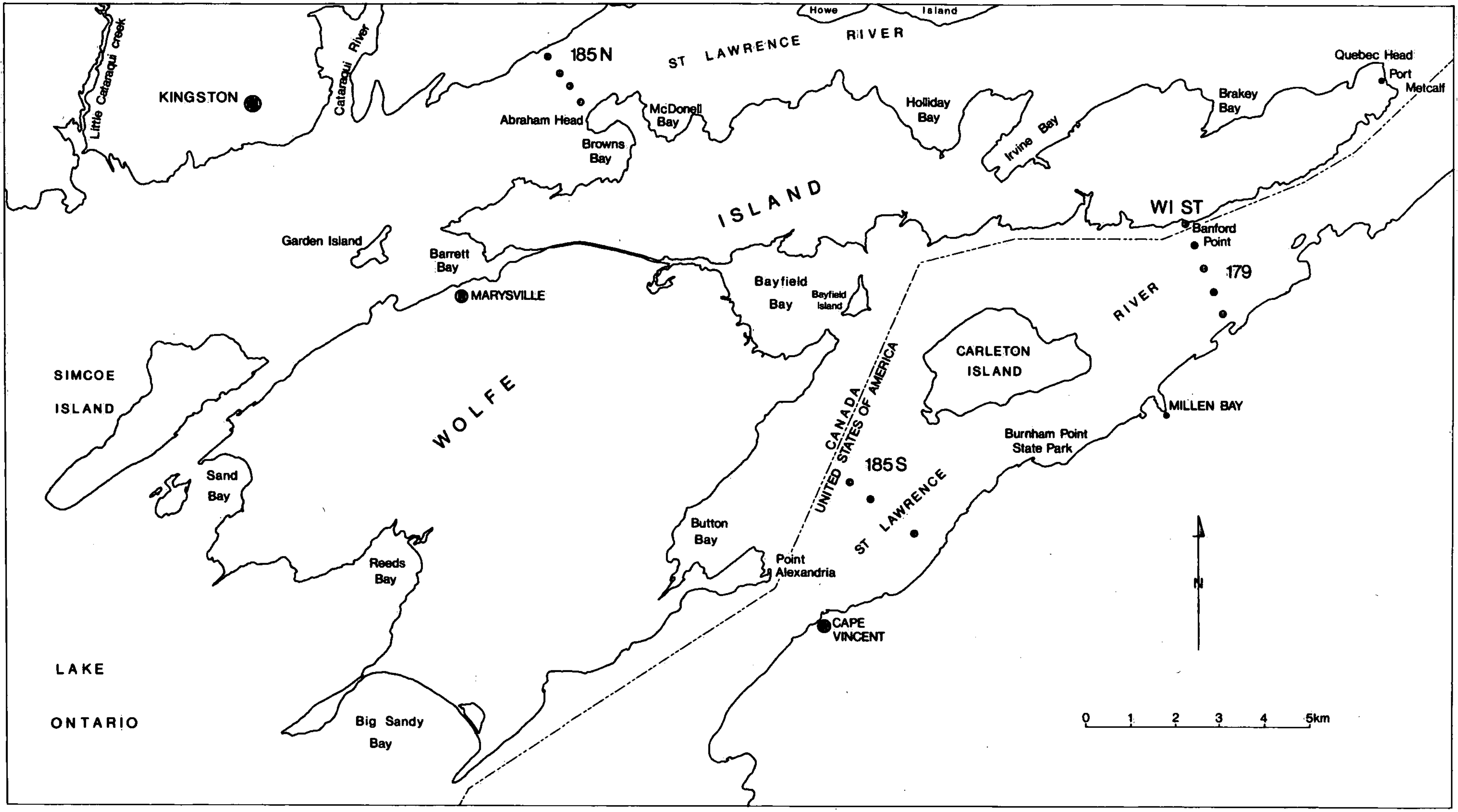

Figure 1. Location of Wolfe Island sampling station (WI ST) and transects.

Table 1. Surveys around Wolfe Island, 1973, 1974, 1975, and 1977

		Parameters						
Date	Transects	pH	Specific conductance	Total phosphorus	Nitrate + nitrite	Total Kjeldahl nitrogen	Major ions*	Trace metals†
73-05	185S-185N	X	X	X	X		X	
73-07	185S-185N	X	X	X	X		X	
73-09	185S-185N	X	X	X	X		X	
74-06	185S-185N	X	X	X	X		X	
74-08	185S-185N	X	X	X	X		X	X
74-10	185S-185N	X	X	X	X		X	X
75-06	185S-185N	X	X	X	X	X	X	X
77-05	185S-185N-179	X	X	X	X	X	X	X
77-06	185S-185N-179	X	X	X	X	X		
77-07	185S-185N-179	X	X	X	X	X	X	X
77-08	185S-185N-179	X	X	X	X	X		
77-09	185S-185N-179	X	X	X	X	X	X	X
77-10	185S-185N-179	X	X	X	X	X		

*Calcium, magnesium, sulphate, chloride, sodium, potassium, and total alkalinity.
†Iron, copper, manganese, and zinc.

Banford Point, on the south channel, was chosen as the most suitable location for the establishment of a permanent water quality monitoring station because there is little human influence on the channel there. The area is not highly populated, the dominant activity is farming, and there are no large upstream tributaries. Furthermore, because the channel in this area is quite deep near the shore, the intake can be located in deep water beyond the influence of any shore activities.

Sampling System

The sampling system (Fig. 2) consists of an intake line, a pump, an automatic sampler, and two timers. The intake line is a ¾-inch polyethylene tube. In the nearshore area, a 15-m section of 2-inch pipe has been placed over the line to protect it from ice damage during the winter. There are also two standard eavestrough heating cables wrapped around the intake line to prevent freezing. A series of lead weights spaced every few metres keeps the intake line submerged. The line is connected to an anchored spar buoy, which allows the intake to float freely up from the river bottom. The intake is extended perpendicular to the buoy about 0.25 m. Small holes were drilled into the intake to act as a coarse filter preventing small fish and weeds from entering the intake.

The pump used to collect the daily samples is a Moyno Model FA-11.

The automatic sampler was designed and built by the Engineering Services Section of the National Water Research Institute. It can contain up to 24 2-L polyethylene sample bottles.

The system is controlled by two timers. One serves to run the pump for half an hour every hour, thereby keeping air out of the line, preventing freezing, and ensuring adequate flushing of the system. The other timer controls the automatic sampler by moving the inlet arm of the sampler from a drain to the sample bottle and then to the next drain.

During winter the shed is heated to keep the system and water samples from freezing.

Shipping and Preservation

Shipment of samples to WQB/OR at the Canada Centre for Inland Waters is provided by a lay collector. Samples are collected in 2-L polyethylene bottles and shipped weekly. No preservative is added to these bottles, except on Mondays, when samples are split and 1 L is preserved with 4 mL of 50% HNO_3 for trace metals (TM) analysis. As soon as the bottles reach the laboratory, they are stored at 4°C.

In preparation for analysis, the samples are subdivided into two 100-mL glass bottles, one for total Kjeldahl nitrogen (TKN) and nitrate + nitrite ($NO_3 + NO_2$) analysis,

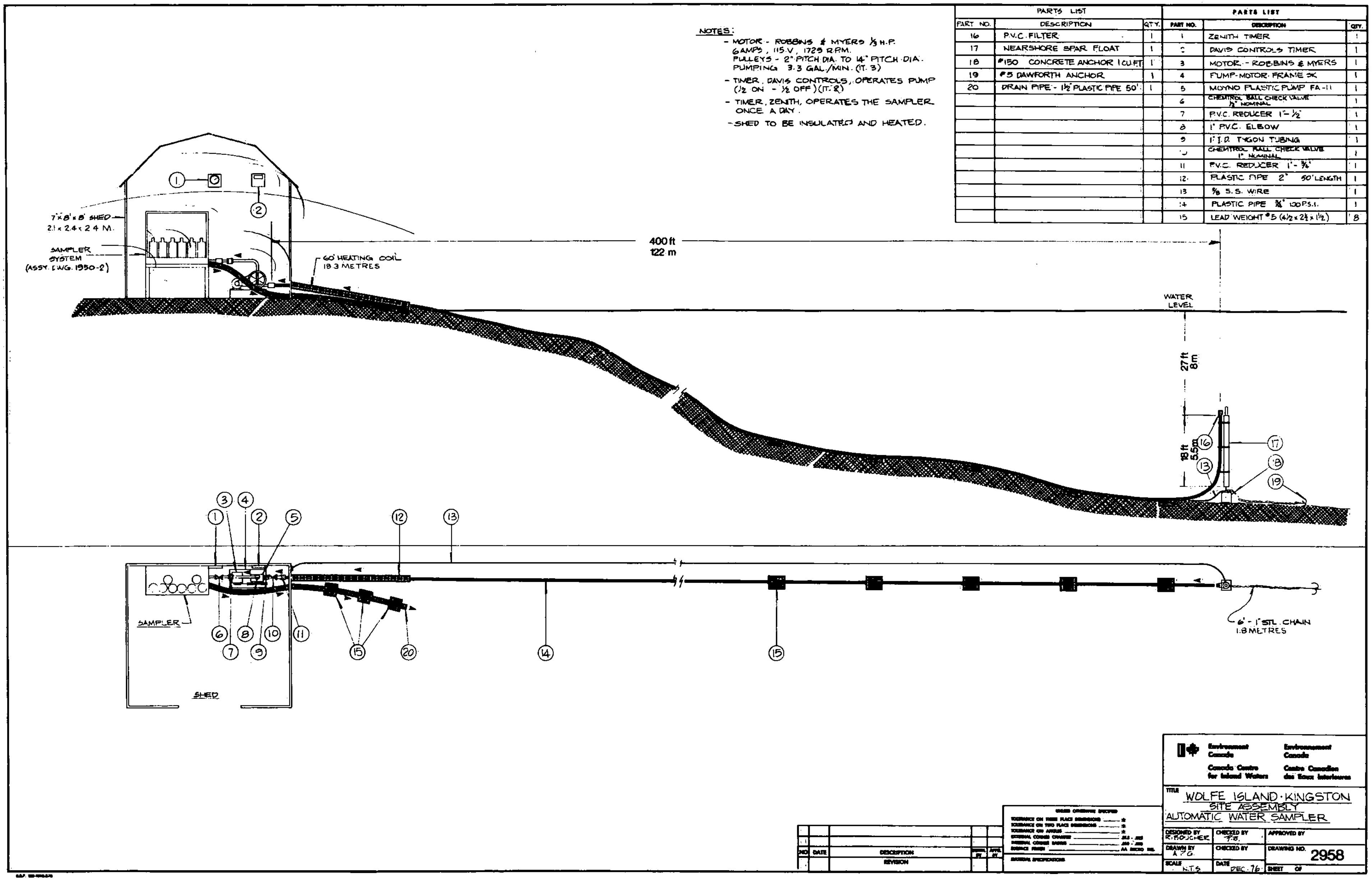

Figure 2. Sampling system at Wolfe Island sampling station.

and the other one, preserved with 1 mL of 30% H_2SO_4, for total phosphorus (TP) analysis. Each week, 125 mL of water is poured into a separate polyethylene bottle and sent to the laboratory for major ions (MI) analysis.

The average delay between sampling and preservation and refrigeration of the samples is about two weeks, but occasionally it can exceed one month.

Discharge Measurement

Daily river flow is measured at the Moses-Saunders Power Plant control facilities at Cornwall, Ontario. Since travel time of water from Kingston to Cornwall is approximately nine days (P. Yee, 1983, Water Planning and Management, Ontario Region, Burlington, Ont., pers. com.), the discharge measured at Cornwall, with a nine-day lag, was used for the flow at Wolfe Island. No compensation has been made, however, for contribution of the tributaries along this section (evaluated at about 1% of the total flow by Casey and Salbach [1974]).

The mean discharge from 1977 to 1983 was 7695 m^3/s. Monthly and annual means are given in Table A-1 (Appendix A). The flow increases from January to a peak in June (8213 m^3/s), then decreases slightly in the summer to increase again in October. Starting in November, there is a large decrease until the minimum flow is reached in January (6658 m^3/s).

Figure A-1 (Appendix A) shows that there was a slight increase (618 $m^3/s/a$) in flow between 1977 and 1983. The flow increased for the first two years of the study, then decreased until 1982, and finally increased slightly the last year.

Analysis and Data Archiving

Analysis of the Parameters

Analyses are made for four main categories: physicals, nutrients, major ions, and trace metals. Table 2 gives a list of parameters measured and their respective NAQUADAT codes (Environment Canada, 1981b) under each of these categories.

Detailed descriptions of the analytical methods for each parameter are summarized in the *Analytical Methods Manual Update 1981* (Environment Canada, 1981a). These methods have not changed significantly since 1976 (D. Sturtevant and O. El Kei, 1983, National Water Quality Laboratory, Burlington, Ont., pers. com.).

Table 2. Parameters Analyzed in Water Samples from Wolfe Island, 1977-83

Parameters	NAQUADAT Codes
Nutrients	
Total phosphorus	15413P
Nitrate + nitrite	07112L
Total Kjeldahl nitrogen	07010L
Major ions	
Calcium	20108L
Magnesium	12106L
Sulphate	16307L
Chloride	17208L
Sodium	11107L
Potassium	19107L
Total alkalinity	10116L
Trace metals	
Iron	26004P
	26005P
Cadmium	48002P
Chromium	24003P
Copper	29005P
Lead	82002P
Manganese	25004P
	25005P
Nickel	28002P
Zinc	30005P
Aluminum (ext.)	13302P
	13305P
Physicals	
Specific conductance	02041L
pH	10301L

Trace metals and major ions analyses are generally completed within six months, and nutrients from one to three months after sampling.

Validation and Data Archiving

One of the standard methods used to validate the data in the laboratory is the calculation of the ionic balance. The details and explanation of the program created to execute this balance are reported by Demayo (1971).

The theoretical basis for using ionic balance is that, in any sample, the sum of cations must equal the sum of anions when both concentrations are expressed in milliequivalents per litre. "In practice, the sums are seldom equal because of unavoidable variations in the analysis. This inequality increases as the ionic concentration increases" (*Standard Methods for the Examination of Water and Wastewater*, 1975). Acceptable limits for the difference between the sum of anions and cations have been taken as

±1 standard deviation. These limits and the equation for calculating them are from *Standard Methods for the Examination of Water and Wastewater* (1975) and take into consideration the ionic concentrations. The cations that enter into the equality equation are calcium, magnesium, potassium, and sodium; the anions are carbonate, bicarbonate, sulphate, chloride, fluoride, nitrate + nitrite, and the hydroxide ion.

The ionic balance program is applied to every sample. When the difference exceeds the acceptable limit, the data are examined in detail or the analyses repeated. This practice has been standard in the laboratories of the WQB since before the permanent station at Wolfe Island was established in October 1976. Therefore, all the parameters mentioned above have been checked by ionic balance calculations.

Blanks, spikes, and duplicates are also performed regularly by the laboratory to check analytical methodologies. All the data must be approved by the chemist in charge of each laboratory before they are given to the project leader.

When the analysis and the validation process are completed, results are entered in AWQUALABS (Automated Water Quality Analytical Laboratory System). After completion of all analyses, the information, including date of sampling, analytical method, and concentration measured, is transferred to the NAQUADAT (National Water Quality Data Bank) data base.

Statistical Methods

Grouping and Editing of Data

In order to show temporal trends and seasonal variations of the parameters, it is important to have a reliable set of data. Because of the considerable amount of data, a statistical method has been used to assist in the validation.

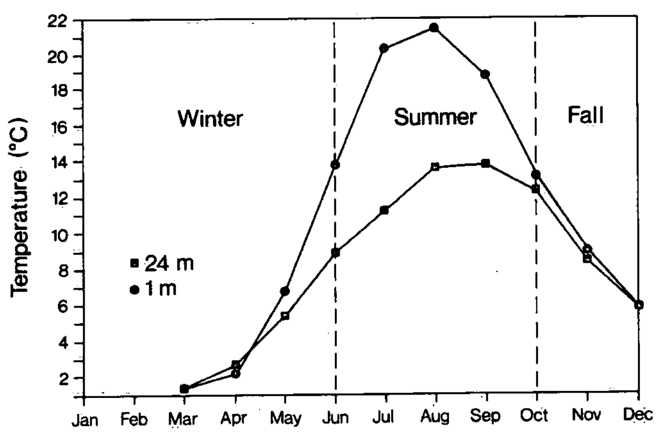

Figure 3. Seasonal grouping based on monthly temperature profiles at station No. 78, 1977–83.

The first step consisted of a seasonal grouping of the data because of the high variability of certain parameters associated with seasonal changes. To determine the limnological seasons, monthly temperature profiles of the nearest station of the Lake Ontario surveillance program (No. 78) were used (Fig. 3). Heterogeneity of temperature in the water column was identified as summer. Two seasons were determined when water was homogeneous: first the fall, corresponding to a decrease in temperature, and second the winter, a period of more stable cold water associated with a slight increase. The resulting grouping of the months into seasons is as follows:

Fall	October, November, December
Winter	January, February, March, April, May
Summer	June, July, August, September

This seasonal cycle corresponds well to the one proposed by Dobson (1984) for Lake Ontario. The differences lie in the fact that the slow-warming period called "early spring" (April and May) by Dobson was classified here as winter and that the rapid-warming period called "late spring" (June) was included here with summer.

Seasonal means were calculated for nutrients and major ions, and yearly means for trace metals. The values exceeding the means, ±3 times the standard deviation, were transferred to another code in the data bank and are not included in this study. Nevertheless, they should be the object of further examination in order to correct any technical problem or to identify particular local phenomena. The limits for each parameter and the number of values that have been transferred are given in Tables 3 and 4.

Statistical Analysis

The main statistical test used in this study is the one-way analysis of variance. It establishes the simultaneous equality of many populations from estimations done on samples extracted from these populations. The following assumptions governed the application of the variance analysis:

(1) Samples are from a normal population.

(2) The variance of the population is equal.

(3) Values are independent.

(4) The model is additive.

Table 3. Statistical Range and Number of Outliers for Nutrients, Major Ions, and Physicals

Parameters	Winter			Summer			Fall			Total no. analyses
	Range*		No. outliers	Range*		No. outliers	Range*		No. outliers	
	Low	High		Low	High		Low	High		
Nutrients										
Total phosphorus	0.0	0.0482	20	0.0	0.0685	25	0.0	0.0605	14	2462
Nitrate + nitrite	0.0	0.708	26	0.0	0.615	22	0.0	0.589	13	2440
Total Kjeldahl nitrogen	0.0	0.489	11	0.0	0.663	22	0.0	0.419	10	2467
Major ions										
Calcium	34.9	42.7	4	30.9	42.9	3	33.9	41.7	2	335
Magnesium	7.0	8.8	2	7.3	8.5	5	7.4	8.6	0	336
Sulphate	22.3	31.3	1	22.7	31.1	3	23.1	32.1	2	336
Chloride	23.4	30.0	0	23.3	29.9	1	23.7	29.7	0	336
Sodium	11.1	14.1	0	11.4	13.8	0	11.4	13.8	0	336
Potassium	1.1	1.7	2	1.1	1.7	4	1.1	1.7	2	336
Total alkalinity	76.5	108.9	2	69.3	109.5	2	74.1	107.7	3	333
Physicals										
pH	7.4	8.6	14	6.9	8.7	3	7.3	8.5	11	2473
Specific conductance	306	360	16	292	358	21	301	355	9	2474

*Seasonal means ±3 times standard deviation.

Table 4. Statistical Range and Number of Outliers for Trace Metals

Parameters	Range*		No. outliers	Total no. analyses
	Low	High		
Iron	0	0.562	13	346
Cadmium	0	0.002	6	345
Chromium	0	0.010	8	343
Copper	0	0.047	9	344
Manganese	0	0.328	4	328
Nickel	0	0.008	7	345
Zinc	0	0.022	6	343
Lead	0	0.007	3	344
Aluminum (ext.)	0	0.740	1	285

Note: Statistics include values "less than detection limit" as equal to detection limit.

*Annual means ±3 times standard deviation.

It was assumed *a priori* that the population was normal and the model additive for all parameters studied in this report. Equality of variance of the population was verified by the Cochran test. Results are shown with the variance analyses results in each table. Even if homogeneity of variance is not respected, the variance analyses results may give an indication of the simultaneous equality of the means. For this reason they are always discussed.

Independence of the values was verified by the autocorrelation test. Nearly independent values were assumed when the autocorrelation coefficient was smaller or equal to $1.96/\sqrt{n}$. For the variance analyses, only the nearly independent values were used. The lag adopted for each parameter is presented in Table 5. These frequencies give a rough idea of the sampling strategy that would give the maximum information for a minimum sampling effort.

A t-test (Student's t) compared the means of two populations estimated by the sample means. Samples should be independent if the means are normally distributed. An F test was performed prior to comparison of the means

Table 5. Lag Giving nearly Independent Values for the Parameters Measured at Wolfe Island, 1977–83

Parameters	Lag
Total phosphorus	2 days
Nitrate + nitrite	8 days
Total Kjeldahl nitrogen	4 days
Total nitrogen	4 days
Specific conductance	5 days
Calcium	21 days
Sulphate	14 days
Magnesium	14 days
Chloride	14 days
Sodium	14 days
Potassium	14 days
Total alkalinity	7 days
Iron	14 days
Copper	14 days
Nickel	14 days
Zinc	14 days
Aluminum (ext.)	14 days

to determine whether the two populations had the same variance.

The analysis of variance and t-test statistics used in this report are part of the Statistical Package for the Social Sciences (SPSS) program library (Nie *et al.*, 1975). The autocorrelation procedure is from *The IMSL Library* (International Mathematical Statistics Libraries, 1980).

RESULTS AND DISCUSSION

This section is divided into two main parts: first, an examination of the spatial variations around the Wolfe Island station to evaluate the representativeness of the station; and second, a study of the temporal variation of the concentrations measured from 1977 to 1983 at the Wolfe Island station for each category of parameters, i.e., nutrients, major ions, and trace metals. Loading estimates are also included in the last section.

Station Representativeness

Wolfe Island Station versus the St. Lawrence River

Cross-sectional variation during the 13 surveys undertaken from 1973 to 1977 was small for all transects and all parameters. Therefore, a hypothesis of homogeneity of the transects was assumed and the mean of all stations on each transect was considered to be representative of the whole transect (Appendix B, Table B-1).

To compare the Wolfe Island station and the other stations on range 179, a t-test was performed between the transect means and the corresponding daily data from the Wolfe Island permanent station (Appendix B, Table B-1). For the parameters considered (Table 1), there was no significant difference ($\alpha = .05$). Therefore, the variations in sample treatment, such as shipping delay and filtration, do not appear to affect the results significantly.

A comparison of transects 185 north and south was also made using the t-test procedure. For all parameters (Table 1), there was no significant difference ($\alpha = .05$) in surface water quality between the two channels before 1978.

The similarity between the Wolfe Island station and the north and south channel transect stations is based on a small number of samples, all of which were collected before 1978. In order to have more confidence in the assumption that the water quality of both channels is basically similar and that the Wolfe Island station is representative of the whole river, year-round surveys should be undertaken every four or five years.

Wolfe Island Station versus Eastern Lake Ontario

To determine the relationship between Wolfe Island data and eastern Lake Ontario data, Wolfe Island data were compared with data from the nearest station of the Lake Ontario surveillance program (No. 78, lat. 44°05′01″ N, long. 76°24′30″ W).

Although the water depth at station No. 78 is 26 m, only the mean of the top 15 m of data has been used in this comparison because the station at Wolfe Island was about 15 m deep. All data available since October 1976 have been used. The frequency of the cruises and the sampling of the parameters are summarized in Table 6.

Although the analytical methods used for the cruises and Wolfe Island samples were the same (Environment Canada, 1981a), sample treatment was somewhat different. Specific conductance, pH, and nitrate + nitrite were analyzed on the ship immediately after sampling, whereas up to a month's delay occurred for Wolfe Island samples. No filtration is performed on the water collected at Wolfe Island, but the samples collected on the ship are filtered for the major ions and nitrate + nitrite analyses. The methods used for total phosphorus and trace metals are identical.

Data for trace metals are available only for 1979 and total only three cruises. They are very different from the Wolfe Island data. Values measured at Wolfe Island are higher for total iron, copper, and zinc and extractable aluminum. Given the high blanks measured at Wolfe Island, sample bottle contamination is the probable cause for these high metal values, particularly in the case of copper.

Data presented in Appendix C, Table C-1, show that conductance, total alkalinity, nitrate + nitrite, and major ions are similar at both stations ($\alpha = .05$). It is interesting to note that the means found at station No. 78 are all higher than at the Wolfe Island station. This observation was surprising because the water from station No. 78 was filtered.

Total phosphorus values are significantly lower ($\alpha = .05$) at the Wolfe Island station than at station No. 78. Delays between the time of sampling and preservation of the sample probably are responsible for the difference. Adsorption of phosphorus on the walls of the polyethylene bottles used for the sampling and shipping of the water is the probable cause of this decrease. In order to verify this assumption, total phosphorus was sampled in glass bottles and preserved on site twice a week in 1984. It appears, after examination of the results, that samples preserved on site are significantly (paired t test, $\alpha = .05$) higher (12%) than the routine samples ($N = 120$; Sylvestre, 1985).

Table 6. Dates of Cruises and Parameters Measured at Station No. 78, 1976–83

Dates	Parameters					
	pH	Specific conductance	Total phosphorus	Nitrate + nitrite	Major ions*	Trace metals†
76-10-06		X				
76-10-27	X	X				
76-11-18		X				
76-12-05		X				
77-05-11	X	X	X	X	X	
77-06-08	X	X				
77-07-20		X				
77-08-17		X				
77-09-15	X	X	X	X	X	
77-10-15		X				
77-11-17		X				
78-04-12	X	X	X	X	X	
78-05-11	X	X				
78-06-07	X	X				
78-07-06		X				
78-08-11		X				
78-09-07	X	X	X		X	
78-10-13		X				
78-11-16		X				
79-04-11	X	X	X	X	X	
79-05-02	X	X	X	X	(Cl)	X
79-05-30	X	X				X
79-06-28	X	X				
79-08-01	X	X				
79-08-30	X	X				X
79-09-19	X	X	X	X	(Cl)	
79-11-21	X	X	X	X	(Cl)	
80-04-23	X	X	X	X	X	
80-10-09	X	X	X	X	X	
81-03-21	X	X	X	X	X	
81-04-08	X	X	X	X	X	
81-04-14	X	X	X			
81-05-21	X	X	X			
81-06-17	X	X	X			
81-07-15	X	X	X			
81-08-13	X	X	X		X	
81-09-16	X	X	X			
81-10-08	X	X	X			
81-11-20	X	X	X	X	X	
81-12-08	X	X	X			
82-04-28	X	X	X	X	X	
82-05-20	X	X	X			
82-06-16	X	X	X			
82-07-14	X	X	X			
82-08-18	X	X	X			
82-09-15	X	X	X	X	X	
82-10-14	X	X	X			
82-11-17	X	X	X	X	X	
83-03-16	X	X	X	X	X	

*Calcium, magnesium, sulphate, chloride (Cl), sodium, potassium, and total alkalinity.
†Iron, copper, aluminum, and zinc.

Summer pH values at Wolfe Island decreased while pH measured at Lake Ontario station No. 78 increased. This behaviour of pH at Wolfe Island during summer seems unusual because photosynthetic processes usually result in an increase in pH as a consequence of utilization of dissolved CO_2 by photoplankton (Wetzel, 1975). A difference as high as 1.0 pH unit was found between the two stations in July and August 1982. Since pH values are taken *in situ* (day) at station No. 78 and the location is approximately 20 km upstream from the Wolfe Island permanent station, it was expected that the values would be similar. As in the case of total phosphorus, the decrease at the Wolfe Island station may be a consequence of the delay between sample collection and measurement. As the bottles are in transit, bacterial respiration may increase the CO_2 level in the bottles, inducing a decrease of pH. This also happens in winter, but at a lower rate, probably because of the decrease in microbiological activity in cold water.

Results from the Wolfe Island Station

Nutrients

Total Phosphorus

It has been stated in the previous section that the concentration of total phosphorus collected from Wolfe Island is biased low. The relative concentration changes with time, however, should be indicative of the trends. For this reason, the data will be briefly examined in this section in terms of trends.

Variations in total phosphorus concentration are frequent and quite erratic at the Wolfe Island station. No regular seasonal pattern emerges from the monthly plot of the data (Appendix D, Fig. D-1). The general mean for the period 1977-83 was 13.7 µg/L, with a median of 12.3 µg/L (Table 7).

Table 7. General Statistics for Nutrients at Wolfe Island, 1977-83

Parameters	Units	N*	Mean	St. dev.	Median
Total phosphorus	mg/L P	2403	0.0137	0.0063	0.0123
Nitrate + nitrite	mg/L N	2379	0.225	0.096	0.237
Total Kjeldahl nitrogen	mg/L N	2424	0.222	0.059	0.218

*Number of observations.

The monthly moving average plot of total phosphorus concentration (Appendix D, Fig. D-1) shows a decline of 0.7 µg/L/a for the study period. This amounts to a decline of 4.3% a year, when measured against the initial 1977 concentration of 16.3 µg/L. This decreasing rate is slightly lower then the decline of 1.1 µg/L/a reported for Lake Ontario (Neilson, 1983) for the period 1970-82 (spring surface data).

An analysis of variance was carried out on the Wolfe Island data. The annual means and the March and April means are significantly different ($\alpha = .05$) (Table 8). The March and April data set was used separately to compare with the data from the Lake Ontario surveillance cruises, which exist only for the March or April period of each of the years from 1977 to 1983. It is apparent that the decline has not been continuous for both Lake Ontario and the Wolfe Island station, and the timing is different. In Lake Ontario the largest decline was observed between 1977 and 1978, while in the St. Lawrence River, the largest decline occurred a year later (Appendix D, Table D-1). It should be noted, however, that as Lake Ontario spring data still decreased in 1982-83, Wolfe Island concentrations increased slightly during the same period.

Table 8. Comparison of Yearly Means for Nutrients at Wolfe Island, 1977-83

Parameters	Homogeneity of variance	Analysis of variance ($\alpha = .05$)
Total phosphorus	heterogeneous	means ≠
Total phosphorus March and April	heterogeneous	means ≠
Nitrate + nitrite	heterogeneous	means =
Nitrate + nitrite March and April	heterogeneous	means ≠
Total nitrogen	homogeneous	means ≠
Total nitrogen March and April	homogeneous	means ≠

Nitrate + Nitrite and Total Nitrogen

The seasonal nitrate + nitrite concentration is shown in Appendix D, Figure D-2. Seasonal variations are well established. High values occur during March and April and then gradually decrease to reach a minimum in August or September. This decrease in the summer corresponds to the intense period of phytoplankton growth (Munawar and Munawar, 1981) and can be attributed to assimilation of nitrate, as this form of nitrogen is largely used for primary production (Wetzel, 1975). In fall and winter, bacterial decomposition of organic matter produces ammonia followed by nitrification and production of nitrate.

No trends could be defined statistically for the nitrate + nitrite concentrations over the seven-year study period (mean 1977-83 = 225 µg/L). Part of the reason for this is probably the large seasonal variation in the concentration of nitrate + nitrite. Although the nitrate + nitrite increase is not statistically significant (α = .05), the calculated increase in this parameter of 4 µg/L/a (Appendix D, Fig. D-2) is believed to be real. When the rate of increase for total nitrogen is calculated, it is about 9 µg/L/a. This compares well with the reported long-term (1970-82) increase of 8.5 µg/L/a reported for Lake Ontario (linear regression analysis of the raw surface data during isothermal conditions [Neilson, 1983]), although in this case, the increase was for nitrate + nitrite only. A possible explanation for the difference in nitrogen trends is that the Kingston basin is an area of intense phytoplankton production. Consequently levels of nitrate + nitrite are always lower than for the rest of Lake Ontario (Neilson and Stevens, 1984). It may be that the trend reported by Neilson (1983) for the entire lake does not reflect the situation in the Kingston basin. Also, the Wolfe Island trend is based on the entire year's data, which include summer low concentrations. This might pull the trend down.

Specific Conductance and Major Ions

Monthly and yearly means and standard deviations of specific conductance and major ions are given in Appendix E, Tables E-1 to E-8, and monthly moving average graphs are presented in Figures E-1 to E-8.

Seasonal Variation

Specific conductance and alkalinity show a similar seasonal behaviour over the study years: low values in summer, especially in August and September, and high values in winter (Appendix E, Figs. E-7 and E-8). Uptake of ionic constituents by phytoplankton in the summer decreases specific conductance, but does not change alkalinity noticeably because most of the ionic species involved do not contribute significantly to alkalinity (Beeton and Sikes, 1978). In the pH range of natural water, alkalinity is mainly composed of bicarbonate (HCO_3^{--}) (Stumm and Morgan, 1970).

Observed decreases in calcium concentration over the seven-year period (Appendix E, Fig. E-1) could lead one to assume that decalcification of the water is occurring. The explanation of the phenomenon is that utilization of carbonate (CO_2^{--}) by phytoplankton shifts the carbonate equilibrium and induces precipitation of calcium carbonate ($CaCO_3$) as in the following equation:

$$2\,HCO_3^{--} + Ca^{++} \rightarrow CaCO_3\downarrow + H_2O + CO_2^{--}$$

This reaction can occur when temperatures are high and solubility of calcium is low (Stumm and Morgan, 1970). Surface pH reported at station No. 78 is often higher than 8.5 in August, and water temperature exceeds 20°C. Calcium concentrations are also high (Appendix E, Table E-1).

Once precipitation of $CaCO_3$ occurs, specific conductance and alkalinity follow the change in Ca^{++} and HCO_3^{--} concentration, and both decrease. This phenomenon has been mentioned by Allen (1977) and reported for the eastern part of Lake Ontario in late summer 1973 by Strong and Eadie (1978). If the hypothesis is accepted, decalcification might have occurred in the Wolfe Island area in 1978, 1979, 1980, 1981, and 1983. In 1982, the value of alkalinity remained high in August and September when calcium decreased a little, so there was probably no precipitation that year.

Sulphate and potassium do not seem to follow a seasonal pattern (Appendix E, Figs. E-3 and E-6).

Chloride, sodium, and magnesium regularly show low values in April or May (Appendix E, Figs. E-4, E-5, and E-2). These periods correspond to the maximum flow so that dilution may reduce their concentrations. Low values of magnesium appear regularly in May. This could also be due to a more intensive utilization of this element by phytoplanktonic organisms during this period, since magnesium is required as an essential component of the chlorophyll molecule (Wetzel, 1975).

Trends

The mean specific conductance at 25°C for the study period is 329 µS/cm (Table 9). Over the seven-year period, specific conductance showed a slight decrease of 1.2 µS/cm/a. The yearly means are significantly different (α = .05) (Table 10). The values measured at the beginning of the study period seem higher then the rest (Appendix E, Table E-7), probably caused by a decrease in most of the major ions, especially chloride and sodium.

Table 9. General Statistics for Specific Conductance and Major Ions at Wolfe Island, 1977-83

Parameters	Units	N*	Mean	St. dev.	Median
Specific conductance	µS/cm	2428	329.0	9.0	329.0
Calcium	mg/L Ca	326	37.9	1.6	38.2
Magnesium	mg/L Mg	329	7.9	0.2	7.9
Sulphate	mg/L SO_4	330	27.0	1.3	27.0
Chloride	mg/L Cl	335	26.6	1.1	26.6
Sodium	mg/L Na	336	12.6	0.4	12.5
Potassium	mg/L K	328	1.4	0.1	1.4
Total alkalinity	mg/L $CaCO_3$	326	91.1	5.2	91.0

*Number of observations.

Table 10. Comparison of Yearly Means for Specific Conductance and Major Ions at Wolfe Island, 1977–83

Parameters	Homogeneity variance	Analysis of variance (α = .05)
Specific conductance	homogeneous	means ≠
Calcium	homogeneous	means =
Magnesium	homogeneous	means =
Sulphate	heterogeneous	means ≠
Chloride	homogeneous	means ≠
Sodium	homogeneous	means ≠
Potassium	homogeneous	means ≠
Total alkalinity	homogeneous	means ≠

Using the monthly mean moving averages, it appears that all major ions except sulphate and total alkalinity show a decreasing trend during the period 1977-83. The rate varies from -0.01 mg/L/a for potassium to -0.36 mg/L/a for chloride (Table 11). Statistically, however, an analysis of variance between years indicates that calcium and magnesium concentrations do not change significantly (α = .05) (Table 10), while all the other major ions do.

Table 11. Rate of Change (with R^2) for Specific Conductance and Major Ions at Wolfe Island, 1977–83

Parameters	Rate*	(R^2)
Specific conductance	−1.2 μS/cm/a	(.77)
Calcium	−0.19 mg/L/a	(.21)
Magnesium	−0.02 mg/L/a	(.21)
Sulphate	+0.16 mg/L/a	(.29)
Chloride	−0.36 mg/L/a	(.95)
Sodium	−0.15 mg/L/a	(.96)
Potassium	−0.01 mg/L/a	(.46)
Total alkalinity	+0.8 mg/L/a	(.50)

*The rate of change was calculated from the regression line for moving average (Appendix E, Figs. E-1 to E-8).

Magnesium and potassium concentrations have remained stable in Lake Ontario. Allen (1977) reported a value of 8 mg/L for magnesium for the period 1930-70, and 1.4 mg/L for potassium from 1959 to 1970. At the Wolfe Island station, means of 7.9 mg/L for magnesium and 1.4 mg/L for potassium were measured between 1977 and 1983 (Table 9). High 1977 values combined with low 1981 potassium values (Appendix E, Table E-6) might be the reason why the yearly means are significantly (α = .05) different for this parameter.

Starting from a concentration of 31 mg/L prior to 1900, calcium increased in Lake Ontario at a rate of 0.16 mg/L/a Ca before 1970 (Beeton, 1965; International Joint Commission, 1969, in Allen, 1977). In fact this rate was probably lower at the end of the sixties as calcium concentration reached only 40.9 mg/L in 1970 (CCIW unpublished data, 1983) instead of the 42.2 mg/L expected. At the end of the seventies and the beginning of the eighties, a decreasing tendency (spring data) appeared in Lake Ontario (CCIW unpublished data, 1983). The Wolfe Island station showed a decreasing rate of 0.19 mg/L/a for the period 1977 to 1983.

"Background" levels of sulphate were 13 mg/L before 1900. For the period 1906 to 1968, sulphate increased by 0.25 mg/L/a (Allen, 1977). This general tendency continued through the beginning of the seventies, but started to decrease at the end of this decade and increased again from 1980 to 1983 (CCIW unpublished data, 1983). The increasing rate of 0.16 mg/L/a found at Wolfe Island for the period 1977 to 1983 is mainly the result of increases found during the last two years of sampling.

The mean total alkalinity concentration during the study period was 91.1 mg/L $CaCO_3$ (Table 9). This parameter shows an increasing tendency (0.8 mg/L/a), probably highly influenced by the lack of the summer decrease in 1982 (Appendix E, Fig. E-8). Spring values (filtered) for the whole of Lake Ontario (1 m, CCIW unpublished data, 1983) indicate an increasing tendency since 1978 for this parameter.

Trends with respect to chloride and sodium concentration are very clear. Yearly means are significantly different (α = .05) (Table 10) and show a decreasing tendency (Appendix E, Tables E-4 and E-5). Allen (1977) reported that levels of sodium in Lake Ontario between 1950 and 1967 increased from 9 mg/L to 12.2 mg/L. The mean for this parameter in 1977 at Wolfe Island was 12.9 mg/L Na, and data from 1977 to 1983 indicate that this concentration is decreasing at a rate of 0.15 mg/L/a.

An IJC report (International Joint Commission, 1979) stated that Lake Ontario chloride levels increased from 7 mg/L Cl in 1907 to a value of 28 mg/L in 1971 and then stabilized in 1972. Fraser (1981) reported that the concentration of chloride in Lake Ontario decreased since 1974 at a rate of 0.30 mg/L/a to reach a concentration of 26.3 mg/L Cl in 1981. At Wolfe Island, the chloride concentration was 27.5 mg/L Cl in 1977 and decreased steadily at a rate of 0.36 mg/L/a to the 1983 level of 25.6 mg/L. A similar decrease has occurred in Lake Ontario (Neilson, 1983), and an even greater rate of decrease of 0.79 mg/L/a (1976 to 1983) has been observed at Niagara-on-the-Lake in the Niagara River (Kuntz, 1985). These declines can be attributed to reduced industrial discharges of chloride, especially to the Detroit River (Sonzogni *et al.*, 1983) and, therefore, to Lake Erie, which accounts (with the Niagara River) for 71% of the chloride load to Lake Ontario (Effler *et al.*, 1985).

Trace Metals

Of all trace metals data regularly collected at Wolfe Island, only four of the nine metals measured can be discussed, either because of obvious contamination, such as with total copper, or because the metals concentrations are generally lower than the analytical detection capability, such as with cadmium, chromium, manganese, and lead. Because of the large variability in the data set, median rather than mean concentrations are used in the discussion, although mean concentrations are also presented in Table 12 for comparison purposes. Data are displayed in Appendix F, Tables F-1 to F-4.

Table 12. General Statistics for Trace Metals (mg/L) at Wolfe Island, 1977-83

Parameters	N*	n†	Mean	St. dev.	Median
Iron	333	0	0.096	0.083	0.066
Cadmium	339	322	–	–	–
Chromium	335	141	–	–	–
Lead	341	158	0.0012	0.0006	0.001
Manganese	324	124	–	–	–
Nickel	338	76	0.0017	0.001	0.001
Zinc	337	60	0.0032	0.0028	0.002
Aluminum (ext.)	284	0	0.04	0.039	0.03

Note: Statistics include values "less than detection limit" as equal to detection limit.

*Total number of samples.

†Number of values for which "less than detection limit" was reported.

Aluminum (extractable) and nickel levels do not vary much from 1977 to 1983 (Table 13). Median concentrations average 0.030 mg/L for aluminum (1978-83) and 0.001 mg/L for nickel (1977-83). Iron and zinc yearly means are significantly ($\alpha = .05$) different. The median concentrations for these parameters are 0.066 mg/L Fe and 0.002 mg/L Zn.

Table 13. Comparison of Yearly Means for Trace Metals at Wolfe Island, 1977-83

Parameters	Homogeneity of variance	Analysis of variance ($\alpha = .05$)
Iron	heterogeneous	means ≠
Nickel	heterogeneous	means =
Zinc	heterogeneous	means ≠
Aluminum (ext.)	heterogeneous	means =

Over the time frame of this study, three cruises on Lake Ontario were completed for trace metals during May and August 1979 (Table 6). The concentrations measured at Wolfe Island during the same period were higher than the concentrations on Lake Ontario for total iron, lead, nickel, and aluminum. This situation was not statistically investigated because of the limited amount of data available for comparison and the large standard deviation associated with the data sets.

All parameters were below the IJC objectives (International Joint Commission, 1978) in 90% of the cases or more (Table 14). Nickel concentrations violated the objective of 0.025 mg/L 9% of the time, while lead violated the objective of 0.025 mg/L 3% of the time.

Table 14. Great Lakes Water Quality Agreement (1978): Specific Objectives and Violations for Trace Metals

Parameters	Objective (mg/L)	Number of data above objective	Percentage of violation
Iron	0.3	13	4%
Lead	0.025	12	3%
Nickel	0.025	37	9%

Loading to the St. Lawrence River from Lake Ontario

Annual reports on material output from Lake Ontario to the St. Lawrence River have been produced since 1980 (Kuntz, 1982a, 1982b; Sylvestre, 1983, 1984) using all available data. In this report, all concentrations falling outside ±3 times the standard deviation of the seasonal mean for nutrients and major ions or the yearly mean for trace metals have been removed, as explained in the section Grouping and Editing of Data.

The concentrations utilized are applied to both channels of the river, although they have been collected from the south channel only. This was done because the results of the t test completed on the survey data of 1973, 1974, and 1977 indicated there was no chemical difference between the north and south channels (see the section Wolfe Island Station versus the St. Lawrence River).

As explained in the section Discharge Measurement, flow data are determined at Cornwall with a lag of nine days. They are not adjusted for the contribution (1%) from the tributaries that flow into the St. Lawrence River between Wolfe Island and Cornwall.

Daily (D.) loadings were calculated as follows:

D. loading = D. conc. (mg/L) × D. discharge (cfs) × 0.002 45

Yearly loadings were calculated by multiplying the daily mean load for the year by 365 (366 for 1980). The results are displayed in Table 15.

Table 15. Yearly Loading (t/a × 10^3) to the St. Lawrence River, 1977-83

Parameters	1977	1978	1979	1980	1981	1982	1983
Total phosphorus	3.9	4.0	3.2	3.5	2.7	3.1	3.1
Nitrate + nitrite	52.6	54.8	52.9	52.8	54.7	58.3	54.6
Total Kjeldahl nitrogen	55.5	47.9	51.3	56.0	57.8	56.0	55.6
Total nitrogen	108.1	102.7	104.2	108.8	112.5	114.3	110.2
Calcium	9 170.0	9 391.6	9 337.3	9 225.1	9 118.0	9 230.3	9 001.0
Magnesium	1 873.5	1 964.7	1 971.1	1 962.0	1 915.1	1 883.0	1 914.3
Sulphate	6 377.3	6 620.9	6 626.9	6 570.7	6 393.6	6 595.2	6 767.1
Chloride	6 552.1	6 802.8	6 759.7	6 618.2	6 378.5	6 248.6	6 171.7
Sodium	3 075.0	3 186.7	3 210.0	3 104.7	3 003.8	2 977.3	2 946.6
Potassium	344.5	355.3	350.6	351.4	331.6	337.7	344.7
Total alkalinity	58 430.1	60 642.5	61 914.8	60 200.2	60 135.7	63 302.6	60 613.2
Iron	13.4	30.5	11.6	23.2	23.3	37.4	24.4
Nickel	0.5	0.7	0.4	0.5	0.3	0.4	0.4
Zinc	0.9	0.6	0.7	1.0	0.6	0.6	1.1
Aluminum (ext.)	–	8.4	6.5	10.1	12.2	11.9	9.2

The loading increase from 1977 to 1978 for total phosphorus and major ions was probably caused by the high flows that occurred at the beginning of the study period. After 1978, the yearly loading is more related to changes in concentration of each parameter than flow.

Total phosphorus loadings in 1982 and 1983 are 78% of loadings in 1977 and 1978. Nitrate + nitrite and total nitrogen loadings are still above 1977-78 levels even though flows have decreased considerably. Calcium, chloride, and sodium loadings clearly decreased from 1979 to 1983, while sulphate loadings decreased from 1979 to 1981, but increased in 1982 and 1983 in spite of the decrease in flow.

Trace metal loading variations are quite erratic, as there are large changes in concentration with time, especially in the case of iron. Aluminum loading seems to have increased since 1979.

Few obvious seasonal variations were detected except in the case of nitrate + nitrite, for which the summer decrease is evident. Calcium might be precipitating in August or September, inducing a reduction in total alkalinity and specific conductance.

Generally, most elements are decreasing in concentration, except total alkalinity, sulphate, and iron. The chloride decrease might be due to a decrease in industrial loading to Lake Erie.

The Wolfe Island station appears to be a good tool for following the general trend of the main water quality parameters. More attention, however, must be focused on the problems of shipping delay and sampling procedures.

CONCLUSIONS

The sampling site at Wolfe Island is chemically representative of both the north and south channels of the St. Lawrence River. This conclusion, however, is based on a small number of surface samples and should be checked.

Comparison with data from the nearest station (No. 78) of the Lake Ontario surveillance program shows that pH and total phosphorus are both higher at station No. 78. This might be due to shipping delays suffered by samples from the Wolfe Island station.

RECOMMENDATIONS

It is recommended that

(1) regular surveys be conducted in both channels at intervals of every four or five years to ensure that the Wolfe Island station remains representative of the whole river;

(2) *in situ* measurements be used if pH values are measured because they provide a greater degree of accuracy;

(3) total phosphorus samples be sampled in glass bottles and preserved on site;

(4) the sampling procedure for trace metals be examined because of the high blank values obtained for trace metals, particularly copper; and

(5) a statistical study be made to determine the minimum sampling strategy for each parameter that would give the maximum information.

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Appendix A
Discharge Data

Table A-1. Monthly and Annual Means and Standard Deviation for Discharge (m^3/s) at Wolfe Island, 1977–83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	6166.	6244.	7373.	7923.	7845.	7169.	7145.	7512.	8120.	8414.	8431.	6870.	7439.
1978	7236.	8238.	8411.	8487.	8918.	8630.	8041.	7855.	7693.	7365.	6855.	6293.	7831.
1979	6489.	7112.	7784.	8057.	8419.	8251.	7825.	7825.	8074.	8318.	8070.	8338.	7884.
1980	6579.	7408.	7156.	8142.	8286.	8187.	8117.	8409.	8428.	8037.	7876.	6705.	7775.
1981	6809.	6957.	7584.	7170.	7036.	7234.	7547.	8033.	8510.	8444.	8408.	8321.	7675.
1982	6527.	7192.	7290.	7999.	8073.	8330.	8113.	7806.	7659.	7435.	7657.	7390.	7623.
1983	6540.	7200.	7644.	7841.	8151.	8318.	7890.	7858.	7782.	7695.	7698.	7066.	7639.

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	325.	371.	276.	72.	117.	266.	49.	132.	321.	184.	30.	644.	776.
1978	599.	186.	392.	351.	84.	98.	146.	34.	77.	90.	242.	351.	799.
1979	463.	178.	87.	198.	194.	171.	100.	72.	151.	60.	63.	339.	577.
1980	298.	110.	369.	368.	174.	62.	40.	118.	136.	103.	62.	664.	685.
1981	176.	376.	67.	180.	97.	107.	122.	125.	93.	45.	12.	680.	660.
1982	356.	55.	269.	500.	111.	93.	116.	77.	77.	61.	108.	414.	532.
1983	261.	663.	81.	122.	468.	164.	143.	48.	101.	103.	130.	763.	578.

No. of Obs: 2556 St. Dev.: 658
Mean: 7695 Median: 7660

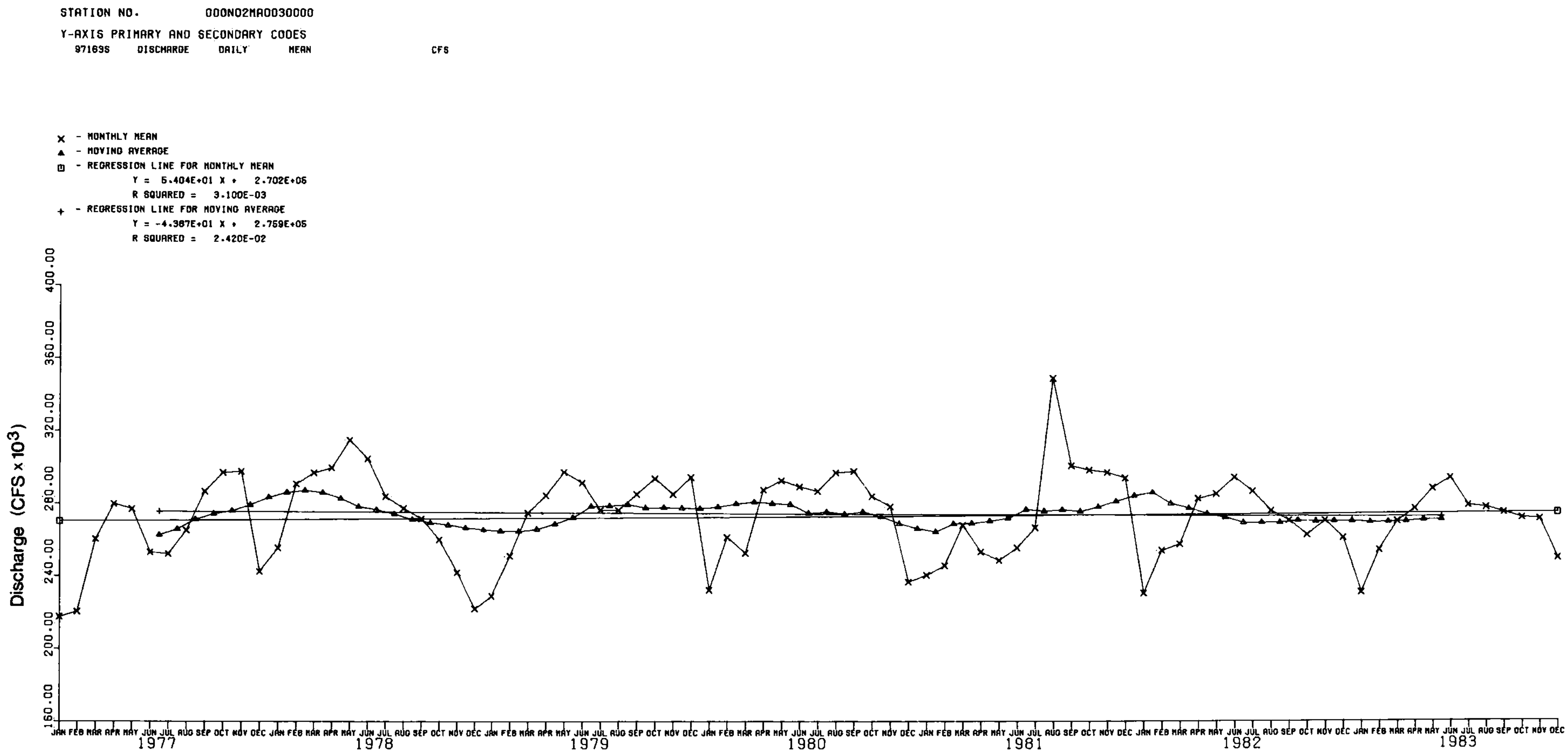

Figure A-1. Discharge graph (CFS) at Wolfe Island, 1977-83.

Appendix B
Means of Transect

Table B-1. Means of Transect: 179, 185 South, 185 North, and Data of Corresponding Day at Wolfe Island

	19-05-73		23-07-73		17-09-73		10-06-74		12-08-14		07-10-74		05-06-75	
	185N	185S	185N	185S	185N	185S	185N	185S	185N	185S	185N	185S	185N	185S
Total Phosphorus	.019	.016	.020	.018	.018	.018	.019	.018	.022	.026	.021	.021	.017	.022
Nitrate + Nitrite	.102	.130	.019	.023	.020	.045	.035	.083	.033	.058	.047	.054	.082	.110
Total Kjeldahl Nitrogen	-	-	-	-	-	-	-	-	-	-	-	-	.325	.349
Specific Conductance	319	332	308	310	314	309	293	336	312	296	320	323	330	355
pH	8.1	8.2	7.9	7.9	8.4	8.4	8.2	8.3	8.4	8.3	8.3	8.3	8.7	8.7
Calcium	37.8	37.8	41.1	38.1	41.9	41.5	40.0	39.2	36.6	36.5	37.7	37.0	39.0	39.4
Magnesium	7.4	7.7	-	-	-	-	6.6	7.5	8.0	8.0	8.1	8.2	7.2	7.9
Sulphate	25.7	27.7	30.0	30.9	25.3	26.0	25.5	28.0	29.8	28.7	28.1	28.0	25.4	28.2
Chloride	25.9	28.2	28.3	27.7	27.5	27.3	21.3	28.2	26.8	27.2	26.4	26.3	22.2	27.3
Sodium	12.7	14.3	13.2	13.2	11.0	11.1	10.3	13.7	12.9	12.8	13.1	13.1	11.1	13.7
Potassium	1.6	1.6	1.1	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4
Total Alkalinity	95.3	92.1	87.0	87.2	83.6	84.0	95.8	90.6	88.7	88.2	88.0	86.2	91.7	88.3
Iron	-	-	-	-	-	-	-	-	.021	.016	.017	.042	.025	.025
Copper	-	-	-	-	-	-	-	-	.004	.002	.003	.002	.002	.002
Manganese	-	-	-	-	-	-	-	-	.005	.002	.003	.002	.003	.003
Zinc	-	-	-	-	-	-	-	-	.004	-	.003	.006	.007	.003

Table B-1. Continued

	01-05-77				13-06-77				11-07-77			
	185N	185S	179	WI	185N	185S	179	WI	185N	185S	179	WI
Total Phosphorus	.025	.021	.021	.018	.013	.017	.014	.009	.021	.032	034	020
Nitrate + Nitrite	.218	.283	.277	.300	.156	.186	.195	.108	.051	.025	.054	.101
Total Kjeldahl Nitrogen	.325	.268	.303	.230	.214	.214	194	.272	.389	.432	.436	.347
Specific Conductance	316	307	312	323	328	330	326	339	312	313	313	311
pH	7.9	7.8	7.9	8.1	8.6	8.7	8.6	7.8	8.7	8.7	8.7	8.3
Calcium	39.4	33.1	36.8	36.8	-	-	-	-	38.4	38.6	38.2	38.2
Magnesium	7.5	7.2	7.3	7.1	-	-	-	-	7.9	7.8	7.9	7.8
Sulphate	24.2	24.1	25.3	25.3	-	-	-	-	26.2	25.3	26.0	26.7
Chloride	24.9	25.4	26.3	26.6	-	-	-	-	27.5	27.6	28.6	28.2
Sodium	11.7	12.2	12.2	11.9	-	-	-	-	13.1	12.9	12.8	13.1
Potassium	1.5	1.4	1.4	1.4	-	-	-	-	1.4	1.4	1.4	1.4
Total Alkalinity	92.9	84.6	85.6	85.0	-	-	-	-	89.6	90.9	90.0	91.0
Iron	.046	.082	.082	.060	-	-	-	-	.037	.047	.046	.059
Copper	.010	.009	.011	.006	-	-	-	-	.007	.009	.007	.013
Manganese	.005	.004	.005	.004	-	-	-	-	.003	.005	.005	.004
Zinc	.001	.001	.001	.001	-	-	-	-	.005	.004	.004	.001

Table B-1. Continued

	15-08-77				19-09-77				24-10-77			
	185N	185S	179	WI	185N	185S	179	WI	185N	185S	179	WI
Total Phosphorus	.019	.019	.022	.020	.017	.021	.029	.028	.020	.020	.021	.017
Nitrate + Nitrite	.014	.028	.117	.094	.050	.045	.048	.108	.130	.162	.165	.187
Total Kjeldahl Nitrogen	.272	.261	.301	.225	.326	.357	.336	.242	.328	.245	.309	.261
Specific Conductance	313	308	307	306	315	309	312	327	322	324	325	333
pH	8.6	8.5	8.5	8.3	-	-	-	8.3	8.5	8.5	8.4	8.3
Calcium	-	-	-	-	36.6	35.7	36.1	36.1	-	-	-	-
Magnesium	-	-	-	-	7.9	7.8	7.8	7.6	-	-	-	-
Sulphate	-	-	-	-	26.2	25.6	26.0	26.2	-	-	-	-
Chloride	-	-	-	-	26.9	26.2	26.6	27.7	-	-	-	-
Sodium	-	-	-	-	13.1	12.8	12.9	13.2	-	-	-	-
Potassium	-	-	-	-	1.5	1.4	1.4	1.5	-	-	-	-
Total Alkalinity	-	-	-	-	86.1	84.7	84.4	82.3	-	-	-	-
Iron	-	-	-	-	.046	.048	.044	.065	-	-	-	-
Copper	-	-	-	-	.008	.007	.008	.001	-	-	-	-
Manganese	-	-	-	-	.004	.004	.004	.003	-	-	-	-
Zinc	-	-	-	-	.004	.004	.004	.004	-	-	-	-

Appendix C
Values at Station No. 78 and Wolfe Island

Table C-1. Values Measured at Station No. 78 of the Surveillance Program and Data of the Corresponding Day at Wolfe Island

	Ph		TP		NO_2+NO_3		Sp. Cond.		T. Alk.		Calcium		Sulphate		Chloride		Magnesium		Potassium		Sodium	
DATE	78	WI	78	WI	78	WI	78	WI	78	WI	78	WI	78	WI	78	WI	78	WI	78	WI	78	WI
06-10-76	--	--	--	--	--	--	328	328	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27-10-76	8.3	8.0	--	--	--	--	337	331	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18-11-76	--	--	--	--	--	--	339	352	--	--	--	--	--	--	--	--	--	--	--	--	--	--
05-12-76	--	--	--	--	--	--	339	334	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11-05-77	8.4	8.2	.0170	.0160	.273	.240	337	335	91.5	88.0	39.3	38.8	28.3	26.6	28.0	27.9	7.9	7.6	1.4	1.4	12.9	12.2
08-06-77	8.7	8.2	--	--	--	--	323	333	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20-07-77	--	--	--	--	--	--	322	324	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17-08-77	--	--	--	--	--	--	319	306	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15-09-77	8.5	7.9	.0154	.0130	.025	.061	320	325	84.0	85.1	36.3	36.9	28.3	27.4	27.1	26.9	8.0	8.0	1.4	1.4	12.8	13.2
15-10-77	--	--	--	--	--	--	335	333	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17-11-77	--	--	--	--	--	--	336	336	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12-04-78	8.1	8.1	.0170	.0100	.305	.223	332	--	89.0	94.0	40.0	38.3	27.8	26.5	27.4	26.5	7.9	8.0	1.4	1.4	12.8	12.6
11-05-78	8.5	8.2	--	--	--	--	287	328	--	--	--	--	--	--	--	--	--	--	--	--	--	--
07-06-78	8.8	--	--	--	--	--	329	325	--	--	--	--	--	--	--	--	--	--	--	--	--	--
06-07-78	--	--	--	--	--	--	320	322	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11-08-78	--	--	--	--	--	--	338	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
07-09-78	8.4	8.2	0.164	.0120	.018	.080	327	331	82.0	83.5	36.0	35.5	28.5	25.5	27.6	27.4	8.1	8.0	1.4	1.4	12.7	13.0
13-10-78	--	--	--	--	--	--	330	330	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16-11-78	--	--	--	--	--	--	327	331	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11-04-79	8.2	7.8	.0176	.0110	.288	.315	332	336	97.0	92.5	40.0	39.0	28.6	26.0	27.9	26.3	8.0	7.8	1.4	1.4	12.8	12.6
02-05-79	8.3	8.1	.0162	.0150	.267	.320	321	326	--	--	--	--	--	--	26.5	26.8	--	--	--	--	--	--
30-05-79	8.6	7.8	--	--	--	--	318	335	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28-06-79	8.5	7.9	--	--	--	--	324	338	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01-08-79	8.5	7.6	--	--	--	--	308	319	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table C-1. Continued

DATE	Ph 78	Ph WI	TP 78	TP WI	NO_2+NO_3 78	NO_2+NO_3 WI	Sp. Cond. 78	Sp. Cond. WI	T. Alk. 78	T. Alk. WI	Calcium 78	Calcium WI	Sulphate 78	Sulphate WI	Chloride 78	Chloride WI	Magnesium 78	Magnesium WI	Potassium 78	Potassium WI	Sodium 78	Sodium WI
30-08-79	8.5	7.4	--	--	--	--	321	323	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19-09-79	8.6	7.8	.0153	.0110	.063	.089	310	321	--	--	--	--	--	--	26.9	27.2	--	--	--	--	--	--
21-11-79	8.3	7.7	.0158	.0110	.207	.108	323	329	--	--	--	--	--	--	27.2	27.2	--	--	--	--	--	--
23-04-80	8.3	7.9	.0152	.0150	.275	.281	336	327	94.0	91.5	39.8	39.0	28.4	27.2	26.6	27.3	7.9	7.7	1.6	1.5	12.8	12.6
09-10-80	8.4	7.6	.0157	.0190	.119	.143	317	310	89.0	86.3	37.1	35.7	27.4	26.6	27.0	26.9	8.2	8.0	1.4	1.5	12.7	12.4
21-03-81	8.3	8.0	.0131	.0092	.289	.143	342	331	96.5	98.0	39.5	39.2	28.7	24.4	26.9	26.5	7.9	8.0	1.4	1.3	12.9	12.5
08-04-81	8.5	8.0	.0124	.0105	.248	.256	319	322	96.1	94.0	39.2	39.0	25.4	26.5	26.3	25.8	8.0	7.7	1.4	1.3	12.6	12.2
29-04-81	8.4	7.7	.0129	.0128	--	--	320	320	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21-05-81	8.4	8.1	.0116	.0108	--	--	333	346	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17-06-81	8.7	7.4	.0208	.0082	--	--	333	333	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15-07-81	8.8	8.0	.0237	.0163	--	--	311	321	--	--	--	--	--	--	--	--	--	--	--	--	--	--
13-08-81	7.4	7.7	.0173	.0109	.036	.102	309	315	83.2	--	34.7	34.5	21.9	25.5	26.4	27.6	8.0	--	--	--	12.8	12.1
16-09-81	8.4	7.7	.0163	.0108	--	--	317	315	--	--	--	--	--	--	--	--	--	--	--	--	--	--
08-10-81	8.3	7.9	.0168	.0109	--	--	319	323	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20-11-81	8.2	7.7	.0156	.0084	.217	.211	321	330	93.7	90.6	38.4	37.8	26.5	28.9	26.4	25.8	7.9	7.7	1.4	1.4	12.6	12.2
08-12-81	8.1	8.0	.0133	.0107	--	--	316	331	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28-04-82	8.2	7.9	.0123	.0093	.312	.276	302	332	98.5	85.7	39.2	39.6	27.6	26.4	26.4	26.4	8.0	7.8	1.4	1.4	12.5	12.4
20-05-82	8.4	8.0	.0109	.0157	--	--	306	324	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16-06-82	8.6	7.5	.0127	.0122	--	--	356	329	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14-07-82	8.6	7.3	.0192	.0080	--	--	317	329	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18-08-82	8.5	7.5	.0173	.0173	--	--	311	315	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15-09-82	8.2	7.6	.0136	.0105	.088	.072	310	315	90.5	89.7	36.1	36.1	28.2	27.4	25.9	26.0	8.0	7.9	1.4	1.3	12.3	11.9
14-10-82	8.2	7.7	.0152	.0112	--	--	310	326	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17-11-82	7.9	7.9	.0164	.0074	.236	.199	320	326	93.9	96.5	36.9	37.9	28.0	28.3	25.6	25.7	7.8	8.0	1.4	1.4	12.2	12.4
16-03-83	8.3	7.8	.0116	.0196	.331	.281	347	321	93.6	92.9	37.5	38.2	28.5	28.1	25.8	25.2	8.0	7.8	1.4	1.4	12.1	12.0

Appendix D
Nutrient Data

Table D-1. Monthly and Annual Means and Standard Deviation for Total Phosphorus (mg/L P) at Wolfe Island, 1977–83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0150	.0183	.0167	.0181	.0165	.0127	.0169	.0191	.0148	.0179	.0161	.0146	.0163
1978	.0144	.0176	.0183	.0162	.0127	.0128	.0245	.0148	.0131	.0147	.0172	.0175	.0162
1979	.0127	.0121	.0121	.0128	.0108	.0108	.0121	.0159	.0143	.0145	.0117	.0133	.0128
1980	.0188	.0130	.0104	.0119	.0104	.0139	.0196	.0219	.0136	.0124	.0114	.0125	.0141
1981	.0103	.0112	.0102	.0103	.0108	.0109	.0122	.0146	.0115	.0157	.0118	.0083	.0112
1982	.0114	.0115	.0109	.0134	.0126	.0116	.0114	.0162	.0145	.0162	.0135	.0131	.0130
1983	.0132	.0114	.0127	.0135	.0130	.0119	.0173	.0153	.0119	.0115	.0100	.0107	.0126

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0019	.0019	.0023	.0035	.0046	.0050	.0053	.0054	.0061	.0095	.0049	.0044	.0052
1978	.0045	.0074	.0065	.0063	.0063	.0067	.0107	.0098	.0050	.0055	.0075	.0077	.0077
1979	.0047	.0032	.0029	.0057	.0074	.0051	.0053	.0072	.0084	.0057	.0038	.0047	.0057
1980	.0095	.0034	.0035	.0037	.0044	.0045	.0117	.0106	.0041	.0049	.0033	.0036	.0072
1981	.0029	.0038	.0024	.0059	.0034	.0043	.0047	.0042	.0062	.0060	.0037	.0022	.0046
1982	.0043	.0054	.0015	.0065	.0036	.0077	.0052	.0067	.0053	.0092	.0061	.0028	.0058
1983	.0034	.0021	.0042	.0025	.0036	.0022	.0128	.0118	.0028	.0061	.0042	.0025	.0060

No. of Obs: 2403 St. Dev.: .0063
Mean: .0137 Median: .0123

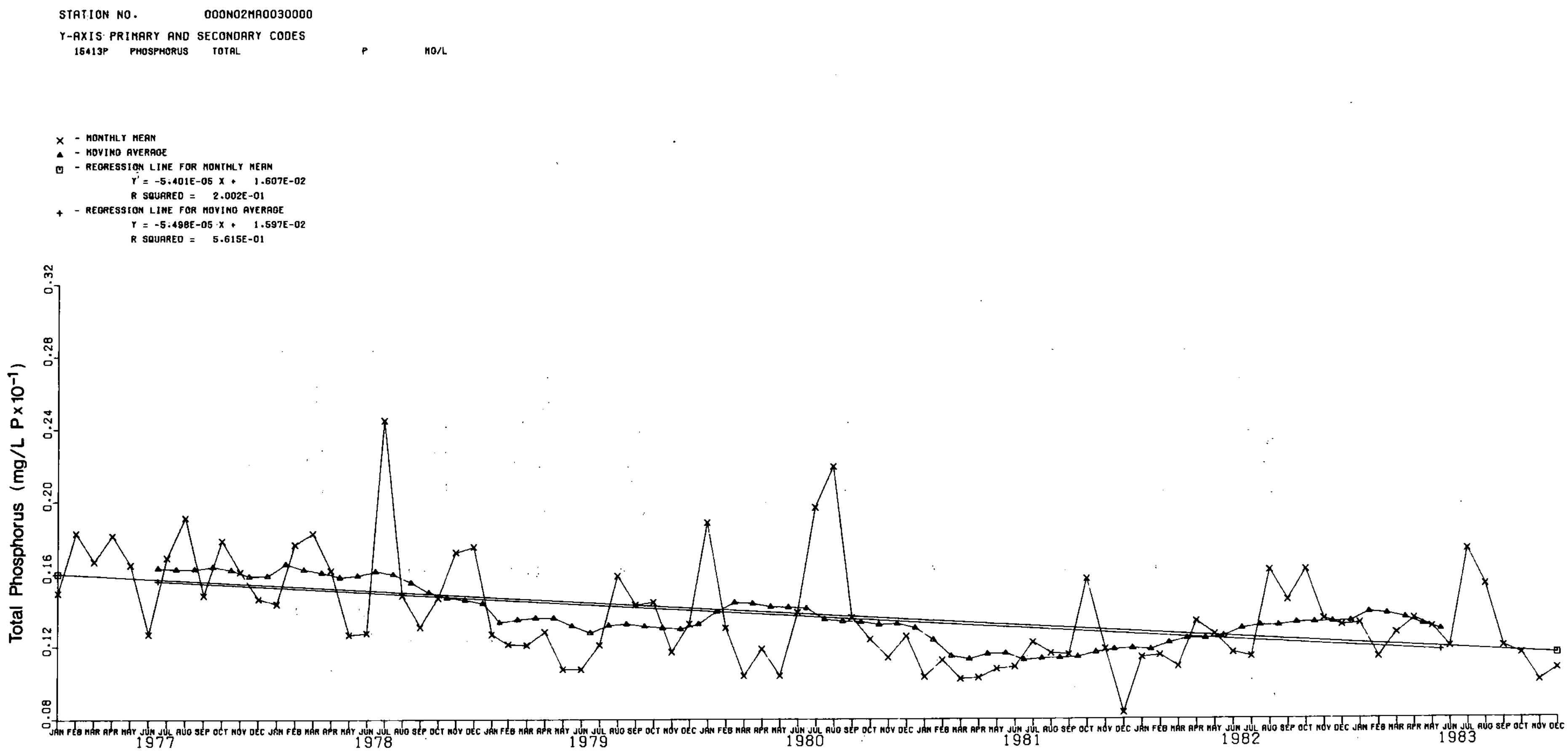

Figure D-1. Total phosphorus concentrations at Wolfe Island, 1977–83.

Table D-2. Monthly and Annual Means and Standard Deviation for Nitrate + Nitrite (mg/L N) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.298	.315	.294	.315	.243	.188	.136	.108	.109	.223	.218	.238	.225
1978	.260	.308	.328	.262	.224	.189	.201	.082	.120	.181	.197	.252	.221
1979	.284	.333	.295	.305	.262	.215	.150	.100	.129	.122	.169	.223	.215
1980	.276	.272	.276	.286	.258	.225	.207	.123	.089	.135	.213	.262	.217
1981	.278	.272	.273	.275	.265	.242	.170	.090	.179	.190	.271	.245	.227
1982	.263	.310	.349	.321	.280	.258	.204	.145	.122	.185	.218	.256	.243
1983	.308	.311	.322	.293	.313	.251	.170	.138	.064	.111	.119	.260	.228

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.052	.018	.041	.034	.044	.029	.059	.034	.071	.112	.037	.031	.087
1978	.068	.067	.039	.084	.090	.055	.091	.046	.097	.019	.053	.068	.095
1979	.038	.026	.051	.091	.078	.059	.073	.057	.098	.095	.033	.041	.101
1980	.071	.027	.037	.051	.045	.056	.100	.061	.055	.047	.040	.055	.086
1981	.022	.053	.029	.024	.051	.129	.084	.107	.104	.070	.114	.061	.096
1982	.051	.054	.029	.078	.087	.077	.082	.098	.077	.066	.060	.021	.095
1983	.079	.043	.075	.014	.079	.036	.084	.130	.043	.056	.044	.052	.109

No. of Obs: 2379 St. Dev.: 0.096
Mean: 0.225 Median: 0.237

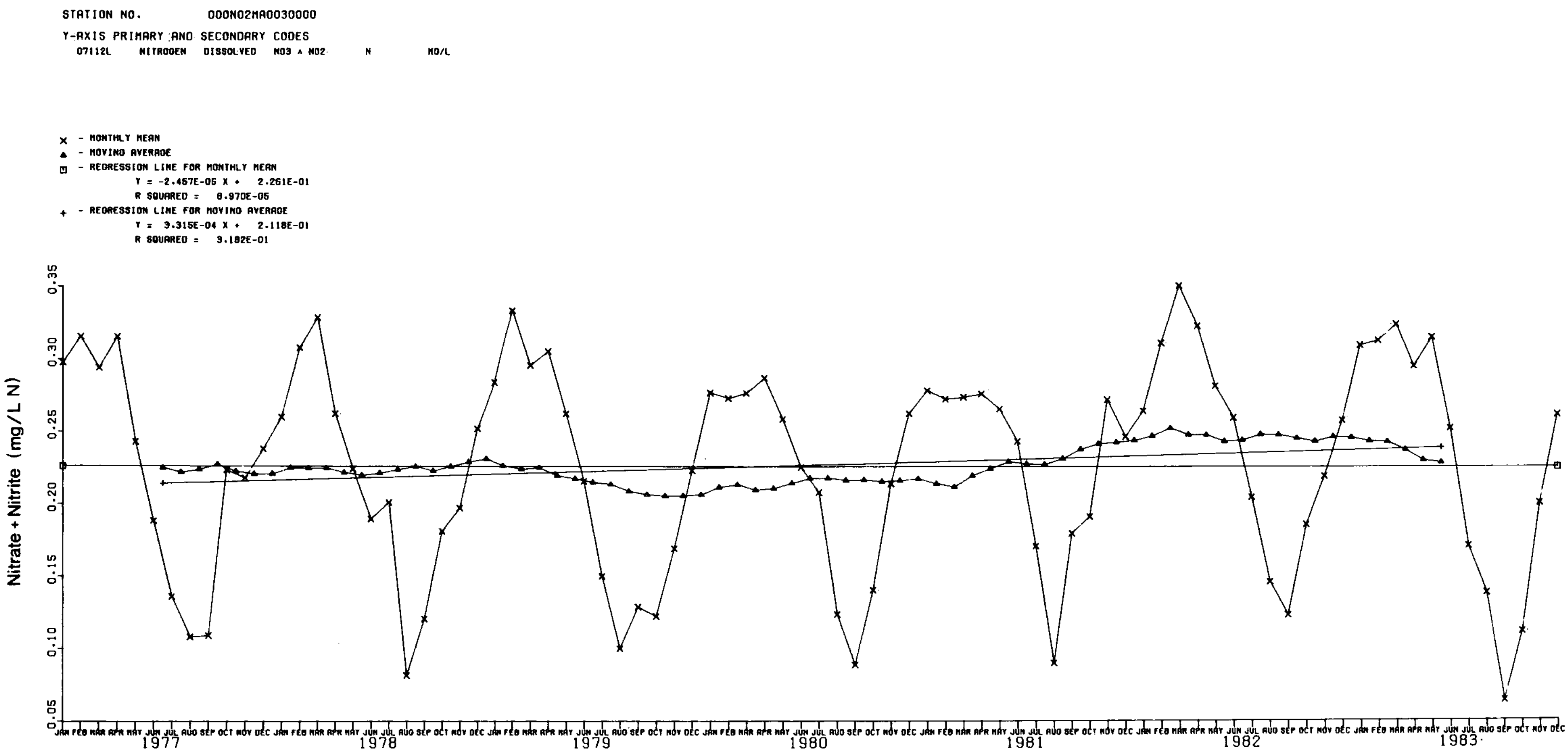

Figure D-2. Nitrate + nitrite concentrations at Wolfe Island, 1977-83.

Table D-3. Monthly and Annual Means and Standard Deviation for Total Kjeldahl Nitrogen (mg/L N) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.193	.196	.215	.248	.268	.282	.274	.256	.241	.231	.177	.212	.233
1978	.214	.210	.171	.206	.235	.255	.197	.215	.181	.159	.146	.115	.191
1979	.100	.108	.132	.217	.247	.225	.229	.258	.237	.239	.225	.225	.203
1980	.247	.220	.213	.209	.225	.233	.248	.266	.237	.219	.201	.199	.226
1981	.187	.198	.196	.219	.217	.296	.233	.298	.322	.226	.251	.201	.237
1982	.224	.250	.208	.220	.218	.235	.230	.260	.235	.244	.242	.231	.233
1983	.220	.233	.194	.229	.239	.240	.227	.237	.214	.259	.230	.244	.231

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.016	.012	.027	.041	.051	.051	.041	.044	.065	.031	.023	.025	.051
1978	.038	.048	.018	.079	.053	.048	.040	.107	.038	.018	.033	.022	.061
1979	.019	.011	.034	.052	.052	.018	.025	.053	.026	.038	.021	.025	.063
1980	.053	.020	.026	.025	.035	.024	.039	.026	.060	.019	.019	.017	.038
1981	.018	.021	.018	.023	.038	.082	.038	.134	.161	.021	.042	.023	.080
1982	.050	.056	.023	.041	.051	.038	.033	.062	.038	.027	.042	.040	.045
1983	.021	.034	.057	.020	.028	.036	.041	.102	.040	.062	.023	.034	.049

No. of Obs: 2424 St. Dev.: 0.059
Mean: 0.222 Median: 0.218

Appendix E
Major Ion and Specific Conductance Data

Table E-1. Monthly and Annual Means and Standard Deviation for Calcium (mg/L Ca) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	39.6	40.3	40.1	38.5	38.0	38.1	39.1	38.0	37.4	38.6	38.4	38.5	38.7
1978	37.8	39.7	39.5	38.5	37.9	37.8	37.6	34.9	37.5	38.8	38.7	38.6	38.1
1979	39.2	38.8	39.1	39.4	36.1	37.8	37.8	34.7	36.1	36.6	37.3	38.6	37.8
1980	39.5	39.4	39.0	38.0	37.7	38.2	36.6	34.8	35.0	36.2	37.8	37.9	37.5
1981	38.7	39.2	38.5	38.7	38.1	37.6	35.7	34.3	35.5	36.7	37.6	38.7	37.4
1982	39.7	40.0	39.5	39.1	39.7	38.4	37.9	35.0	36.3	37.8	38.0	38.0	38.3
1983	38.8	37.5	38.5	38.4	37.8	38.8	37.9	36.0	34.4	35.7	36.8	37.1	37.3

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	1.4	.7	.6	1.3	1.1	.3	.2	2.1	.5	.5	.2	.2	1.2
1978	.7	.2	.2	.4	1.4	.8	.3	.8	2.2	.8	.3	.2	1.3
1979	.6	.4	1.3	.5	.9	1.1	1.7	.5	.2	.6	.3	.8	1.6
1980	.4	.2	.4	1.3	.4	.3	1.2	.3	.2	1.0	.8	.7	1.6
1981	.6		1.0	.8	.4	1.7	.9	.7	.9	.2	.4	.5	1.6
1982	.3	.5	.7	.8	.8	1.6	1.4	.4	.6	.8	.2	.2	1.6
1983	.6	.1	.9	.2	1.1	.5	1.4	2.1	.6	.4	.4	.2	1.4

No. of Obs: 326 St. Dev.: 1.6
Mean: 37.9 Median: 38.2

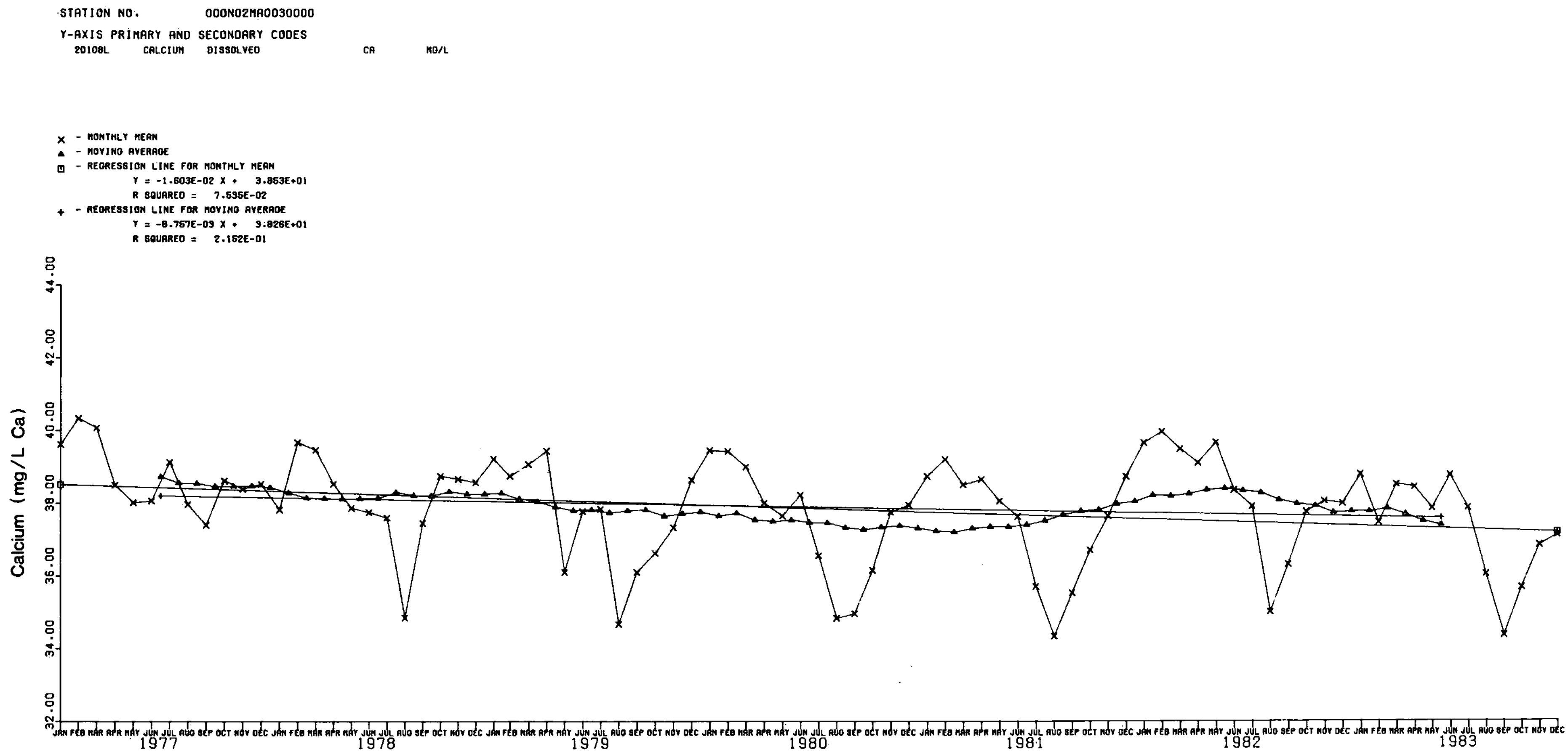

Figure E-1. Calcium concentrations at Wolfe Island, 1977–83.

Table E-2. Monthly and Annual Means and Standard Deviation for Magnesium (mg/L Mg) at Wolfe Island, 1977–83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	8.3	7.9	7.9	7.6	7.4	7.6	7.9	8.0	7.9	7.9	8.3	8.2	7.9
1978	7.8	8.1	8.4	8.0	7.7	7.8	8.0	7.9	8.1	8.2	8.0	7.9	8.0
1979	8.1	8.1	7.9	7.9	7.8	7.7	8.0	8.0	8.0	7.9	8.0	8.1	8.0
1980	8.2	8.1	8.1	7.6	7.6	7.8	7.9	8.0	8.0	8.1	8.1	7.9	8.0
1981	8.0	8.1	7.7	7.9	7.7	7.6	8.0	7.8	8.0	7.9	7.6	7.8	7.8
1982	7.6	7.8	7.9	7.7	7.7	7.7	7.7	7.9	7.9	8.0	8.0	8.0	7.8
1983	8.0	7.9	7.9	7.9	7.8	8.0	8.2	8.2	8.1	7.9	7.9	7.7	7.9

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.2	.2	.3	.4	.3	.1	.1	.1	.1	.1	.1	.1	.3
1978	.1	.1	.2	.2	.3	.1	.1	.1	.1	.1	.0	.1	.2
1979	.1	.1	.3	.1	.5	.1	.1	.0	.0	.2	.0	.1	.2
1980	.1	.1	.1	.3	.1	.1	.1	.1	.1	.1	.2	.2	.2
1981	.1		.2	.2	.1	.2	.1	.1	.2	.2	.1	.2	.2
1982	.1	.3	.3	.3	.2	.2	.2	.1	.1	.1	.1	.1	.2
1983	.2	.0	.1	.2	.3	.1	.1	.2	.2	.1	.1	.1	.2

No. of Obs: 329 St. Dev.: 0.2
Mean: 7.9 Median: 7.9

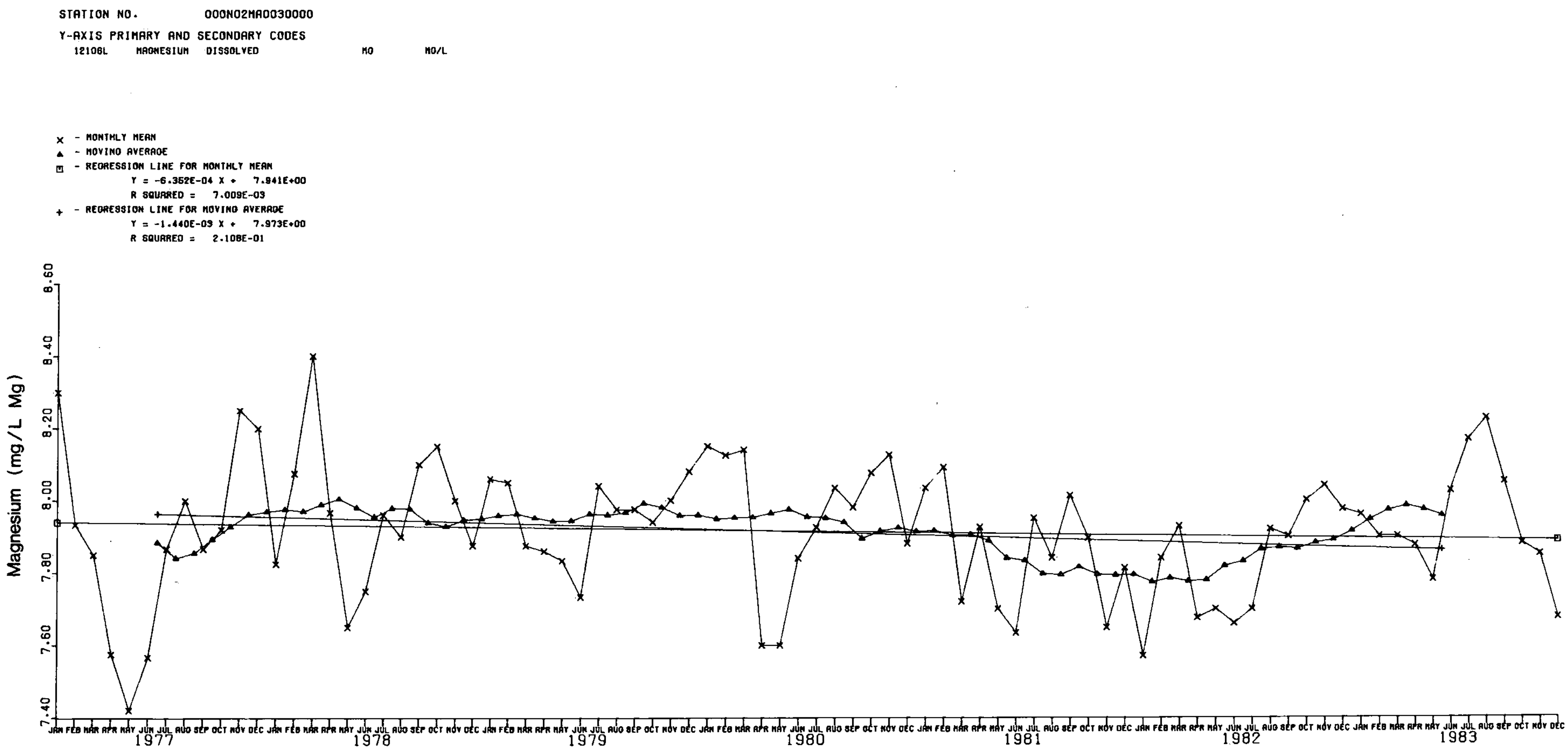

Figure E-2. Magnesium concentrations at Wolfe Island, 1977-83.

Table E-3. Monthly and Annual Means and Standard Deviation for Sulphate (mg/L SO_4) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	27.8	28.4	27.2	26.1	25.8	25.9	27.0	28.0	26.6	26.0	27.2	27.4	26.9
1978	26.7	27.9	27.4	26.7	25.5	26.0	26.3	26.6	27.1	26.8	26.2	28.1	26.7
1979	27.4	26.8	26.5	26.8	26.5	26.2	26.2	25.4	28.2	27.0	26.9	26.5	26.7
1980	25.9	26.8	26.3	26.4	26.7	26.0	26.8	26.4	26.6	26.5	27.6	27.2	26.6
1981	27.9	25.7	25.4	24.0	24.7	24.6	25.1	25.9	26.6	25.7	30.4	27.4	26.2
1982	25.4	26.1	28.0	27.2	27.2	27.0	27.2	27.6	27.6	28.0	27.8	28.4	27.3
1983	28.2	27.9	28.0	28.1	27.8	28.8	28.6	28.2	28.1	28.5	28.0	27.7	28.1

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.5	.1	.7	.6	.6	.3	.5	.2	.7	.7	.1	.1	1.0
1978	.5	.1	1.0	.3	1.4	.9	.4	.1	1.1	.6	1.6	.2	1.0
1979	1.3	.5	1.0	.6	1.0	1.1	1.5	2.0	.7	1.2	.4	.4	1.2
1980	.8	.1	.9	.8	.5	.9	.3	.4	.2	.4	.3	1.0	.7
1981	.3		1.3	1.7	1.0	.5	.1	.3	.2	1.3	1.7	1.5	2.2
1982	.5	1.3	1.0	1.0	.9	.6	.4	.4	.2	.7	.4	.2	1.0
1983	.2	.3	.3	.2	.8	.2	.1	.3	.3	.5	.1	.3	.4

No. of Obs: 330 St. Dev.: 1.3
Mean: 27.0 Median: 27.0

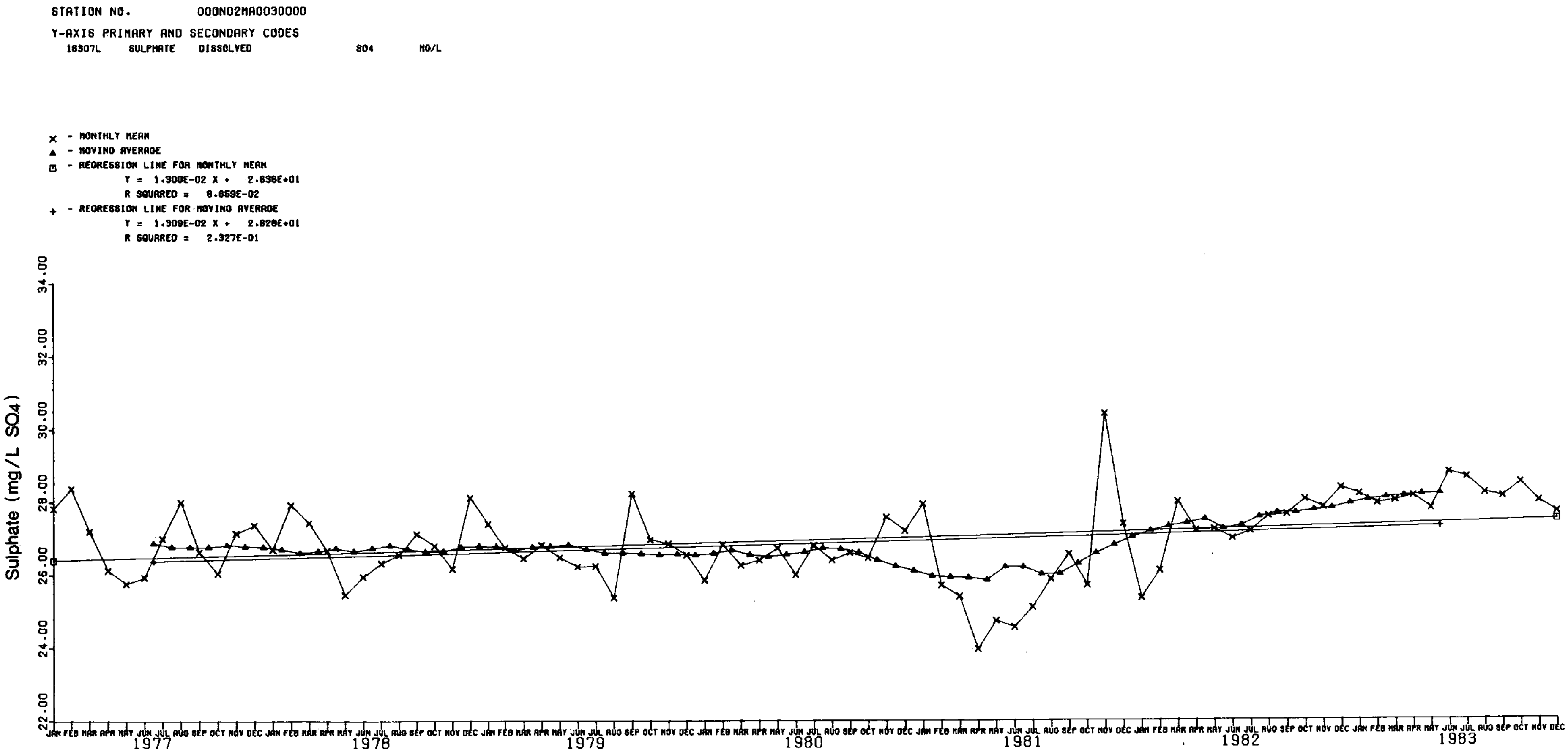

Figure E-3. Sulphate concentrations at Wolfe Island, 1977–83.

Table E-4. Monthly and Annual Means and Standard Deviation for Chloride (mg/L Cl) at Wolfe Island, 1977–83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	28.0	28.7	27.9	26.7	26.8	26.8	27.7	28.9	27.4	27.5	28.0	26.9	27.5
1978	27.3	28.3	28.5	27.0	26.2	27.7	27.1	27.3	28.2	27.1	27.7	27.2	27.4
1979	27.6	27.9	27.2	26.7	26.1	27.4	27.2	27.5	27.0	27.8	27.2	27.3	27.2
1980	27.3	27.5	27.4	26.3	26.3	27.0	26.3	26.7	26.7	27.0	27.0	26.5	26.8
1981	26.8	27.6	26.1	26.0	25.7	26.1	25.4	26.6	26.4	26.2	26.0	26.4	26.1
1982	26.1	25.4	26.2	25.8	26.1	25.9	25.8	25.9	26.2	25.9	25.7	26.2	25.9
1983	25.9	25.8	25.7	26.0	25.4	26.3	25.4	24.5	25.4	26.0	25.4	25.2	25.6

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.5	.2	.6	.8	.7	.3	.6	1.3	.5	.9	1.5	.6	1.0
1978	.7	.2	1.0	.6	1.6	.7	.5	.4	.6	.1	.5	.3	.9
1979	.3	.5	.8	.5	1.1	1.0	.4	.3	.3	1.2	.4	.1	.8
1980	.4	.1	.3	1.1	1.0	.9	.4	.3	.4	.2	.5	.2	.6
1981	.2		.6	.2	.1	1.7	.2	.9	.2	.2	.4	.1	.7
1982	.3	1.0	1.4	.6	.9	.4	.3	.5	.2	.2	.1	.6	.7
1983	.1	.2	.3	.2	1.0	.5	.3	.7	.1	1.4	.3	.1	.7

No. of Obs: 335 St. Dev.: 1.1
Mean: 26.6 Median: 26.6

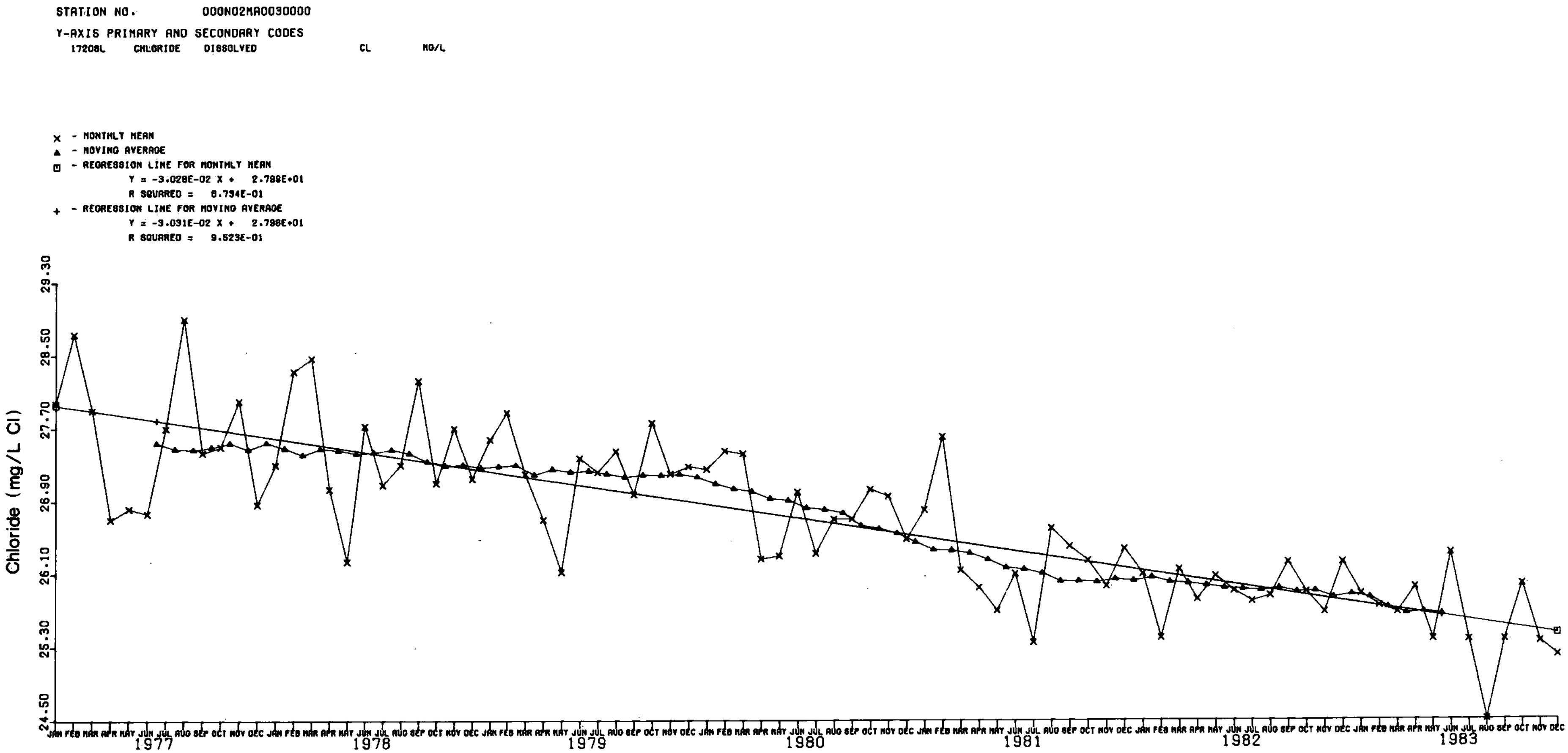

Figure E-4. Chloride concentrations at Wolfe Island, 1977–83.

Table E-5. Monthly and Annual Means and Standard Deviation for Sodium (mg/L Na) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	12.6	13.8	13.2	12.3	12.2	12.8	13.1	13.3	13.0	13.1	13.2	13.2	12.9
1978	12.9	13.1	13.2	12.8	12.4	12.8	12.7	13.0	13.0	12.8	12.9	12.9	12.9
1979	13.0	12.9	12.8	12.7	12.4	12.9	13.0	13.1	13.0	13.4	12.9	12.9	12.9
1980	12.8	13.2	12.6	12.3	12.4	12.8	12.7	12.4	12.6	12.5	12.4	12.4	12.6
1981	12.5	13.1	12.3	12.3	12.4	12.5	12.1	12.2	12.3	12.2	12.2	12.5	12.3
1982	12.6	12.7	12.7	12.2	12.4	12.3	12.4	12.3	11.9	12.2	12.3	12.3	12.4
1983	12.3	12.1	12.0	12.2	12.1	12.5	11.9	12.1	12.1	12.4	12.4	12.4	12.2

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.3	.0	.2	.5	.4	.2	.1	.1	.2	.1	.3	.2	.5
1978	.3	.1	.1	.3	.6	.6	.2	.1	.0	.1	.1	.1	.4
1979	.2	.1	.5	.2	.4	.5	.3	.1	.1	.3	.4	.2	.3
1980	.1	.1	.3	.4	.1	.3	.2	.1	.2	.1	.1	.1	.3
1981	.1		.2	.3	.1	.6	.1	.2	.1	.2	.1	.1	.3
1982	.1	.1	.2	.2	.2	.1	.0	.3	.1	.4	.1	.1	.3
1983	.1	.1	.2	.1	.5	.4	.1	.1	.2	.1	.1	.1	.3

No. of Obs: 336 St. Dev.: 0.4
Mean: 12.6 Median: 12.5

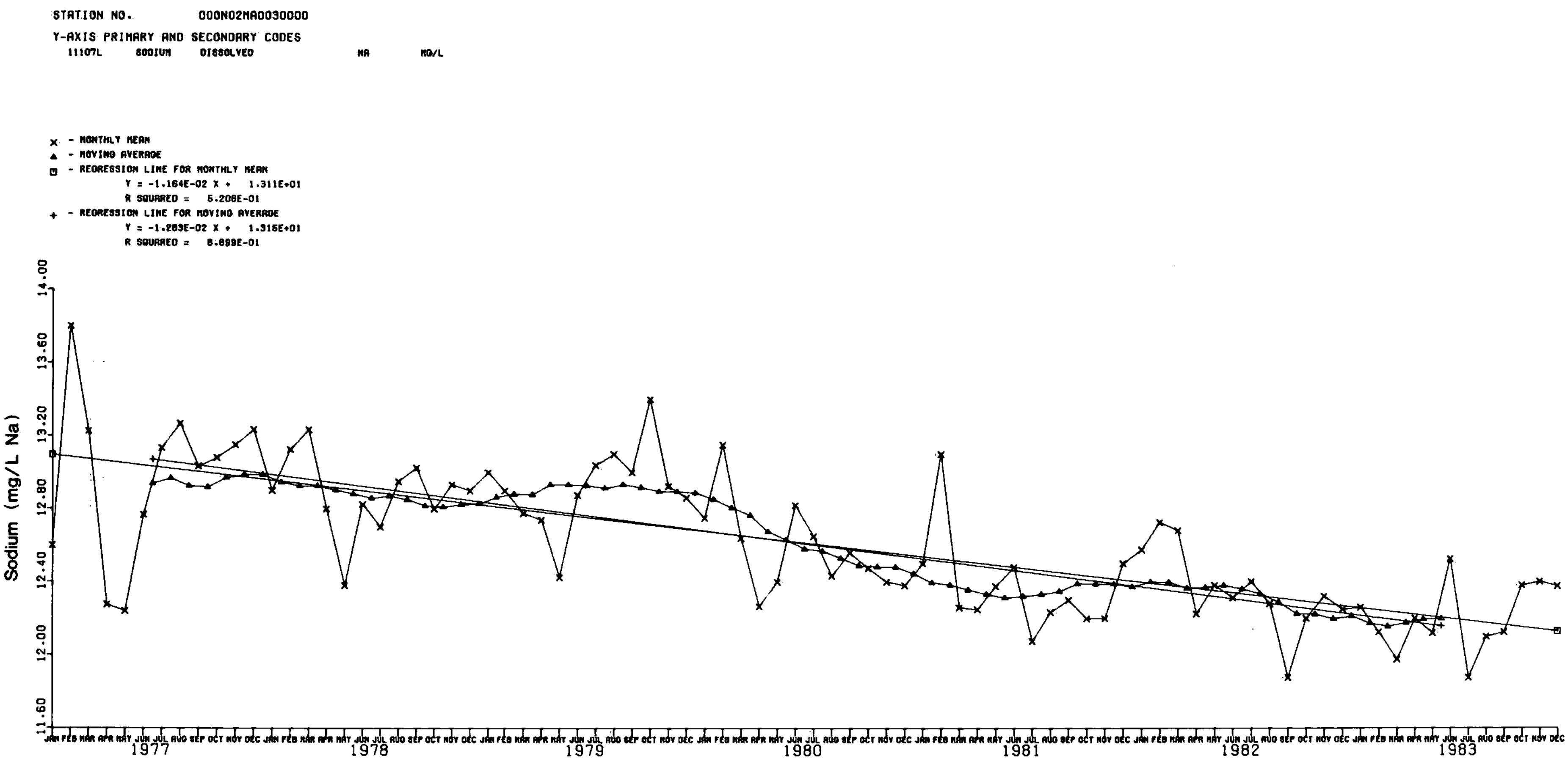

Figure E-5. Sodium concentrations at Wolfe Island, 1977-83.

Table E-6. Monthly and Annual Means and Standard Deviation for Potassium (mg/L K) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	1.4	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.5
1978	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.5	1.4	1.4	1.4	1.5	1.4
1979	1.5	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
1980	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
1981	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4
1982	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4
1983	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.4

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.1	.0	.1	.0	.0	.0	.0	.0	.1	.0	.0	.0	0.1
1978	.0	.0	.1	.0	.0	.0	.0	.1	.1	.0	.1	.1	0.1
1979	.0	.1	.1	.0	.3	.1	.0	.1	.1	.0	.1	.0	0.1
1980	.0	.1	.1	.1	.1	.0	.0	.0	.0	.1	.0	.0	0.1
1981	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.1	0.1
1982	.0	.0	.0	.0	.0	.0	.0	.1	.0	.1	.0	.0	0.1
1983	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	0.0

No. of Obs: 328 St. Dev.: 0.1
Mean: 1.4 Median: 1.4

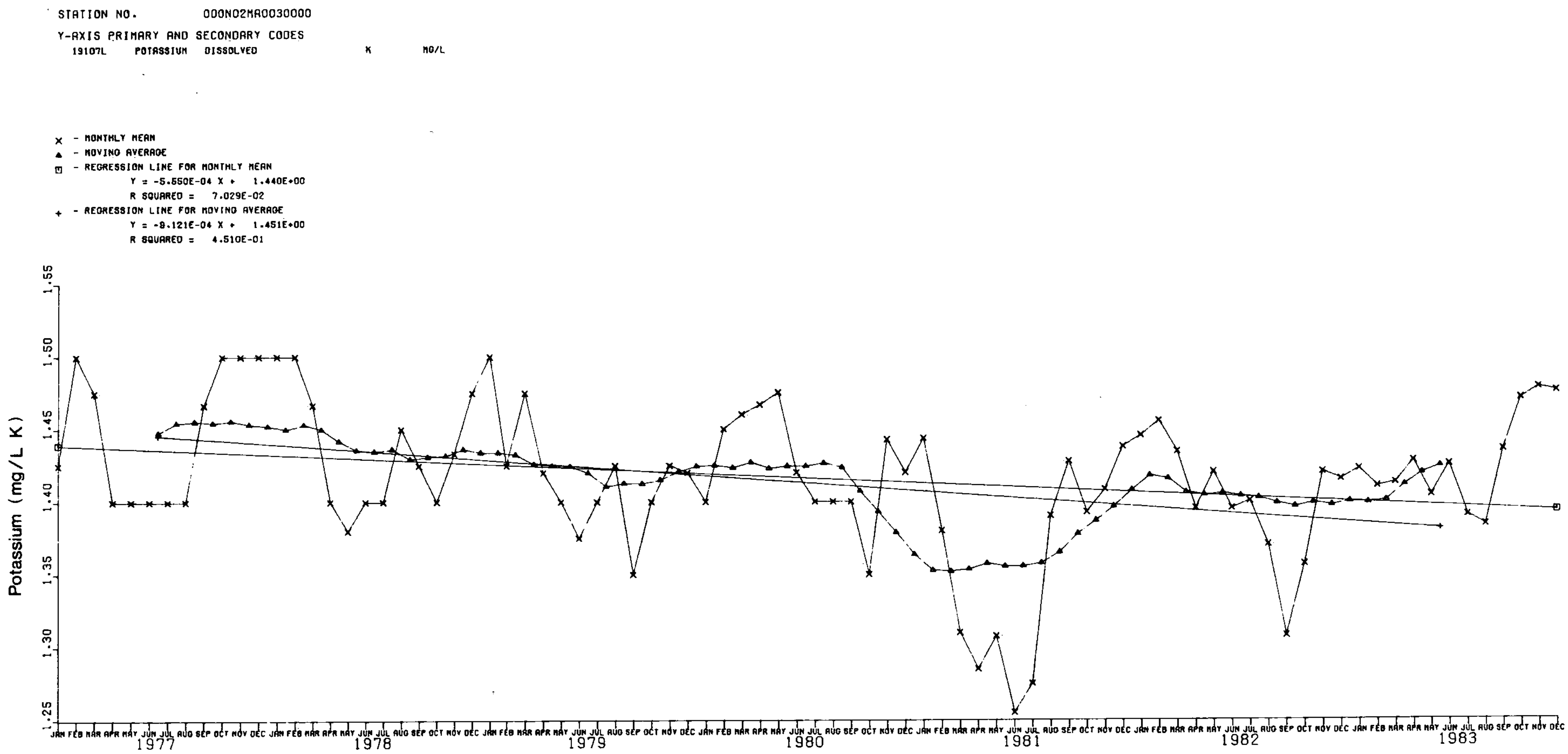

Figure E-6. Potassium concentrations at Wolfe Island, 1977–83.

Table E-7. Monthly and Annual Means and Standard Deviation for Specific Conductance ($\mu S/cm$) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	340.	341.	338.	322.	323.	330.	325.	321.	328.	335.	335.	336.	331.
1978	339.	341.	342.	334.	324.	331.	329.	324.	322.	329.	332.	334.	332.
1979	338.	338.	338.	335.	326.	332.	332.	321.	322.	326.	330.	332.	331.
1980	332.	337.	336.	328.	324.	334.	325.	315.	317.	320.	328.	326.	327.
1981	334.	334.	329.	331.	337.	327.	322.	319.	320.	327.	326.	330.	328.
1982	334.	338.	336.	332.	328.	326.	329.	319.	317.	325.	325.	322.	328.
1983	327.	328.	331.	330.	325.	330.	325.	322.	308.	317.	324.	327.	325.

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	6.	2.	3.	8.	8.	6.	9.	11.	6.	5.	2.	2.	9.
1978	5.	2.	2.	4.	12.	7.	6.	8.	6.	5.	2.	5.	9.
1979	3.	7.	4.	5.	10.	6.	9.	5.	3.	3.	2.	3.	8.
1980	7.	2.	3.	6.	6.	6.	9.	6.	6.	8.	6.	18.	10.
1981	3.	8.	5.	7.	10.	10.	4.	10.	7.	8.	2.	2.	9.
1982	5.	4.	3.	4.	6.	5.	3.	7.	6.	5.	4.	6.	8.
1983	7.	3.	5.	5.	7.	7.	6.	15.	10.	3.	3.	2.	9.

No. of Obs: 2428 St. Dev.: 9.0
Mean: 329 Median: 329

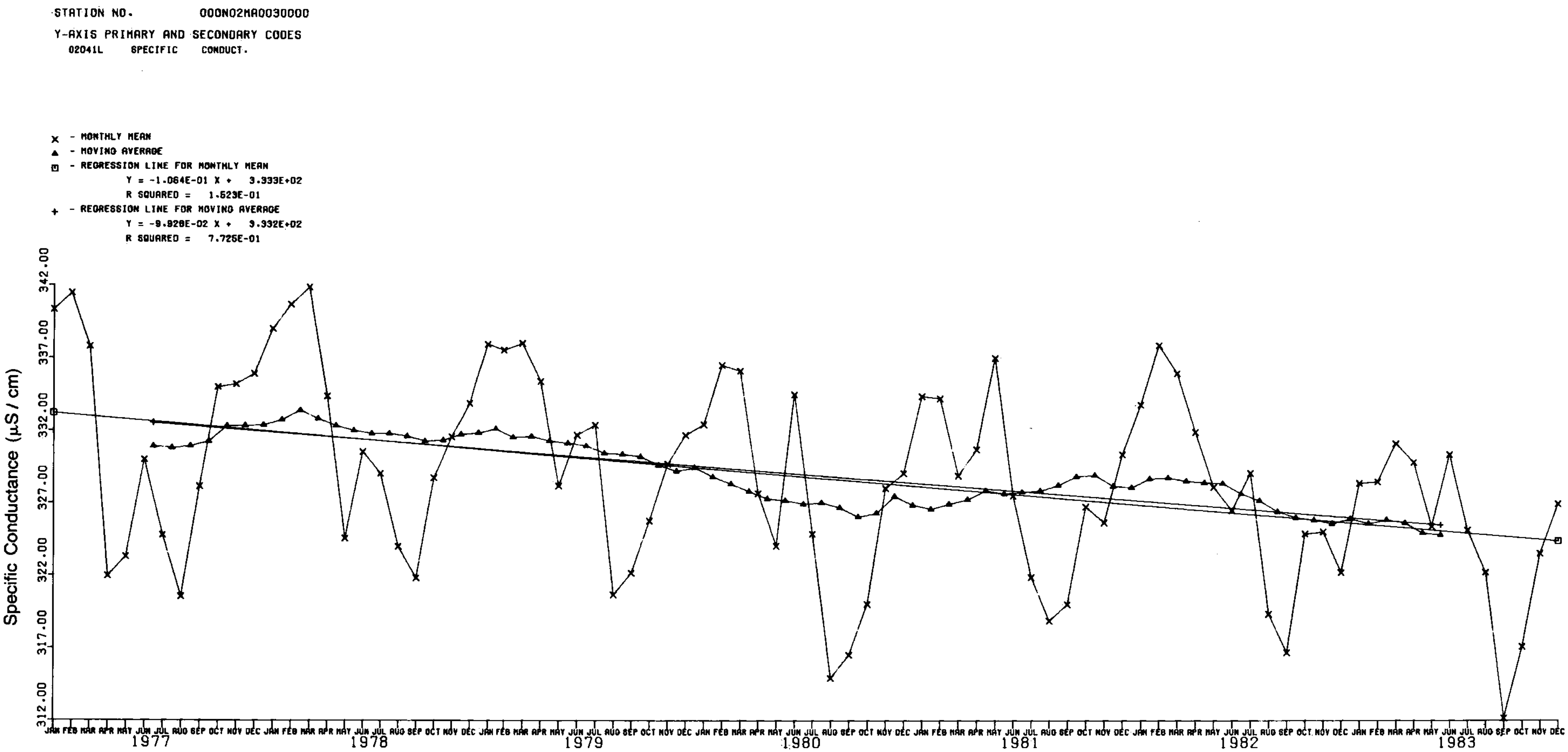

Figure E-7. Specific conductance at Wolfe Island, 1977-83.

Table E-8. Monthly and Annual Means and Standard Deviation for Total Alkalinity (mg/L $CaCO_3$) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	93.1	92.3	90.7	87.4	87.8	90.4	91.3	85.5	86.3	91.3	90.0	91.1	89.8
1978	88.8	92.0	90.9	92.7	89.5	88.0	86.8	79.8	87.4	90.6	89.6	93.4	89.3
1979	94.4	94.8	94.8	93.2	91.3	93.8	92.9	82.0	82.6	90.4	89.8	92.7	91.2
1980	91.3	92.8	92.6	88.6	89.0	91.3	85.5	82.8	82.8	87.0	94.0	89.3	89.0
1981	94.3	99.0	94.2	89.5	92.0	90.6	83.5	84.5	95.4	89.1	89.5	91.8	90.6
1982	97.3	99.0	98.1	95.0	97.1	95.4	93.1	92.3	93.9	98.3	94.8	92.8	95.5
1983	94.7	91.8	93.6	93.1	89.4	96.4	98.4	95.2	83.1	85.9	89.7	94.0	91.9

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	2.0	.5	2.1	2.8	2.0	.4	1.0	3.5	1.3	4.9	1.6	.4	3.2
1978	1.6	2.4	3.3	3.2	3.6	2.0	2.1	4.6	4.2	.2	.6	2.0	3.8
1979	1.6	1.2	2.6	1.9	13.8	3.7	5.2	.7	4.5	7.2	1.3	2.7	5.9
1980	.1	1.2	3.7	3.7	1.6	1.6	.7	.3	.5	3.6	3.6	8.2	4.7
1981	4.6		2.4	3.7	1.4	4.9	7.4	1.4	8.4	7.3	1.2	2.2	5.5
1982	1.5	1.2	3.2	7.2	1.6	4.3	7.9	1.7	2.9	1.6	3.1	2.8	4.1
1983	4.7	3.5	1.4	1.2	2.6	.3	3.9	4.3	4.2	6.5	1.2	1.0	5.4

No. of Obs: 326 St. Dev.: 5.2
Mean: 91.1 Median: 91.0

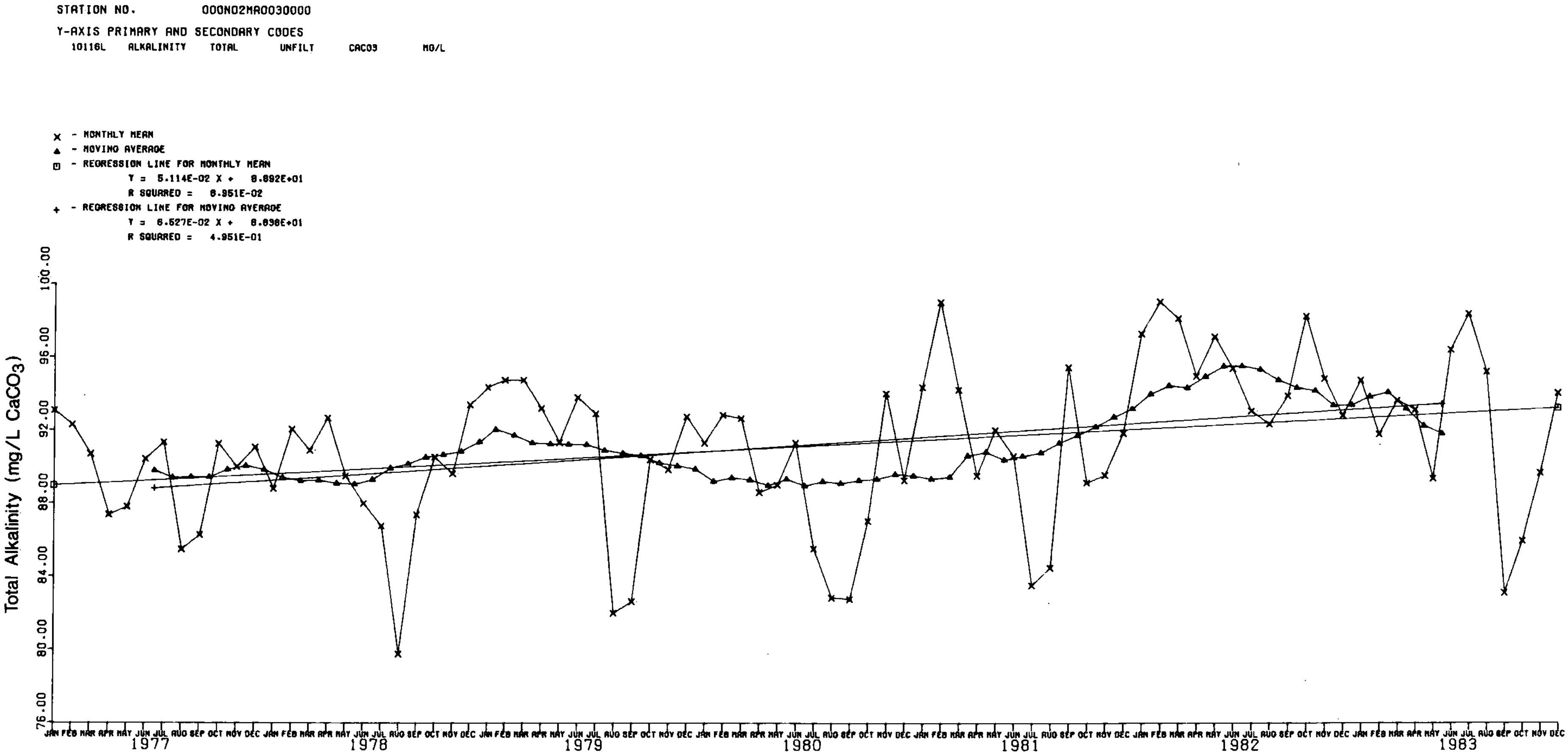

Figure E-8. Total alkalinity at Wolfe Island, 1977-83.

Appendix F
Trace Metal Data

Table F-1. Monthly and Annual Means and Standard Deviation for Total Iron (mg/L Fe) at Wolfe Island, 1977-83

MEANS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.033	.020	.138	.090	.042	.060	.044	.052	.038	.040	.052	.045	.056
1978	.048	.041	.046	.042	.064	.055	.209	.260	.363	.151	.202	.252	.127
1979	.052	.023	.060	.115	.039	.020	.015	.026	.036	.056	.053	.048	.047
1980	.056	.054	.097	.101	.093	.069	.060	.225	.144	.116	.063	.082	.093
1981	.112	.060	.162	.125	.058	.036	.047	.062	.088	.101	.082	.228	.095
1982	.267	.122	.148	.183	.148	.204	.168	.167	.095	.069	.130	.183	.155
1983	.184	.128	.075	.153	.121	.066	.057	.053	.051	.085	.118	.115	.103

STANDARD DEVIATION	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.012	.006	.101	.018	.022	.015	.015	.021	.024	.011	.015	.013	.044
1978	.018	.011	.036	.013	.028	.034	.191	.191	.061	.078	.293	.169	.140
1979	.029	.007	.035	.070	.020	.014	.006	.026	.007	.016	.025	.025	.038
1980	.023	.013	.060	.034	.055	.040	.031	.177	.051	.046	.012	.020	.058
1981	.093	.003	.105	.023	.023	.017	.012	.040	.021	.015	.014	.034	.066
1982	.071	.072	.134	.034	.031	.171	.050	.127	.040	.042	.010	.049	.090
1983	.050	.060	.030	.040	.066	.043	.062	.041	.016	.043	.035	.027	.059

No. of Obs: 333　　St. Dev.: .083
Mean: .096　　Median: .066

Table F-2. Monthly and Annual Means and Standard Deviation for Total Copper (mg/L Cu) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0130	.0143	.0143	.0125	.0088	.0083	.0070	.0030	.0033	.0022	.0048	.0053	.0081
1978	.0040	.0038	.0030	.0048	.0067	.0058	.0083	.0065	.0045	.0053	.0050	.0108	.0056
1979	.0172	.0225	.0283	.0170	.0083	.0095	.0110	.0070	.0093	.0120	.0170	.0086	.0140
1980	.0100	.0113	.0222	.0120	.0100	.0046	.0028	.0030	.0022	.0015	.0010	.0030	.0070
1981	.0081	.0058	.0083	.0134	.0159	.0094	.0025	.0024	.0033	.0028	.0016	.0033	.0063
1982	.0038	.0020	.0110	.0053	.0060	.0060	.0128	.0072	.0113	.0073	.0092	.0030	.0072
1983	.0020	.0020	.0013	.0110	.0200	.0237	.0103	.0260	.0188	.0173	.0020	.0153	.0128

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0070	.0021	.0057	.0104	.0033	.0040	.0052	.0010	.0021	.0013	.0005	.0015	.0060
1978	.0000	.0013	.0008	.0032	.0072	.0031	.0042	.0021	.0024	.0019	.0034	.0050	.0036
1979	.0060	.0052	.0068	.0078	.0026	.0090	.0043	.0053	.0010	.0079	.0050	.0092	.0084
1980	.0060	.0100	.0071	.0066	.0141	.0033	.0017	.0010	.0013	.0006	.0000	.0017	.0083
1981	.0087	.0010	.0045	.0066	.0056	.0038	.0030	.0017	.0017	.0010	.0009	.0025	.0058
1982	.0021	.0014	.0173	.0031	.0035	.0038	.0043	.0018	.0088	.0081	.0063	.0022	.0071
1983	.0000	.0008	.0006	.0112	.0141	.0118	.0039	.0144	.0065	.0091	.0000	.0122	.0117

No. of Obs: 335 St. Dev.: .0081
Mean: .0087 Median: .0060

Table F-3. Monthly and Annual Means and Standard Deviation for Total Nickel (mg/L Ni) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0018	.0020	.0020	.0023	.0026	.0030	.0040	.0013	.0017	.0018	.0013	.0017	.0021
1978	.0018	.0018	.0018	.0018	.0010	.0015	.0012	.0020	.0018	.0015	.0023	.0015	.0016
1979	.0020	.0035	.0028	.0016	.0020	.0018	.0016	.0015	.0010	.0012	.0010	.0020	.0018
1980	.0020	.0028	.0025	.0033	.0013	.0010	.0010	.0010	.0010	.0023	.0040	.0024	.0021
1981	.0026	.0018	.0015	.0008	.0011	.0020	.0013	.0012	.0010	.0010	.0010	.0010	.0013
1982	.0013	.0010	.0013	.0018	.0018	.0020	.0013	.0022	.0020	.0013	.0010	.0010	.0015
1983	.0010	.0010	.0013	.0018	.0022	.0020	.0018	.0023	.0013	.0020	.0010	.0013	.0016

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0005	.0000	.0000	.0005	.0005	.0000	.0017	.0006	.0006	.0008	.0005	.0006	.0009
1978	.0005	.0010	.0005	.0005	.0000	.0006	.0004	.0000	.0015	.0006	.0005	.0006	.0007
1979	.0012	.0024	.0017	.0005	.0012	.0005	.0005	.0007	.0000	.0004	.0000	.0017	.0012
1980	.0000	.0015	.0017	.0032	.0006	.0000	.0000		.0000	.0010	.0014	.0005	.0014
1981	.0008	.0003	.0006	.0005	.0004	.0022	.0005	.0004	.0000	.0000	.0000	.0000	.0009
1982	.0005	.0000	.0005	.0010	.0008	.0008	.0005	.0008	.0014	.0005	.0000	.0000	.0008
1983	.0000	.0000	.0006	.0005	.0008	.0008	.0010	.0005	.0005	.0000	.0000	.0005	.0007

No. of Obs: 338　　St. Dev.: .0010
Mean: .0017　　Median: .0010

Table F-4. Monthly and Annual Means and Standard Deviation for Total Zinc (mg/L Zn) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0060	.0030	.0038	.0035	.0016	.0017	.0023	.0120	.0043	.0056	.0028	.0047	.0038
1978	.0040	.0058	.0013	.0015	.0013	.0023	.0020	.0010	.0020	.0030	.0030	.0013	.0024
1979	.0034	.0020	.0015	.0038	.0038	.0010	.0010	.0010	.0035	.0044	.0030	.0042	.0029
1980	.0100	.0037	.0074	.0027	.0038	.0058	.0028	.0047	.0030	.0030	.0020	.0036	.0043
1981	.0049	.0040	.0038	.0036	.0013	.0028	.0013	.0012	.0010	.0010	.0010	.0033	.0024
1982	.0040	.0018	.0026	.0015	.0016	.0023	.0040	.0020	.0028	.0018	.0028	.0015	.0024
1983	.0012	.0020	.0013	.0030	.0102	.0073	.0028	.0075	.0033	.0052	.0063	.0023	.0045

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	.0050	.0010	.0015	.0010	.0005	.0006	.0023		.0006	.0013	.0005	.0035	.0027
1978	.0027	.0059	.0005	.0006	.0005	.0005	.0017	.0000	.0012	.0026	.0010	.0005	.0024
1979	.0017	.0020	.0006	.0013	.0032	.0000	.0000	.0000	.0017	.0039	.0018	.0004	.0021
1980	.0036	.0015	.0056	.0006	.0030	.0013	.0024	.0021	.0012	.0008	.0008	.0009	.0030
1981	.0017	.0006	.0011	.0007	.0003	.0027	.0005	.0004	.0000	.0000	.0000	.0013	.0017
1982	.0027	.0010	.0026	.0010	.0009	.0006	.0008	.0007	.0024	.0015	.0027	.0006	.0017
1983	.0004	.0008	.0006	.0014	.0068	.0042	.0017	.0060	.0010	.0038	.0031	.0010	.0042

No. of Obs: 337 St. Dev.: .0028
Mean: .0032 Median: .0020

Table F-5. Monthly and Annual Means and Standard Deviation for Extractable Aluminum (mg/L Al) at Wolfe Island, 1977-83

MEANS

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	--	--	--	--	--	--	--	--	--	--	--	--	--
1978	--	--	--	--	.037	.014	.024	.024	.017	.026	.105	.036	.035
1979	.022	.011	.038	.057	.040	.020	.041	.016	.006	.015	.015	.019	.026
1980	.013	.016	.019	.043	.054	.023	.044	.123	.059	.048	.027	.025	.039
1981	.033	.027	.049	.060	.041	.029	.041	.053	.058	.075	.061	.065	.049
1982	.135	.036	.019	.047	.030	.037	.045	.056	.030	.025	.105	.037	.050
1983	.054	.038	.020	.062	.074	.027	.019	.021	.023	.026	.038	.047	.039

STANDARD DEVIATION

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1977	--	--	--	--	--	--	--	--	--	--	--	--	--
1978	--	--	--	.057	.024	.003	.014	.018	.002	.005	.164	.015	.059
1979	.007	.005	.013	.047	.020	.009	.028	.010	.004	.011	.008	.009	.023
1980	.017	.008	.006	.018	.037	.014	.013	.075	.007	.015	.005	.005	.033
1981	.022	.002	.013	.014	.013	.011	.006	.018	.011	.011	.014	.022	.019
1982	.165	.011	.004	.028	.004	.019	.020	.053	.012	.014	.066	.010	.058
1983	.018	.017	.007	.016	.036	.014	.006	.010	.008	.011	.014	.021	.024

No. of Obs: 284 St. Dev.: .039
Mean: .040 Median: .030

Date Due

05 JAN 2009			