Lake Champlain Basin Program

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Assessment of Sediment Phosphorus Distribution and Long-Term Recycling in St. Albans Bay, Lake Champlain

Prepared by
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Assessment of Sediment Phosphorus Distribution and Long-Term Recycling in St. Albans Bay, Lake Champlain

FINAL REPORT

by

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Lake Champlain Basin Program Technical Reports

1. *A Research and Monitoring Agenda for Lake Champlain.* Proceedings of a Workshop, December 17-19, 1991, Burlington, VT. Lake Champlain Research Consortium. May, 1992.

2. *Design and Initial Implementation of a Comprehensive Agricultural Monitoring and Evaluation Network for the Lake Champlain Basin.* NY-VT Strategic Core Group. February, 1993.

3. (A) *GIS Management Plan for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc., and Associates in Rural Development. March, 1993.

   (B) *Handbook of GIS Standards and Procedures for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc. March, 1993.

   (C) *GIS Data Inventory for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc. March, 1993.

4. (A) *Lake Champlain Economic Database Project. Executive Summary.* Holmes & Associates. March 1993.

   (B) *Socio-Economic Profile, Database, and Description of the Tourism Economy for the Lake Champlain Basin.* Holmes & Associates. March 1993

   (C) *Potential Applications of Economic Instruments for Environmental Protection in the Lake Champlain Basin.* Anthony Artuso. March 1993.

   (D) *Conceptual Framework for Evaluation of Pollution Control Strategies and Water Quality Standards for Lake Champlain.* Anthony Artuso. March 1993.

5. *Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 1.* Alan McIntosh, Editor, UVM School of Natural Resources. February 1994.

   Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 1. Executive Summary. Alan McIntosh, Editor, UVM School of Natural Resources. February 1994.

6. *(A) Lake Champlain Nonpoint Source Pollution Assessment.* Lenore Budd, Associates in Rural Development Inc. and Donald Meals, UVM School of Natural Resources. February 1994.

   (B) Lake Champlain Nonpoint Source Pollution Assessment. Appendices A-J. Lenore Budd, Associates in Rural Development Inc. and Donald Meals, UVM School of Natural Resources. February 1994.

7. *Internal Phosphorus Loading Studies of St. Albans Bay. Executive Summary.* VT Dept of Environmental Conservation. March 1994.

(A) *Dynamic Mass Balance Model of Internal Phosphorus Loading in St. Albans Bay, Lake Champlain.* Eric Smeltzer, Neil Kamman, Karen Hyde and John C. Drake. March 1994.

(B) *History of Phosphorus Loading to St. Albans Bay, 1850 - 1990.* Karen Hyde, Neil Kamman and Eric Smeltzer. March 1994.

(C) *Assessment of Sediment Phosphorus Distribution and Long-Term Recycling in St. Albans Bay, Lake Champlain.* Scott Martin, Youngstown State University. March 1994.

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SECTION 1

EXECUTIVE SUMMARY

For many years, St. Albans Bay has exhibited highly eutrophic conditions, including intense summer algal blooms, resulting from excessive phosphorus (P) enrichment. During the 1980's, point source phosphorus loadings to the Bay were reduced by about 94% through a combination of the Vermont Phosphorus Detergent Ban and process improvements at the City of St. Albans Wastewater Treatment Facility (WWTF). Despite this loading reduction, no dramatic improvements in water quality have occurred in the Bay. It is suspected that recycling of phosphorus stored in the Bay's bottom sediments is delaying the response of the water column to the loading reductions. The goals of this study were: to determine whether levels of phosphorus in the bottom sediments have declined as a result of point source loading reductions; and, to estimate the time frame of any further improvements in water quality. The study consisted of two major components: 1) phosphorus fractionation studies on bottom sediment cores from St. Albans Bay and Stevens Brook Wetland; and 2) application of a mass balance model for total phosphorus in the water column and bottom sediments of the Bay/Wetland system.

Sediment cores were collected at 43 locations in the Bay and Wetland, including 25 sites sampled by Ackerly in 1982. Sediments from depths of 0-1 cm, 1-2 cm, 3-4 cm, 7-8 cm, and 11-12 cm, were analyzed for total P, % organic matter, porosity, total iron (by Vermont DEC), and phosphorus fractionation using an extraction sequence of NH_4Cl-NaOH-HCl. Total phosphorus in the bottom sediments varies considerably with location, averaging 919 μg/g dry sediment in the Middle Bay, 980 μg/g in the Inner Bay, 1255 μg/g in the Outer Bay, and 1817 μg/g in the Wetland. Biologically available inorganic phosphorus (BAIP; the sum of P extracted by NH_4Cl and NaOH) is also highly variable spatially, accounting for 49.9% of total P in Wetland bottom sediments, 36.2% in the Outer Bay, 25.2% in the Inner Bay, and 23.6% in the Middle Bay. Organic P (total sediment P minus total extractable inorganic P) accounts for a relatively constant fraction (18.3-26.6%) of total sediment P, while the mass of HCl-extractable P shows little variation (averages ranged from 499 μg/g to 544 μg/g) with location in the Bay/Wetland system. Phosphorus levels and fractionation do not vary significantly with depth in the bottom sediments.

Phosphorus levels in the Bay and Wetland bottom sediments have decreased substantially from those reported by Ackerly (1983) for 1982. The decreases in total sediment P, BAIP, HCl-P, and Organic P are statistically significant at the $p<0.001$ level (i.e. probability > 99.9%). Total sediment P decreased by an average of 350 μg/g between 1982 and 1992. Of this, 50% came from the Organic P fraction, 30% from the BAIP fraction, and 20% from the HCl-P fraction. It is estimated that 591,900 kg of total P and 173,100 kg of BAIP are presently (1992) stored in the top 8 cm of St. Albans Bay bottom sediments, compared with 16,170 kg of total P and 7,790 kg of BAIP in Stevens Brook Wetland sediments. The decreases in Organic P and % Organic Matter since 1982 indicate that, on an annual average basis, primary productivity has declined significantly in the Bay and Wetland.

A review of historical total phosphorus loading estimates for the St. Albans WWTF indicates that a substantial reduction in point source loading occurred in 1983 from the closing of a Hood Dairy facility. This loading reduction was comparable to that achieved by the 1986-87 WWTF upgrade. Thus, the Bay and Wetland have had ten years or more to respond to loading reductions. Some disagreement exists in estimates of nonpoint phosphorus loading rates. The mean loading reported by the St. Albans Bay Rural Clean Water Program (RCWP) for 1982-89 is 3-4 times that estimated for 1991-92 by the Lake Champlain and St. Albans Bay Diagnostic-Feasibility Studies. Similar discrepancies are also evident in water colunm phosphorus levels.

The total phosphorus model of Chapra and Canale (1991) was successfully calibrated for the period 1900-1992 by adjusting kinetic coefficients (settling, resuspension, and burial velocities) to obtain reasonable agreement between model predictions and annual average measured concentrations in the Bay and Wetland. Whole-system mass balances based on the calibrated model results indicate that sediment-water interactions have a major impact on water quality in St. Albans Bay, but not in Stevens Brook Wetland. Following the WWTF upgrade (1988 conditions), the bottom sediments became a net source of phosphorus to the water column.

Model predictions of future conditions are highly sensitive to uncertainty in the nonpoint phosphorus loads. The calibrated model was applied to simulate total P levels in the water column and sediments of the Bay and Wetland for the period 1980-2050 under two different future loading assumptions: 1) Scenario F1 - total P loadings set at rates estimated for 1992 by St. Albans Bay Diagnostic-Feasibility Study; and 2) Scenario F2 -nonpoint loads set at eight-year (1982-89) means from RCWP. Under Scenario F1, the model predicts that significant future decreases in total P would occur, and the Bay-wide water quality goal of 0.017 mg/L for total P would be met by 1995. Under Scenario F2, only slight future improvement in water quality would be expected, and the water quality goal would not be met without reductions in the nonpoint source phosphorus loadings. In order to reduce the uncertainty associated with these predictions, an intensive tributary monitoring program, combined with a thorough evaluation of sampling and analytical procedures, would be required.

A procedure was developed to calculate the "effective" phosphorus loading from bottom sediments based on a comparison of concentrations in the water column and bottom sediments at any given time with those at steady-state. Using the two future loading scenarios considered, it is estimated that the effective phosphorus loading from St. Albans Bay sediments has decreased from about 64 kg/d in 1988 to between 29 kg/d and 54 kg/d (28-78% of the total P load) in 1993. The loading will continue to decrease to 19.0-36.4 kg/d (20.5-63.7% of total P load) by 1998, to 11.2-22.1 kg/d (13.2-52.8% of total P load) by 2005, and to 5.6-11.2 kg/d (7.1-36.6% of total P load) by the year 2015. Nuisance conditions associated with algal blooms in St. Albans Bay occur primarily during periods when tributary flows and dispersive exchange rates are low (e.g. mid- to late-summer). The frequency, severity, and spatial extent of this problem are expected to decrease in the future as the effective rate of phosphorus release from the bottom sediments declines.

SECTION 2

INTRODUCTION

2.1 Background

St. Albans Bay is located on the Northeast Arm of Lake Champlain, about 40 km (25 mi) north of Burlington, Vermont. For many years, the Bay has exhibited highly eutrophic conditions, including intense summer algal blooms, resulting from excessive phosphorus enrichment. The deterioration in water quality was preceded by the construction of sewers in the City of St. Albans and increased discharge from the City's Wastewater Treatment Facility (WWTF), which enters Stevens Brook a short distance from the Bay. The onset of eutrophic conditions was accompanied by a significant decline in recreational use of the Bay.

In an effort to reduce algal productivity, two major programs were implemented during the 1980's to control phosphorus loadings to the Bay. In 1987, the St. Albans WWTF was upgraded to meet a discharge limit of 0.5 mg/L for phosphorus, resulting in a 90% reduction in phosphorus loading from this source. In 1991, the decade-long St. Albans Bay Rural Clean Water Program (RCWP) was completed. This program focused on reductions in nonpoint source phosphorus loadings through implementation of best management practices on agricultural land in the St. Albans Bay watershed (Smeltzer, et al., 1993).

A steady-state mass-balance modeling analysis performed by Smeltzer (1983) indicated that the WWTF upgrade should (eventually) result in substantial decreases in phosphorus levels, particularly in the northern end of the Bay where the eutrophication problem is most severe. To date, however, long-term monitoring data from the St. Albans Bay Rural Clean Water Program (1991) and the Vermont Lay Monitoring Program (Picotte and Lohner, 1993) have shown little evidence of improvement in the Bay's trophic condition. The possibility of delayed recovery following a reduction in phosphorus loading was forseen by Henson and Gruendling (1977). More recent mass-balance modeling analyses (Smeltzer, 1991; Smeltzer, et al., 1993) suggest that internal loadings of phosphorus from the bottom sediments of St. Albans Bay and Stevens Brook Wetland are responsible for the lack of water quality improvement. Under these conditions, sediment phoshporus levels and the rate of internal loading should gradually decline, resulting in lower phosphorus concentrations and algal productivity in the water column of the Bay.

2.2 Objectives of Study

Corliss and Hunt (1973) found that total phosphorus concentrations in the bottom sediments of St. Albans Bay were considerably higher than those in nearby Lapan Bay. Ackerly (1983) analyzed sediment core samples from 23 locations in the Bay and Wetland for total phosphorus and related parameters such as total iron and organic matter. In addition, a series of chemical extractions was also applied to samples from most of the cores in order to characterize the form and potential bioavailability of sediment phosphorus.

These studies provide background information on conditions existing prior to the WWTF upgrade.

The objectives of the present study were:

1) to determine what changes, if any, have occurred in sediment phosphorus levels since the WWTF upgrade; and
2) to predict what period of time will be required before water quality improvements are observed in St. Albans Bay.

The first objective was accomplished by repeating the study of Ackerly (1983) as closely as possible, using the same sampling locations and analytical procedures. The second objective was met by applying the total phosphorus model of Chapra and Canale (1991) to St. Albans Bay and Stevens Brook Wetland.

This project is Task 2 of the Diagnostic-Feasibility Study for the Contol of Internal Phosphorus Loading from Sediments in St. Albans Bay. The study was supported by the Lake Champlain Management Conference. Task 1, performed concurrently by the Vermont Department of Environmental Conservation (DEC), focused on development of a phosphorus mass balance for the Stevens Brook Wetland. To the extent possible, Task 1 results have been incorporated into the modeling component of this study.

SECTION 3

REVIEW OF RELATED RESEARCH

Because of its long history of water quality problems, St. Albans Bay has been the subject of many scientific studies. Much of the information generated was useful in meeting the objectives of this project. In this section, a review of the available literature and data related to the following topics is presented: sediment phosphorus levels; nutrient loadings; water quality monitoring; and mass-balance modeling. First, however, to facilitate interpretation of previous work, as well as the results of this study, a brief summary of previous research on the chemical fractionation of sediment-bound phosphorus is included.

3.1 Chemical Fractionation of Sediment Phosphorus

Phosphorus (P) bound to aquatic sediments often represents a large potential source of algal nutrients in lakes and embayments. The fraction of the sediment phosphorus that can actually be utilized by algae depends on its location (or accessibility) and chemical form. Several techniques, including chemical extractions and bioassays, have been used to estimate the biologically available fraction of phosphorus associated with soils, suspended solids, and bottom sediments.

The development of extraction procedures for the chemical characterization of sediment-bound phosphorus can be largely attributed to researchers in the field of soil science. These procedures usually remove phosphorus by one or more of the following processes (Logan, 1978):

1) displacement of soluble phosphorus held in soil pores;
2) exchange of H_2PO_4 adsorbed to soil surfaces with another anion;
3) dissolution or hydrolysis of soil phosphorus complexes.

Several methods originally developed for soils have been adapted for application to river and lake sediments. One of the early techniques applied to aquatic sediments was that of Chang and Jackson (1957). They suggested that sequential extraction with NH_4F, NaOH, H_2SO_4, citrate-dithionite reagent, and NH_4F again would selectively remove aluminum phosphate, iron phosphate, calcium phosphate, occluded iron phosphate, and occluded aluminum phosphate, respectively. While this view, known as the "discrete phosphate theory" (Williams and Walker, 1969) has been widely discredited (Bache, 1964; Hsu, 1964; Williams et al., 1971a), many of the extractions now in common use are based on modifications of the Chang and Jackson (1957) procedure.

It is now generally accepted that inorganic phosphorus in sediments consists of phosphate ions chemisorbed onto reactive surfaces such as iron and aluminum oxides or hydrous oxides and amorphous alumino-silicates ("non-occluded" P), or retained within the matrices of these materials or various mineral phases (Williams and Walker, 1969; Logan, 1978). This is known as the "dispersed phosphate theory". A certain amount of sediment phosphorus may also be present in discrete phosphate minerals such as apatite, or in organic forms such as esters of phosphoric acid (Williams, et al., 1971a).

Many of the notable developments in the evolution of sediment phosphorus extraction techniques are attributable to Williams and co-workers (Williams, et al., 1971a, 1971b, 1971c, 1976a, 1976b, 1980). They evaluated the effectiveness of several different extraction sequences in removing specific forms of phosphorus from aquatic sediments. These and other chemical fractionation studies performed on sediments from the Great Lakes (e.g. Logan, 1978; Armstrong et al., 1971) have led to a reasonably, but not totally, consistent interpretation of phosphorus forms removed by various extractants. Four of the most common extractants employed are NH_4Cl, NaOH, CDB (citrate-dithionite-bicarbonate), and HCl. If applied in the order listed, the sediment phosphorus forms extracted may be roughly interpreted as follows (Martin et al., 1984):

1) NH_4Cl - inorganic P in sediment interstitial water;
2) NaOH - P sorbed to iron and aluminum oxides and hydrous oxides, and organic P;
3) CDB - P occluded within matrices of iron and aluminum oxides and minerals;
4) HCl - P bound in apatite minerals.

Chemical extractions have been employed to estimate the fraction of sediment phosphorus available for algal uptake. The fraction extracted by NaOH is often used as a surrogate measurement of the bioavailable fraction (e.g. Armstrong et al., 1979; Baker, 1982), although Logan (1978) suggested that the CDB-extractable fraction may also be ultimately available. Martin et al. (1984) applied the extraction sequence NaOH-CDB-HCl to suspended sediments from Lower Great Lakes trubutaries in parallel with direct algal bioassay measurements of sediment phosphorus bioavailability. Both the NaOH and CDB fractions showed strong correlations with algal-available phosphorus.

3.2 Sediment Phosphorus Levels

Elevated sediment phosphours levels in St. Albans Bay were documented two decades ago by Corliss and Hunt (1973). They reported concentrations ranging from 513 to 1576 μg/g, with a mean of 983 μg/g, in the Bay. The highest concentrations (>1200 μg/g) were observed near the mouth of Stevens Brook and in the deeper waters (>10 m) of the outer Bay. The lowest concentrations (<800 μg/g) were found in the middle portion of the Bay and in shallow waters (<2 m) along the Bay's western shore. By comparison, levels in nearby Lapan Bay were substantially lower, ranging from 298 to 760 μg/g with a mean of 535 μg/g. The elevated sediment phosphorus concentrations were attributed primarily to heavy loadings from the City of St. Albans WWTF entering the Bay via Stevens Brook (Henson and Greundling, 1977).

An extensive study of phosphorus levels and chemical forms in sediment cores from St. Albans Bay and Stevens Brook Wetland was performed by Ackerly (1983). Cores were taken from 20 locations in the Bay, six in the Wetland, and one in Mill River; these were sectioned into 1 cm "slices", and sediments from 0-1 cm, 1-2 cm, 3-4 cm, and 7-8 cm depths were retained for analysis. Total phosphorus measurements were performed on 23 of the cores, and a phosphorus fractionation sequence of NH_4Cl, "Vermont buffer", NaOH, and HCl was applied to 20 cores. These reagents were assumed to extract soluble reactive P, readily available P, mineral P (potentially available), and residual inorganic P, respectively. An overview of the results from this study are presented in Table 3-1. In this table, "Inorganic P" refers to the sum of all extractable fractions listed.

Table 3-1. Summary of Sediment Phosphourus Measurements by Ackerly (1983). All Values in μg P/g sed.

Fraction	St. Albans Bay		Stevens Brook Wetland	
	Range	Mean	Range	Mean
NH_4Cl-P	0.0-7.0	1.5	9.8-45.8	26.8
VTBuf-P	0.0-95.0	18.7	60-326	186
NaOH-P	7.0-1781	292	376-1473	960
HCl-P	398-1141	597	286-758	545
Inorg P	511-2605	909	734-2408	1717
Total P	276-3234	1198	1378-3255	2340

The range of total phosphorus concentrations obtained by Ackerly (1983) in St. Albans Bay is considerably wider, and the mean slightly higher, than reported by Corliss and Hunt (1973). The highest concentrations were again found in the deep waters of the outer Bay. Very low phosphorus concentrations were measured on samples taken along a transect from Hathaway Point to Lime Rock Point. Total phosphorus levels in cores from Stevens Brook Wetland averaged nearly twice those in the Bay.

The percentage contributions of extractable fractions to total phosphorus in both St. Albans Bay and Stevens Brook Wetland are summarized in Table 3-2. In St. Albans Bay, sediment phosphorus was dominated by the HCl-extractable fraction (51.3%). The sum of the potentially bioavailable fractions (NH_4Cl + VT Buffer + NaOH) accounted for only 21.9% of total P. In the Wetland, on the other hand, the potentially bioavailable fractions accounted for 48.5% of total P, while the HCl fraction averaged only 24.5%. Ackerly's data suggest that most of the phosphorus accumulation by bottom sediments exposed to high external loadings occurs in biologically available forms.

3.3 Nutrient Loadings

Early (pre-1980) estimates of nutrient loadings to St. Albans Bay were obtained from several studies. From data collected during the National Eutrophication Survey, the total phosphorus and nitrogen loadings to Lake Champlain (i.e. St. Albans Bay) from Stevens Brook were estimated at 52,310 kg/yr and 174,210 kg/yr, respectively (USEPA, 1974). Multiplying median measured total phosphorus concentrations from 1970-74 by tributary flows, Henson and Gruendling (1977) obtained loading estimates of 16,760 kg/yr for Stevens Brook and 970 kg/yr for Mill River. Based on monitoring conducted during 1975-76, the Vermont Agency of Environmental Conservation (1977) calculated a total phosphorus loading to St. Albans Bay of 32,747 kg/yr from all sources. The St. Albans WWTF accounted for 76.2% (24,939 kg/yr) of this. These loading estimates are highly variable and

Table 3-2. Percentage Contributions of Extractable Phosphorus Fractions to Total Phosphorus in St. Albans Bay and Stevens Brook Wetland, Based on Data from Ackerly (1983).

Fraction	St. Albans Bay		Stevens Brook Wetland	
	Range	Mean	Range	Mean
NH_4Cl-P	0.0-0.57	0.12	0.60-1.8	1.1
VTBuf-P	0.0-3.7	1.4	4.1-11.1	7.6
NaOH-P	0.67-60.6	20.4	27.3-47.4	39.8
TotBAP	1.8-63.2	21.9	32.5-57.5	48.5
HCl-P	21.8-83.7	51.3	16.6-48.7	24.5
Inorg P	47.6-95.3	73.2	53.3-81.5	73.1

of questionable reliability since the number of samplings was not adequate to establish the relationship between nutrient concentrations and tributary flows, and/or flows were not gaged continuously.

As part of the St. Albans Bay Rural Clean Water Program, comprehensive gaging and monitoring of tributaries and point sources entering the Bay were conducted from late 1981 to mid-1990. This information was used to develop estimates of phosphorus loadings from Jewett Brook, Stevens Brook, Mill River, and the St. Albans WWTF. Since these estimates were developed from extensive monitoring data and continuous flow gaging records, they should be much more reliable than previous attempts. Monthly total phosphorus loadings for the period of record were obtained from Meals (personal communication, 1992). Tributary loadings at the gaging/monitoring stations were adjusted by the ratio of total drainage area to gaged area. The monthly loadings are tabulated in Table A-1 of Appendix A. A summary of annual total phosphorus loadings for the eight full years of record is presented in Table 3-3.

Since 1990, tributary gaging and monitoring in the St. Albans Bay watershed has continued as part of the Lake Champlain Diagnostic-Feasibility Study (VDEC and NYSDEC, 1992), and Task 1 of the St. Albans Bay Diagnostic-Feasibility Study (Smeltzer et al., 1993). The following preliminary estimates of annual phosphorus loadings, based on data from the two-year period from March, 1990 to February, 1992, were developed by Smeltzer (personal communication, 1993):

Stevens Brook:	3300 kg/yr
Mill River:	5200 kg/yr
Point Sources (WWTFs):	800 kg/yr

In order to apply a mass balance model for total phosphorus that includes a sediment compartment (like the one developed by Chapra and Canale, 1991), the model must first

Table 3-3. **Estimates of Total Phosphorus Loadings to St. Albans Bay for 1982 to 1989 Developed from Rural Clean Water Program Data (Meals, Personal Communication, 1992).**

Year	Total Phosphorus Loads (kg/yr) to St. Albans Bay					
	Jewett Brook	Stevens Brook	Mill River	Total Nonpoint	St Albans WWTF	Total Load
1982	10700	7303	9221	27244	21523	48746
1983	8771	7994	6703	23468	12227	35695
1984	10648	7898	29772	48318	10327	58646
1985	4017	2972	5490	12478	12011	24489
1986	3770	10469	37817	52056	9676	61732
1987	6417	3475	8307	18199	5755	23954
1988	2230	3464	4536	10230	1358	11588
1989	5818	4209	9898	19925	1497	21422

be calibrated to provide a realistic simulation of sediment phosphorus accumulation under historic loading conditions. To support the modeling component of this study, Hyde et al. (1993) developed estimates of historical phosphorus loadings to St. Albans Bay for the period 1850-1990. Because the St. Albans Bay watershed has been used extensively (>65% of the land area) for agriculture since the mid-1800's, only very gradual increases in nonpoint source phosphorus loadings are believed to have occurred since then. However, point source loadings increased dramatically between 1880 and 1930 as sewers were constructed in the City of St. Albans, and approached or exceedeed 20,000 kg/yr until the 1978 Vermont Phosphorus Detergent Ban took effect and tertiary treatment was added (1987). Summaries of the historical loading estimates are reproduced from Hyde et al. (1993) in Table A-2 and Figure A-1 of Appendix A.

3.4 Water Quality Monitoring

As with estimates of phosphorus loadings, monitoring studies of water quality in St. Albans Bay can be divided into two groups. Early studies (1960s and 1970s) were mostly short-term and/or intermittent in nature, and served to identify the seriousness of water quality problems in the Bay. During the 1980s and 1990s, long-term and/or more intensive monitoring programs were conducted, providing data that may be used to analyze the impact of past or future management programs on water quality.

In this study, previous monitoring data were used primarily to calibrate a mass balance model for total phosphours in Stevens Brook Wetland and St. Albans Bay. The only parameters required for this were total phosphorus and chloride concentrations. Therefore, discussion is primarily confined to these two substances.

Henson and Gruendling (1977) summarized many of the early studies of water quality in St. Albans Bay, and made the following observations:

1) Strong gradients in chemical concentrations (especially of phosphorus and nitrogen) exist from the inner Bay to the outer Bay.
2) Phosphorus levels are typical of an eutrophic water body.
3) The water column seldom develops thermal stratification for any length of time.
4) During late summer and early fall, bottom waters remain nearly saturated with dissolved oxygen, while surface waters are generally supersaturated.
5) A decline in Secchi disk transparency and an increase in surface oxygen supersaturation between 1966 and 1974 suggest an increase in algal productivity.
6) Extensive growth of rooted aquatic plants is a major impediment to recreation in the inner Bay.

More recent monitoring programs have contributed to the extensive data base that now exists on water quality in St. Albans Bay. These include the Vermont Lay Monitoring Program (LMP; 1979-93), the St. Albans Bay Rural Clean Water Program (RCWP; 1981-90), the Lake Champlain Diagnostic-Feasibility Study (LCDFS; 1990-92), and the Diagnostic-Feasibility Study for Control of Internal Phosphorus Loading from Sediments in St. Albans Bay (SABDFS; 1992).

In the LMP, total phosphorus measurements were made weekly during the summer months (June to August) at one station (#17) in the middle of St. Albans Bay, and one station (#16) in Lake Champlain just outside the Bay. In the RCWP, total phosphorus was measured weekly to monthly (conditions permitting) throughout the year at three sites. Station #11 was near the tip of St. Albans Point, Station #12 in the inner Bay, and Station #14 (1984-89 only) at the extreme inner tip of the Bay near the mouth of Stevens Brook. The locations of the sampling stations from these two studies are shown in Figure 3-1 (modified from Smeltzer, 1991).

Summer mean total phosphorus concentrations for 1979-91 from the LMP are presented in Table 3-4. Smeltzer (1991) found that the difference between 1989-91 levels and 1979-88 levels at Station #17 was statistically significant (t-test, $p<.05$). Total phosphorus concentrations at the RCWP stations showed no consistent trend in the years following the WWTF upgrade. However, an analysis of the RCWP data yields some valuable insights into the dominant processes controlling total phosphorus levels in St. Albans Bay.

Measured total phosphorus concentrations versus time for the three RCWP sampling stations are shown in Figures 3-2 through 3-4. These plots emphasize the highly eutrophic conditions in inner St. Albans Bay (TP frequently >0.1 mg/L) and the extreme variability in phosphorus concentrations throughout the Bay. In addition, differences in the timing of the largest "spikes" in concentration among the three stations are evident. At Station #14, the highest levels were observed during mid-summer. At Station #12, the largest spikes occurred during mid-winter, although some sizeable peaks were seen during mid-summer as

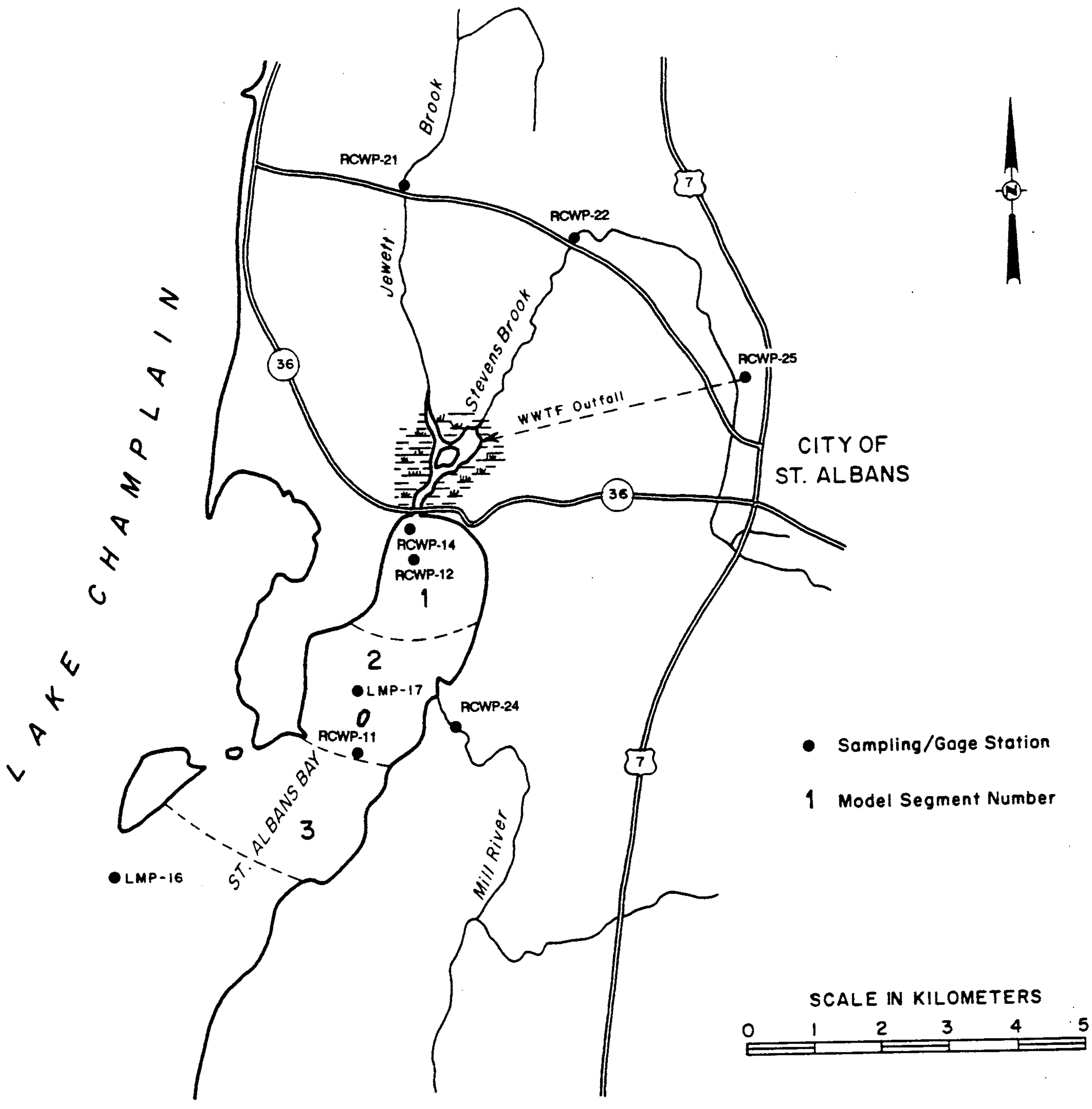

Figure 3-1. Location of Sampling Stations Used in Lay Monitoring Program (LMP) and St. Albans Bay Rural Clean Water Program (RCWP). Figure modified from Smeltzer (1991).

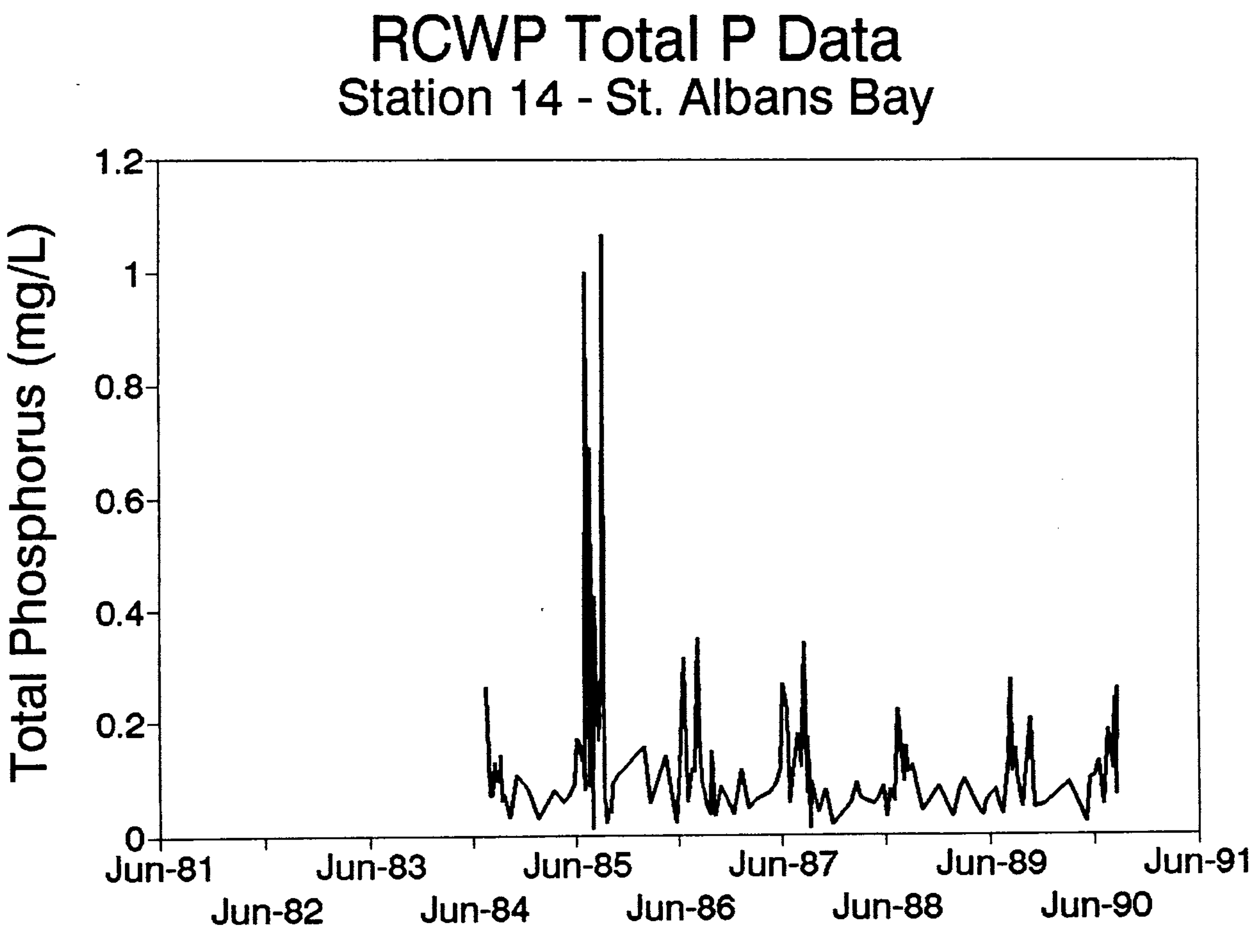

Figure 3-2. Measured Total Phosphorus Versus Time at St. Albans Bay Rural Clean Water Program Station #14 (Near Mouth of Stevens Brook).

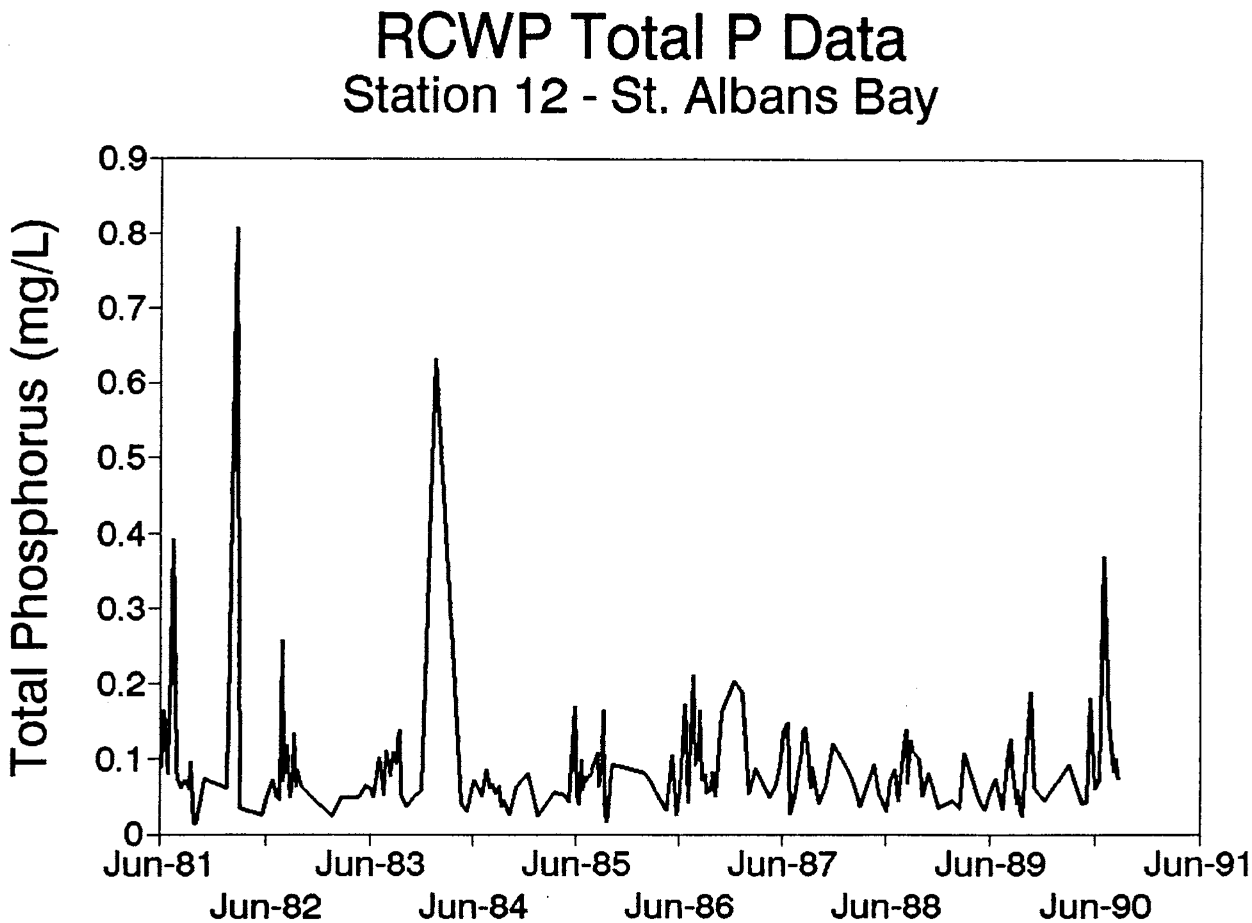

Figure 3-3. Measured Total Phosphorus Versus Time at St. Albans Bay Rural Clean Water Program Station #12 (Inner St. Albans Bay).

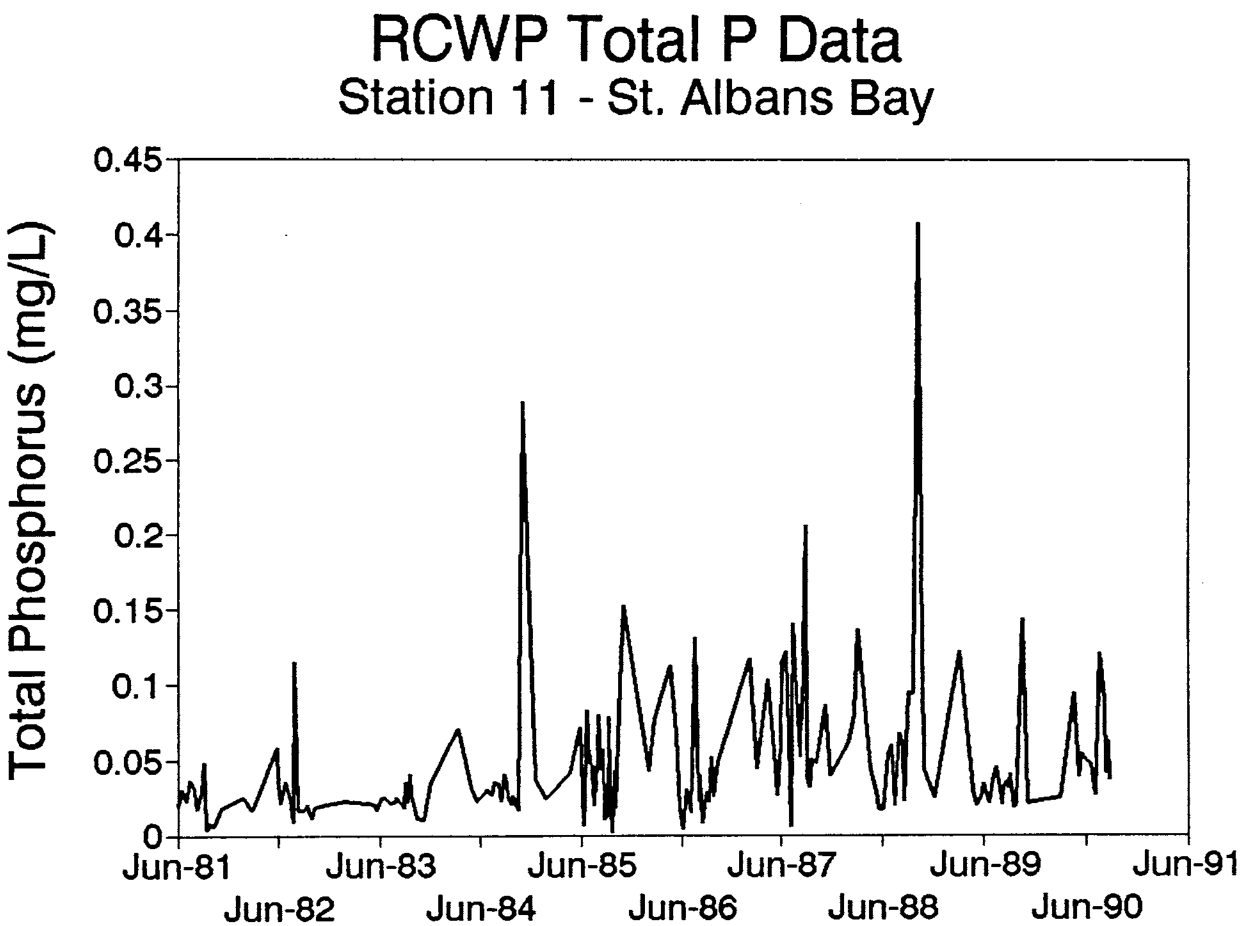

Figure 3-4. Measured Total Phosphorus Versus Time at St. Albans Bay Rural Clean Water Program Station #11 (Outer St. Albans Bay).

Table 3-4. Summary of Summer Total Phosphorus Data from Vermont Lay Monitoring Program Stations #16 and #17, 1979-91.

Year	Total P (mg/L) Station #16		Total P (mg/L) Station #17	
	Mean	St Dev	Mean	St Dev
1979	-	-	0.0317	0.0133
1980	0.0120	0.0043	0.0409	0.0191
1981	0.0180	0.0088	0.0386	0.0112
1982	-	-	0.0385	0.0068
1983	0.0179	0.0016	0.0343	0.0104
1984	0.0183	0.0029	0.0394	0.0074
1985	0.0180	0.0056	0.0361	0.0119
1986	0.0204	0.0058	0.0330	0.0099
1987	0.0193	0.0038	0.0486	0.0132
1988	-	-	0.0435	0.0301
1989	-	-	0.0278	0.0033
1990	0.0130	0.0017	0.0315	0.0124
1991	0.0140	0.0029	0.0283	0.0081

well. At Station #11, the pattern was more complex, with significant peaks in phosphorus concentration occurring at all times of the year.

To gain further insight into seasonal trends in total phosphorus, and the controlling factors, the measured concentrations for the entire period of record at each RCWP station were sorted by month. Monthly means and standard deviations were then calculated; these are plotted in Figures 3-5 through 3-7. Each station shows a unique pattern. The following explanations are proposed for these patterns:

1) At Station #14, total phosphorus levels are highest in mid-summer when flows in Stevens and Jewett Brooks are lowest. Since the total phosphorus loading from the St. Albans WWTF does not vary much seasonally, the concentration in the inflow to the Bay from Stevens Brook reaches a maximum in mid-summer. Thus, phosphorus levels at Station #14 appear to be dominated by inflows from the Stevens Brook Wetland.

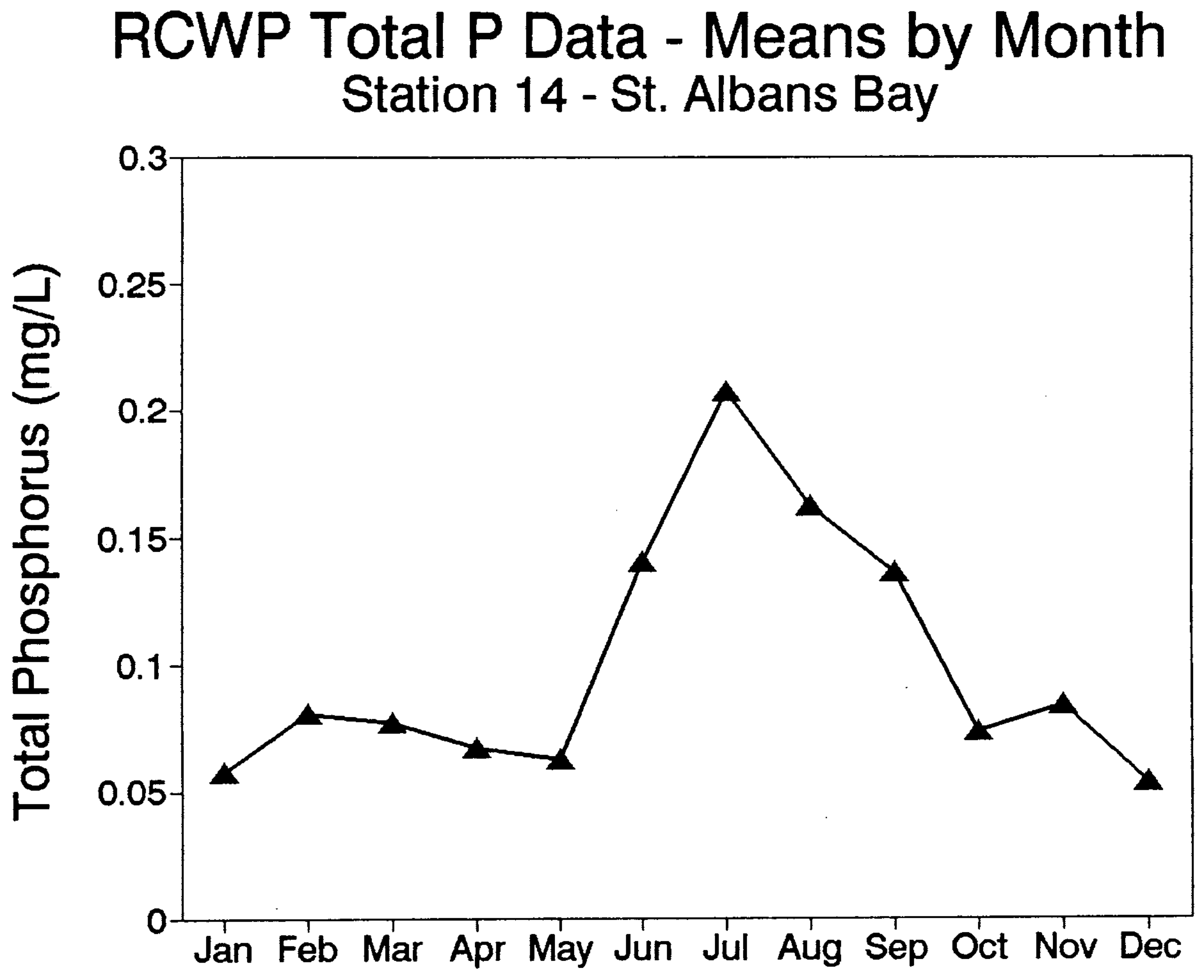

Figure 3-5. **Mean Measured Total Phosphorus Concentration Versus Month for the Period 1984-89 at St. Albans Bay Rural Clean Water Program Station #14 (Near Mouth of Stevens Brook).**

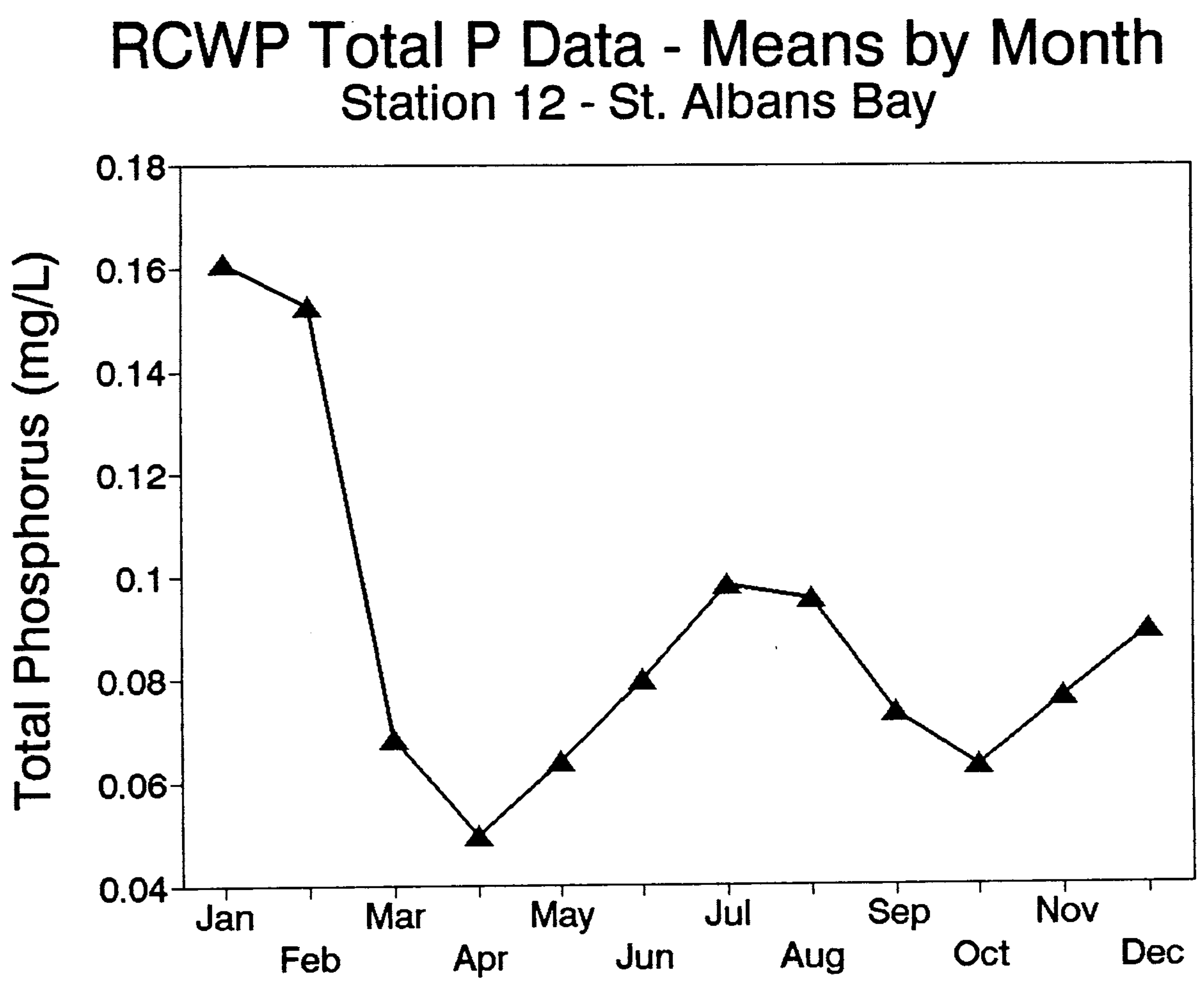

Figure 3-6. Mean Measured Total Phosphorus Concentration Versus Month for the Period 1981-90 at St. Albans Bay Rural Clean Water Program Station #12 (Inner St. Albans Bay).

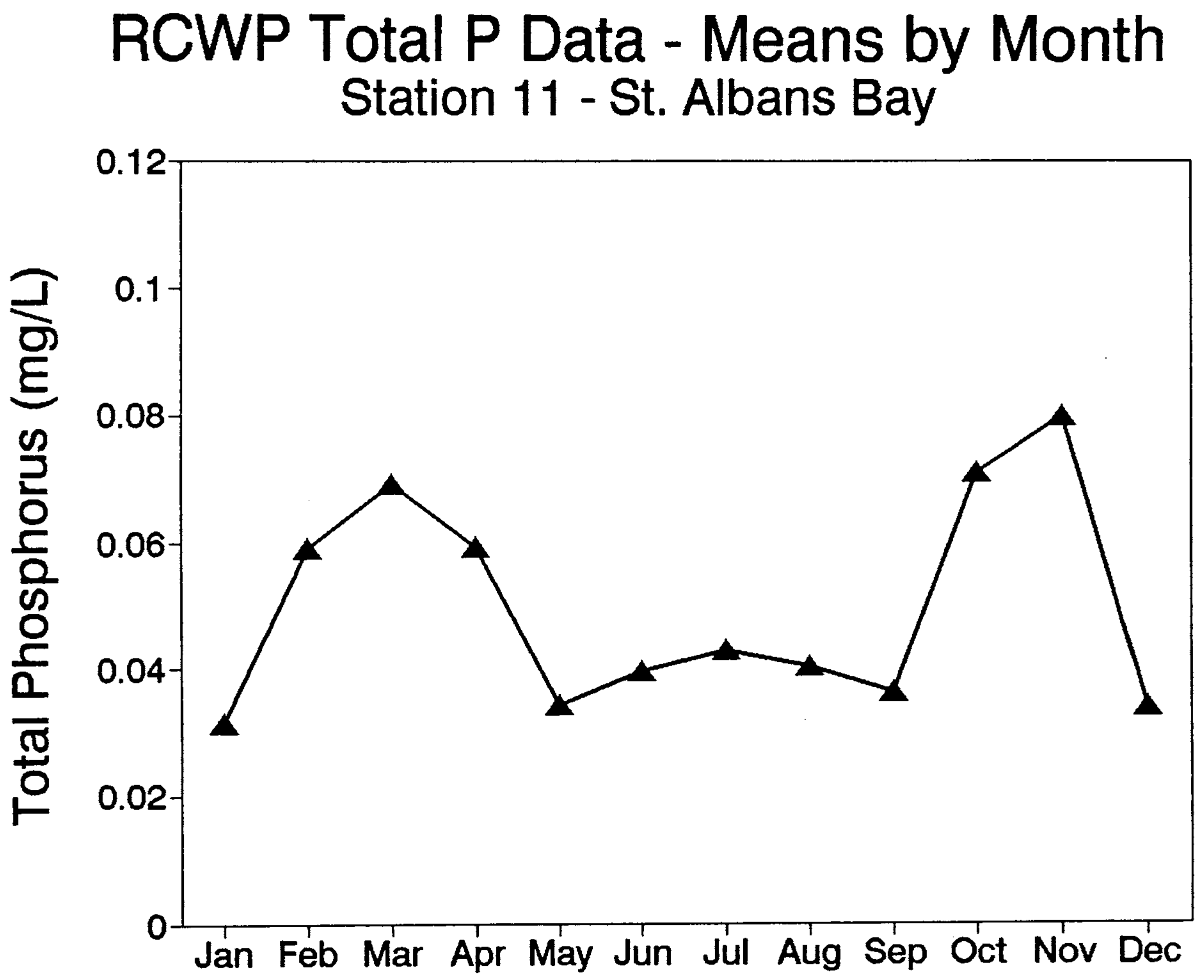

Figure 3-7. **Mean Measured Total Phosphorus Concentrations Versus Month for the Period 1981-90 at St. Albans Bay Rural Clean Water Program Station #11 (Outer St. Albans Bay).**

2) At Station #12, total phosphorus concentrations are highest when the intensity of wind-driven mixing (dispersion) with the main lake (or the outer Bay) is lowest. This occurs in winter under ice cover, and during mid-summer when average wind speed is typically low. During these periods, the lack of hydrodynamic flushing in the inner Bay permits phosphorus from both internal and external sources to accumulate.
3) At Station #11, total phosphorus concentrations are **generally** greater in the spring and fall when higher dispersive exchange and tributary flows move phosphorus from the inner Bay out into the middle and outer Bay.

The LCDFS provided data on total phosphorus and chloride at stations in the inner Bay (#40), middle Bay (#41) and outer Bay (#37). Samples were collected roughly biweekly for a six month period (spring through fall) each year from 1990 to 1992. A summary of data obtained for 1990 and 1991 is presented in Table 3-5.

Table 3-5. Summary of Total Phosphorus and Chloride Data from Lake Champlain Diagnostic-Feasibility Study, 1990-91.

Station	Total Phosphorus (mg/L)		Chloride (mg/L)	
	Mean	Std Dev	Mean	Std Dev
37	0.0153	0.003	9.43	0.25
40	0.0225	0.007	10.02	0.49
41	0.0256	0.008	10.28	0.54

More intensive sampling of St. Albans Bay and Stevens Brook Wetland was conducted during 1992 as part of the SABDFS. Samples were collected weekly to biweekly at 16 stations from April to November. A map of sampling locations for this study is reproduced from Smeltzer et al. (1993) in Figure A-2 of Appendix A. All of the stations used in other major monitoring studies were included in the SABDFS. The correspondence between sampling locations from different studies was summarized by Smeltzer et al. (1993), and is shown in Table A-3 of Appendix A. A summary of the SABDFS data is presented in Table 3-6.

Vermont DEC has also conducted two additional short-term studies that provided data useful in calibrating the mixing (dispersion) term in mass balance models. In 1982, chloride was measured daily for a two-week period (Aug 27 to Sep 9) at ten stations in St. Albans Bay. The results (from Smeltzer, 1983) are summarized in Figure A-3 of Appendix A. A second, spatially intensive study yielded total phosphorus and chloride measurements at 60 locations in the Bay on six dates during July and August from both 1986 and 1988.

Table 3-6. Summary of Total Phosphorus (TP), Dissolved Phosphorus (DP) and Chloride (CL) Data from St. Albans Bay Diagnostic-Feasibility Study, 1992.

STATION	TP mg/l Mean	TP mg/l St Dev	DP mg/l Mean	DP mg/l St Dev	CL mg/l Mean	CL mg/l St Dev
01	0.0980	0.0875	0.0433	0.0502	22.49	17.29
02	0.0393	0.0155	0.0160	0.0112	12.16	1.24
03	0.0315	0.0127	0.0106	0.0036	11.33	0.79
04	0.0296	0.0110	0.0106	0.0038	11.13	0.82
05	0.0250	0.0087	0.0096	0.0029	10.65	0.57
06	0.0213	0.0061	0.0083	0.0027	10.20	0.96
07	0.0203	0.0073	0.0076	0.0019	10.17	0.54
08	0.0160	0.0032	0.0070	0.0015	9.85	0.36
09	0.0158	0.0033	0.0067	0.0015	9.69	0.24
10	0.0145	0.0031	0.0065	0.0018	9.64	0.24
11	0.0141	0.0026	0.0069	0.0024	9.61	0.24
13	0.2321	0.1018	0.0968	0.0531	51.15	18.91
14	0.3240	0.1588	0.1417	0.0838	77.41	15.90
15	0.3464	0.1766	0.1532	0.1236	77.53	19.42
16	0.6920	0.4497	0.4405	0.4182	50.26	14.78
17	0.2898	0.1973	0.1019	0.0716	86.51	11.47

The data were summarized in a plot by Smeltzer (1991), shown in Figure A-4 of Appendix A.

3.5 Mass Balance Modeling Studies

Mass balance modeling studies were performed by the Vermont DEC both before and after the St. Albans WWTF improvements (1987) in order to assess the likely response of total phosphorus levels in the Bay to loading reductions. Smeltzer (1983) divided St. Albans Bay into three spatial segments (see Figure A-5 in Appendix A) and applied steady-state models for chloride and total phosphorus. The chloride model was calibrated to 1982 chloride data to estimate dispersive exchange rates between model segments; values ranging from 1.48×10^6 to 4.83×10^6 m^3/day were obtained. Using a typical apparent phosphorus settling velocity of 0.036 m/day from the literature (Dillon and Kirchner, 1975), model predictions of total phosphorus agreed reasonably well with 1982 LMP data. Model predictions also indicated that imposing a 0.5 mg/L limit on St. Albans WWTF discharges would (ultimately) result in a 70-75% decrease in total phosphorus concentrations in the inner Bay. However, calculations showed that the reservoir of phosphorus in the bottom sediments could delay the recovery for six years or more.

An updated modeling analysis was performed by Smeltzer (1991) using the same mass balance equation (essentially that of Chapra and Reckhow, 1983) applied at steady-state, but with a different spatial segmentation (see Figure 3-1). The 1986 and 1988 chloride data were used to calibrate the dispersive exchanges between segments; values ranging from 1.6 X 10^6 to 8.8 X 10^6 m^3/day were obtained. Model predictions for total phosphorus in the Bay agreed with LMP and RCWP monitoring data collected before the WWTF upgrade, but greatly underpredicted observed post-upgrade concentrations. This model did not account for the release of stored phosphorus from the bottom sediments. It was reasoned that, since the WWTF improvements reduced the external phosphorus loading by about 27 kg/day with no apparent reduction in phosphorus levels in the Bay, an increase in internal loading from the bottom sediments on the order of 27 kg/day must have occurred following the upgrade.

A third modeling study was performed by Smeltzer et al. (1993), once again using the model of Chapra and Reckhow (1983), with data from the SABDFS. Utilizing the greater spatial resolution of the 1992 data set, the Bay/Wetland system was divided into six segments, as shown in Figure A-2. First, monthly average exchange flows were calculated at each segment interface by applying the steady-state solution to the mass balance equation for chloride. Then, daily values of net apparent phosphorus settling velocities required to match time-variable model predictions with observed total phosphorus concentrations were computed for each spatial segment. The monthly exchange flows are given in Table A-4 and a graphical summary of the net phosphorus settling velocities in Figure A-6, both taken from Smeltzer et al. (1993). The authors found that seasonally low dispersive exchange rates, rather than high sediment phosphorus release rates, were primarily responsible for the high phosphorus concentrations observed in the inner Bay during mid-summer. The internal phosphorus loading was attributed to mechanisms functioning predominately under aerobic conditions, such as sediment resuspension, mineralization of organic phosphorus, ion exchange at high pH, and secretion from growing or senescent aquatic plants.

SECTION 4

SAMPLING AND ANALYTICAL METHODS

To meet the objectives of this study, the work plan was divided into two main components. The first was a survey of phosphorus levels in the bottom sediments of St. Albans Bay and Stevens Brook Wetland, and comparison with results obtained ten years ago by Ackerly (1983). Then, this information was combined with data from other studies to apply a dynamic mass balance model for total phosphorus in the water column and bottom sediments of the Bay/Wetland system. In this section, sampling and analytical procedures are described. The modeling approach is presented in Section 6.

4.1 Collection of Sediment Cores

The goals of this portion of the study were to determine whether phosphorus levels in bottom sediments have declined in response to the WWTF upgrade, and to estimate the current "pool" (i.e. mass) of biologically available phosphorus in the bottom sediments of the Bay and Wetland. To accomplish these objectives, a network of 45 sampling locations was laid out, as shown in Figure 4-1 and described in Table 4-1. Of these, 27 were sampled by Ackerly (1983) and labeled "old" sites in Table 4-1; the rest are "new" locations.

Sediment core samples were collected from 43 of the 45 locations during the period of August 17-20, 1992. It was not possible to obtain a core from Site #6 since the bottom was well scoured and rocky. Site #26, in Mill River, was assumed to be unimportant with respect to internal sediment phosphorus loading to the Bay, and was omitted. Three colocated (duplicate) cores were collected, at Sites #12, #25, and #33, for quality assurance work. Cores were obtained using a Wildlife Supply Co. KB core sampler with a 2" diameter (X 20" long) clear plastic liner tube. In water depths up to 25 ft., the sampler was attached to threaded sections of brass pipe. Where water depths exceeded 25 ft., a 14 lb. lead weight was attached to the barrel of the core sampler, and it was lowered on a steel cable. Following collection, supernatant water on top of the core was siphoned off and plastic end caps were placed on the core tubes. Field notes taken during sampling appear in Table B-1 of Appendix B.

Sediments were extruded from the core tubes within 48 hours of collection by clamping the tube into a stationary frame and moving a piston through it from the bottom. As cores emerged from the tops of the tubes, sediments from 0-1 cm, 1-2 cm, 3-4 cm, 7-8 cm and 11-12 cm were removed using a teflon-coated steel spatula and placed in screw-cap plastic cups. While sectioning the cores, field duplicate (FD) samples were obtained for quality assurance work by dividing ten selected sediment samples into two equal portions and placing them in separate cups. Descriptions of the physical appearance and characteristics of the cores were recorded as they were extruded; these are presented in Table B-2 of Appendix B.

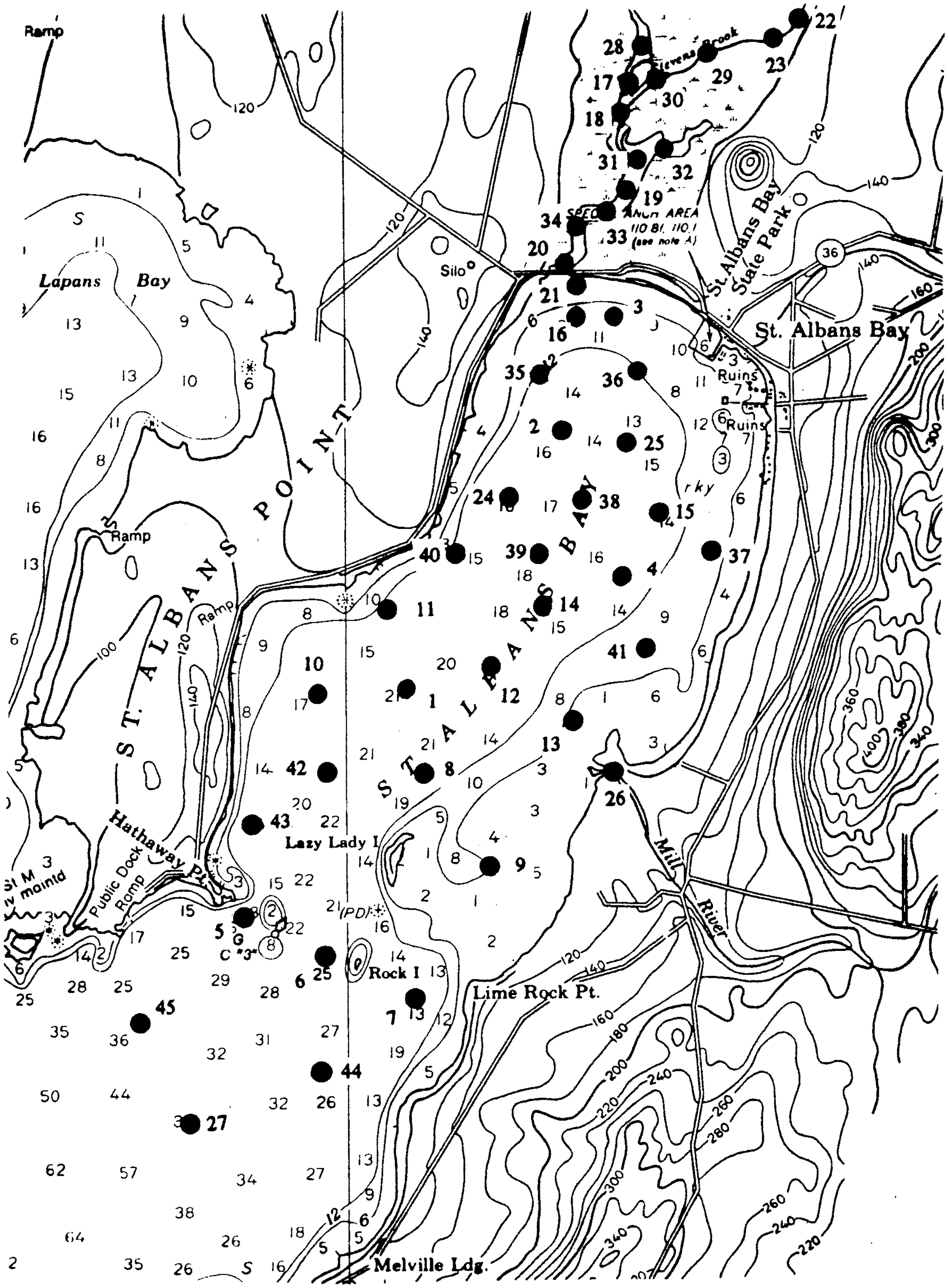

Figure 4-1. Location of Sediment Core Sampling Sites in St. Albans Bay and Stevens Brook Wetland.

Table 4-1. Longitude and Latitude of Sediment Core Sampling Sites in St. Albans Bay and Stevens Brook Wetland.

			(decimal	minutes)			
			Latitude	Longitude	(deg,	min, sec)	Water
	Site	Status	44 deg.	73 deg.	Latitude	Longitude	Depth (m)
	17	Old	49.208	8.797	44-49-12	73-08-48	0.6
	18	Old	49.103	8.847	44-49-06	73-08-51	0.3
	19	Old	48.878	8.801	44-48-53	73-08-48	0.2
Stevens	20	Old	48.678	9.062	44-48-41	73-09-04	1.8
Brook	22	Old	48.616	8.101	44-48-37	73-08-06	0.3
Wetland	23	Old	49.319	8.230	44-49-19	73-08-14	0.4
	28	New	49.319	8.752	44-49-19	73-08-45	0.2
	29	New	49.292	8.472	44-49-18	73-08-28	0.7
	30	New	49.222	8.695	44-49-13	73-08-42	0.9
	31	New	48.965	8.767	44-48-58	73-08-46	0.2
	32	New	48.995	8.646	44-49-00	73-08-39	0.3
	33	New	48.824	8.809	44-48-49	73-08-49	0.6
	34	New	48.778	9.017	44-48-47	73-09-01	0.9
	2	Old	48.149	9.066	44-48-09	73-09-04	4.9
	3	Old	48.519	8.899	44-48-31	73-08-54	3.0
	4	Old	47.738	8.835	44-47-44	73-08-50	4.3
	14	Old	47.635	9.172	44-47-38	73-09-10	5.1
Inner	15	Old	47.930	8.684	44-47-56	73-08-41	4.6
St. Albans	16	Old	48.514	9.032	44-48-31	73-09-02	2.4
Bay	21	Old	48.616	9.043	44-48-37	73-09-03	0.9
	24	Old	47.968	9.319	44-47-58	73-09-19	5.0
	25	Old	48.128	8.812	44-48-08	73-08-49	4.6
	35	New	48.346	9.168	44-48-21	73-09-10	4.0
	36	New	48.341	8.763	44-48-20	73-08-46	4.0
	37	New	47.803	8.480	44-47-48	73-08-29	3.0
	38	New	47.959	9.013	44-47-58	73-09-01	4.9
	39	New	47.814	9.175	44-47-49	73-09-11	5.0
	40	New	47.811	9.523	44-47-49	73-09-31	4.6
	1	Old	47.395	9.735	44-47-24	73-09-44	6.2
	5	Old	46.724	10.424	44-46-43	73-10-25	6.0
	6	Old	46.608	10.042	44-46-36	73-10-02	7.0
	7	Old	46.486	9.705	44-46-29	73-09-42	5.0
	8	Old	47.146	9.679	44-47-09	73-09-41	5.7
Middle	9	Old	46.900	9.440	44-46-54	73-09-27	2.5
St. Albans	10	Old	47.370	10.110	44-47-22	73-10-07	5.6
Bay	11	Old	47.670	9.830	44-47-40	73-09-50	1.4
	12	Old	47.459	9.391	44-47-28	73-09-23	5.7
	13	Old	47.316	9.028	44-47-19	73-09-02	1.4
	26	Old	47.149	8.884	44-47-09	73-08-53	
	41	New	47.514	8.741	44-47-31	73-08-44	2.7
	42	New	47.162	10.083	44-47-10	73-10-05	6.4
	43	New	47.000	10.378	44-47-00	73-10-23	4.8
Outer	27	Old	46.103	10.677	44-46-06	73-10-41	11.5
St. Albans	44	New	46.238	10.098	44-46-14	73-10-05	9.0
Bay	45	New	46.405	10.877	44-46-24	73-10-53	10.3

4.2 Analytical Procedures

Sectioned sediment core samples were transported to the Youngstown State University (YSU) Environmental Engineering Lab on August 24, 1992, and were stored at 4°C pending processing. Prior to analysis, sediments were dried at 60°C for 48 hours, ground using a glass mortar and pestle, and passed through a #140 sieve.

The moisture content of each "air dried" sediment sample was determined from the weight loss upon drying at 105°C for 8 hours. Samples from the 25 "old" sites were analyzed for sediment phosphorus fractionation using an extraction sequence of 1N NH_4Cl, 1N NaOH, and 0.5N HCl, as well as for total phosphorus and percent organic matter. Samples from "new" core locations were only analyzed for total phosphorus and percent organic matter. In addition to these analyses, performed at YSU, a small amount of each "air dried" sediment sample was sent to Vermont DEC for analysis of several heavy metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn). All sample processing and analytical methods were designed to be as close as possible to those used by Ackerly (1983) in order to ensure that data from the two studies could be compared directly. Original references for the methods used are listed in Table 4-2. Where significant modifications were made by Ackerly (1983), these were adopted in the present study. It should be noted that the phosphorus fractionation procedure used in this study differs slightly from that of Ackerly (1983), who applied an extraction sequence of 1N NH_4Cl, "Vermont buffer", 1N NaOH, and 0.5N HCl. However, this earlier study showed that the sum of phosphorus removed by "Vermont buffer" and NaOH was not significantly greater than that removed by NaOH alone.

Prior to the collection of samples, a Quality Assurance Project Plan (QAPP) was developed and approved. A number of data quality objectives were established, and activities were included in the plan of study to evaluate whether these objectives were met. Among these

Table 4-2. Original References for Analytical Methods.

Parameter	Method	Reference
Sediment P Fractionation:		
Soluble Reactive P	1N NH_4Cl	Williams et al (1967)
Mineralizable P	1N NaOH	Jackson (1970)
Residual Inorganic P	0.5N HCl	Williams et al (1976)
Total Sediment P	Perchloric acid	APHA (1975)
P in Extracts and Digests	Ascorbic acid	Harwood et al (1969)
Organic Matter	Ignition at 380°C	Ackerly (1983)

activities were analyses conducted on duplicate core (DC), field duplicate (FD), and laboratory duplicate (LD) samples, a standard reference material, and samples spiked with known amounts of analyte. A complete description and evaluation of the QA results is provided in a separate report. A summary of the key findings is presented in Appendix C.

SECTION 5

SEDIMENT PHOSPHORUS MEASUREMENTS

In this section, the results of all measurements performed on bottom sediment core samples are presented and discussed. First, the analytical data are summarized and spatial trends in sediment phosphorus fractionation evaluated. Then, 1992 phosphorus levels are compared with 1982 levels reported by Ackerly (1983). Next, statistical correlations among the measured parameters are explored in an effort to find a procedure for estimating unmeasured phosphorus fractions. Finally, the data are used to estimate the "pool" of biologically available phosphorus remaining in the bottom sediments of St. Albans Bay and Stevens Brook Wetland.

5.1 Tabulation of Analytical Data

A complete listing of all analytical results obtained in this study is presented in Table D-1 of Appendix D. This table includes: the extractable phosphorus fractions NH_4Cl-P, NaOH-P, and HCl-P; the sums of (NH_4Cl-P + NaOH-P) and total extractable inorganic phosphorus (NH_4Cl-P + NaOH-P + HCl-P); total sediment P; percent organic matter; estimated porosity; and total iron (measured by Vermont DEC). The sediment phosphorus and iron results are all expressed in μg per gram of oven dry (105°C) sediment. Porosity was estimated from weight loss upon air drying of sediments at 60°C using the same equation employed by Ackerly (1983). Table D-1 contains all primary samples and all samples analyzed for quality assurance (QA) purposes. QA samples are designated by code letters of "DC" for duplicate cores, "FD" for field duplicates, and "LD" for laboratory duplicates.

For convenience in the following discussion, the sum of (NH_4Cl-P + NaOH-P) will be referred to as "biologically available inorganic phosphorus", or BAIP, while the sum of all three extractable fractions is abbreviated TEIP (total extractable inorganic phosphorus). The difference between total sediment P and TEIP is considered to give the organic P content of the sediments. Individual samples will be designated by the core number and depth; for example sample 24-4 is from the 3-4 cm depth in core number 24.

While results of the QA work (see Appendix C) indicated that the data are generally very reliable, some anomolies are noticeable in Table D-1. For eight of the 120 primary samples, the magnitude of TEIP exceeded that of total sediment phosphorus. The offending samples are 3-8, 5-2, 5-4, 11-12, 13-4, 21-4, 23-2, and 25-12. This discrepancy did not arise for any of the QA samples. It may be attributed, at least in part, to slight inhomogeneities in the sediment samples. Analyses from five of these locations were repeated as part of the QA program. Of these, total phosphorus exceeded TEIP in three samples. Where necessary, steps were taken to account for this problem in the analysis of the data.

5.2 Spatial Variations in Sediment Phosphorus Levels

Variations in the measured parameters in two different spatial directions - vertical and horizontal - were assessed. First, trends as a function of depth within the bottom sediment cores were examined. Then, differences with location along the longitudinal axis of the Bay/Wetland system were evaluated. For the latter analysis, the spatial segmentation used by Smeltzer (1991) was adopted to divide St. Albans Bay into Inner, Middle and Outer Bay segments.

Three different data screening strategies were investigated in this portion of the study. In all of these approaches, only primary samples were considered; all QA sample results were removed from the data base, to avoid counting results from any given location more than once. The first strategy involved inclusion of **all** primary samples (i.e. no further screening). The second approach involved removal of the eight samples with TEIP > TP from the data base. Then, for the third strategy, samples without complete phosphorus data sets (cores 28-33 and 35-45 - no extractions) were also removed. While the choice of strategy did result in some minor differences in the summary statistics obtained, presentation of all results in the main body of this report is not warranted. Therefore, results obtained by using only the third strategy are presented here, while those from the first and second strategies are summarized in Tables D-2 to D-5 of Appendix D.

Statistical summaries (means, standard deviations, and number of samples) of all measured parameters at each sediment depth are presented in Table 5-1, along with statistics for all depths combined. The mean contributions of BAIP, HCl-P, and organic P to total sediment P at each depth are also shown graphically in Figure 5-1. The results indicate that, on average, the concentrations and forms of phosphorus change very little with depth in the sediments of St. Albans Bay and Stevens Brook Wetland. With data from all depths combined, BAIP accounts for an average of 36.8% of total P, HCl-P for 42.8%, and organic P for 20.4%. Mean levels of BAIP and total P are just slightly higher in the 0-1 cm layer than in the deeper layers. Likewise, percent organic matter and total iron show no significant variation with depth. Porosity decreases slightly with depth, as would be expected (Chapra and Reckhow, 1983).

The analytical measurements are summarized by segment of the Bay/Wetland system in Table 5-2; bar graphs of sediment phosphorus fractionation are presented in Figure 5-2. The data show considerable variations in sediment characteristics with location. Mean total sediment P levels measured in the Wetland samples are roughly double, and BAIP levels roughly four times, those in the Inner and Middle Bay samples. Values of these two parameters obtained for the Outer Bay were intermediate between those for the Wetland and the Inner Bay. The mean BAIP was 49.9% of total P in the Wetland, 25.2% in the Inner Bay, 23.6% in the Middle Bay, and 36.2% in the Outer Bay. Organic P accounts for a relatively constant fraction (mean of 20.4% for all samples) of total sediment P regardless of location. In addition, the **size** of the HCl-P fraction varies little with location, averaging 530.3 μg/g for all samples. In the Inner and Middle Bay, HCl-P is the dominant form of sediment phosphorus, accounting for over 50% of total P.

Table 5-2 indicates that the percent organic matter in bottom sediments follows the same spatial trend as total P and BAIP - i.e. highest in the Wetland, followed by the Outer Bay, Inner

Table 5-1. Statistical Summary of Measured Parameters for Primary Sediment Core Samples from St. Albans Bay and Stevens Brook Wetland, Sorted by Sediment Depth. Only Samples with Complete Phosphorus Data Sets are Included.

	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
All Data:									
Mean	6.76	449.44	456.21	530.28	986.48	1238.58	5.51	76.25	25374.04
Std Dev	8.76	380.79	388.04	102.25	377.91	493.54	3.99	14.37	9049.89
Number	120	120	120	120	120	120	119	120	120
Depth = 0-1 cm:									
Mean	7.57	473.85	481.42	528.67	1010.08	1281.26	5.21	79.10	24787.42
Std Dev	9.67	375.75	382.59	95.44	384.08	512.08	3.00	14.26	9835.46
Number	26	26	26	26	26	26	26	26	26
Depth = 1-2 cm:									
Mean	6.21	441.67	447.88	511.60	959.48	1213.92	5.63	78.44	25137.95
Std Dev	7.91	346.27	352.48	107.45	340.34	439.63	2.62	14.54	10022.73
Number	24	24	24	24	24	24	24	24	24
Depth = 3-4 cm:									
Mean	5.46	425.92	431.39	532.16	963.53	1189.86	5.22	75.39	25950.96
Std Dev	7.71	353.83	360.25	89.02	345.09	421.52	2.66	16.40	8858.99
Number	23	23	23	23	23	23	23	23	23
Depth = 7-8 cm:									
Mean	5.37	427.55	432.92	532.42	965.33	1208.04	4.87	73.89	26489.18
Std Dev	7.17	368.92	375.04	105.73	394.69	492.69	3.16	14.15	8093.43
Number	22	22	22	22	22	22	21	22	22
Depth = 11-12 cm:									
Mean	6.52	394.16	400.68	549.40	950.09	1187.53	6.25	72.40	25136.10
Std Dev	9.32	442.82	451.77	118.63	406.51	568.13	7.14	11.68	8656.55
Number	21	21	21	21	21	21	21	21	21

Primary Samples Only - QA Samples Excluded
Samples with Total Extr. P > Total P Eliminated
Only Samples with Complete Phosphorus Data Sets Included

Table 5-2. Statistical Summary of Measured Parameters for Primary Sediment Core Samples from St. Albans Bay and Stevens Brook Wetland, Sorted by Location Within the Bay/Wetland System. Only Samples with Complete Phosphorus Data Sets are Included.

	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
All Data:									
Mean	6.76	449.4	456.2	530.3	986.5	1238.6	5.51	76.25	25374
Std Dev	8.76	380.8	388.0	102.3	377.9	493.5	3.99	14.37	9050
Number	120	120	120	120	120	120	119	120	120
Stevens Brook Wetland:									
Mean	17.58	890.7	908.3	534.7	1443.0	1819.5	7.69	75.38	24808
Std Dev	7.73	310.8	316.0	127.2	268.4	358.9	5.62	15.40	5742
Number	38	38	38	38	38	38	37	38	38
Inner St. Albans Bay:									
Mean	2.31	249.8	252.1	544.4	796.5	1000.8	4.53	79.66	24255
Std Dev	2.80	123.4	124.2	88.4	131.9	163.8	1.87	10.17	8368
Number	40	40	40	40	40	40	40	40	40
Middle St. Albans Bay:									
Mean	1.25	207.5	208.7	514.6	723.3	885.3	4.27	72.10	25781
Std Dev	1.49	190.9	190.7	90.0	177.6	262.0	2.80	16.28	11714
Number	37	37	37	37	37	37	37	37	37
Outer St. Albans Bay:									
Mean	0.96	484.0	485.0	499.2	984.2	1340.4	6.51	86.38	35620
Std Dev	0.93	347.4	348.4	31.6	350.1	440.5	2.09	5.84	4566
Number	5	5	5	5	5	5	5	5	5

Primary Samples Only - QA Samples Excluded
Samples with Total Extr. P > Total P Removed
Only Samples with Complete Phosphorus Data Set Included

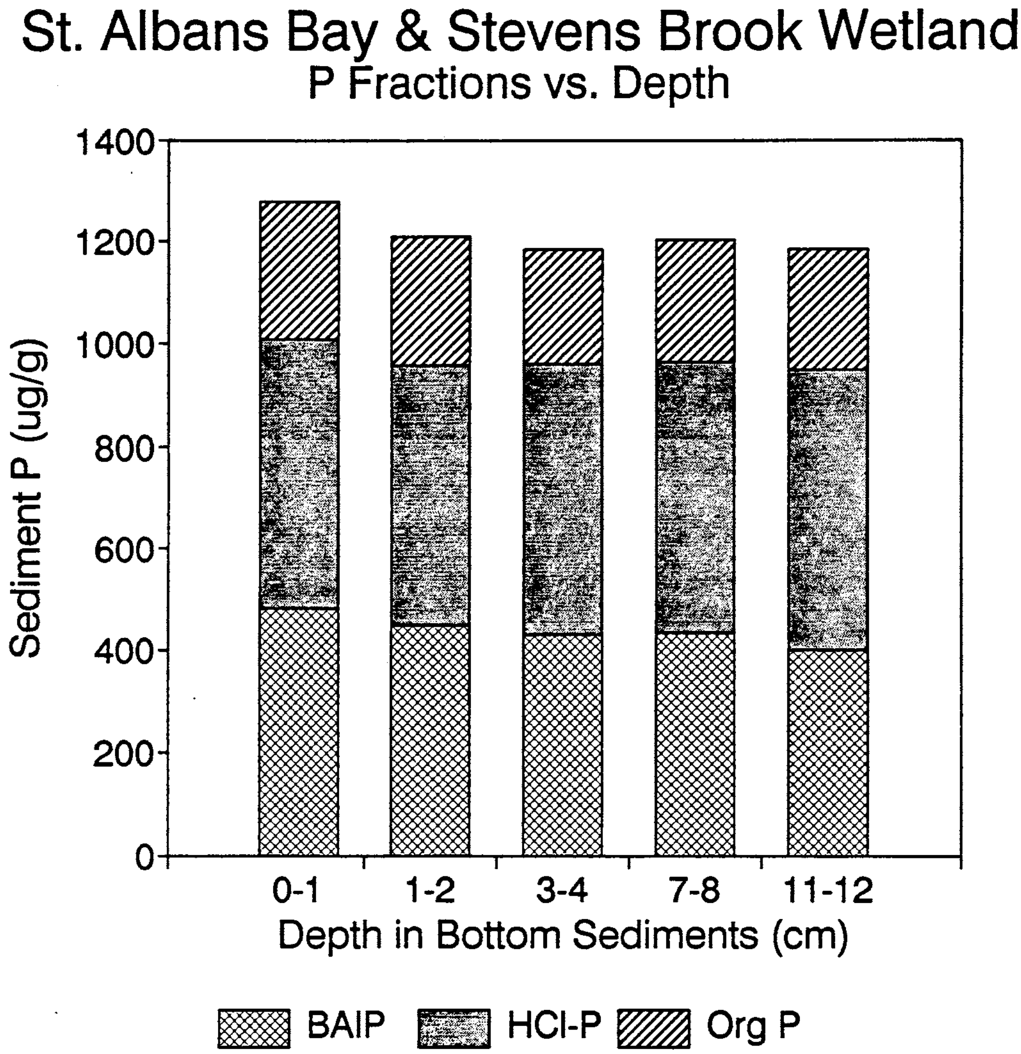

Figure 5-1. Mean Contribution of Biologically Available Inorganic Phosphorus (BAIP), HCl-P, and Organic P Fractions to Total Sediment P Versus Depth in the Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

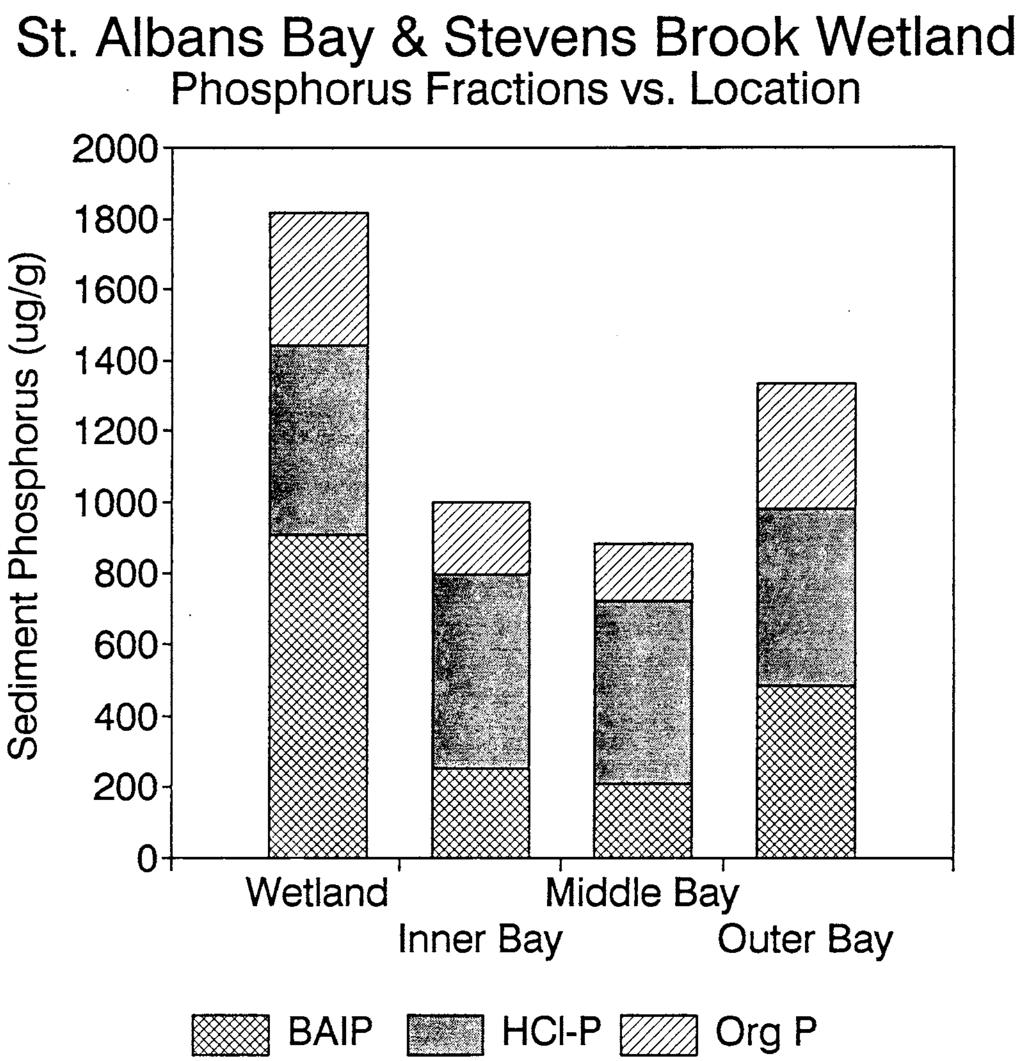

Figure 5-2. Mean Contributions of Biologically Available Inorganic Phosphorus (BAIP), HCl-P, and Organic P Fractions to Total Sediment P Versus Core Sample Location Within the St. Albans Bay/Stevens Brook Wetland System.

Bay, and Middle Bay. This suggests that organic matter contributes either directly (e.g. via organic P) or indirectly (e.g. via adsorption of BAIP) to the accumulation of phosphorus in the bottom sediments. Estimated porosity was highest for the Outer Bay and lowest for the Middle Bay, with intermediate values obtained for the Wetland and Inner Bay. In lakes and streams, as in soils, porosity typically reflects the grain size of the sediment particles. Values may range from 0.4 for well sorted sand to 0.9-0.95 for clays (Chapra and Reckhow, 1983). The calculated mean values of porosity are consistent with observations of sediment grain size during sampling and extrusion of sediment cores. In St. Albans Bay, the grain size distribution is largely controlled by the patterns of hydrodynamic scouring.

5.3 Comparison with 1982 Data from Ackerly (1983)

Summaries of analytical results for all samples where a side-by-side comparisons between 1982 and 1992 values are possible are presented in Tables 5-3 (phosphorus fractionation results) and 5-4 (total phosphorus, organic matter and total iron). Comparison of the mean values for all samples at the bottom of Tables 5-3 and 5-4 shows the following percentage decreases in the various sediment phosphorus fractions between 1982 and 1992:

NH_4Cl-P	-	32.8%
NaOH-P	-	19.7%
BAIP	-	19.9%
HCl-P	-	11.6%
TEIP	-	15.5%
Organic P (TP-TEIP)	-	48.3%
Total P	-	23.3%

Before commenting further on these differences, it is important to consider whether they are statistically significant. Throughout this discussion, the symbol "Δ" will be used to represent the change in chemical parameters between 1982 and 1992. An evaluation of statistical significance can be accomplished using the t-test for paired observations, provided the data fit a normal distribution (Walpole and Myers, 1993). In Figures 5-3 through 5-9, frequency distributions for the change in all phosphorus fractions are presented. These bear some resemblance to normal distributions, although the "tails" are generally longer in the direction of large negative change in concentration. The changes in selected chemical fractions were plotted on probability paper to determine whether the data better fit a normal or a log-normal distribution. ΔBAIP for the entire data set is plotted on normal and log-normal probability paper in Figures 5-10 and 5-11, respectively. Corresponding plots are shown for ΔTotal P in Figures 5-12 and 5-13. In both cases, while the normal plot is not exactly linear, it is certainly more linear than the log-normal plot. Similar plots (not shown) were also developed for changes in these same two parameters using data sorted by depth within the bottom sediments. These yielded the same observation. Therefore, it was concluded that the changes in sediment phosphorus fractions can best be described by normal distributions.

Next, the t-test was applied to evaluate the hypothesis that 1992 mean concentrations are less than 1982 means versus the null hypothesis that the means are, in fact, equal. The results are expressed in terms of the probability, p, that the null hypothesis is valid. It was decided a priori that $p<0.10$ would be considered conclusive evidence that an observed difference in

Table 5-3. Direct Comparison of 1992 Phosphorus Fractionation Results with Measurements Performed at the Same Locations by Ackerly (1983).

CORE NUMBER	DEPTH	NH4Cl		NaOH		NH4Cl+NaOH		HCl		EXTRACTABLE INORGANIC 'P'	
	cm	1982 ug/g	1992 ug/g	1982 ug/g	1992 ug/g	1982 ug/g	1992 ug/g	1982 ug/g	1992 ug/g	1982 ug/g	1992 ug/g
2	1	6.7	0.63	391	251.8	397.7	252.4	544	520	942	773
2	2	2.9	1.05	319	219.2	321.9	220.3	548	266	870	486
2	4	0.9	1.01	285	245.3	285.9	246.3	547	556	833	803
2	8	1.7	1.00	241	179.7	242.7	180.7	556	550	799	731
3	1	6.5	2.10	285	143.3	291.5	145.4	745	724	1037	869
3	2	4.5	1.87	274	138.0	278.5	139.9	760	754	1039	894
3	4	2.8	1.12	279	104.1	281.8	105.3	712	753	994	858
3	8	1.9	1.50	182	106.0	183.9	107.5	768	763	952	870
4	1	0	0.80	197	404.9	197	405.7	487	480	684	886
4	2	0	0.67	138	309.3	138	310.0	508	482	646	792
4	4	0	0.85	109	399.1	109	400.0	519	495	628	895
4	8	0	1.22	69	233.1	69	234.3	528	488	597	722
8	1	2.6	1.14	331	519.2	333.6	520.3	478	506	812	1026
8	2	0.8	0.86	229	250.5	229.8	251.4	426	488	656	740
8	4	0.0	0.63	106	130.9	106	131.5	467	513	573	645
8	8	0.0	0.53	73	78.5	73	79.0	609	633	682	712
9	1	5.1	2.00	40	26.7	45.1	28.7	1141	522	1186	550
9	2	0.0	2.05	45	21.6	45	23.7	639	520	684	544
9	4	0.0	0.16	26	23.7	26	23.9	537	453	563	476
9	8	0.0	0.15	22	37.9	22	38.0	575	396	597	434
10	1	0.1	0.16	728	484.0	728.1	484.1	398	412	1126	896
10	2	0.0	0.16	639	532.0	639	532.2	484	415	1123	947
10	4	0.0	0.43	568	593.6	568	594.0	476	447	1044	1041
10	8	0.0	0.14	463	218.2	463	218.4	523	462	986	681
11	1	1.1	0.30	169	51.7	170.1	52.0	1040	438	1210	490
11	2	0.0	1.08	150	44.1	150	45.2	878	470	1028	515
11	4	0.0	2.27	138	36.4	138	38.7	738	510	876	548
11	8	0.0	3.64	20	27.0	20	30.6	491	433	511	464
12	1	0.8	1.50	724	371.4	724.8	372.9	568	494	1293	867
12	2	0.0	1.35	402	411.3	402	412.7	469	474	871	886
12	4	0.0	1.62	387	328.5	387	330.1	432	473	819	803
12	8	0.0	0.79	472	148.4	472	149.2	446	552	918	701
13	1	0.5	2.10	160	70.0	160.5	72.1	498	610	659	682
13	2	0.1	2.11	148	45.2	148.1	47.4	591	531	739	579
13	4	0.2	1.85	141	35.4	141.2	37.3	561	560	702	598
15	1	2.9	1.67	428	299.9	430.9	301.5	564	524	995	825
15	2	0.5	1.95	385	362.5	385.5	364.5	547	523	933	887
15	4	0.6	2.13	342	409.9	342.6	412.0	576	520	919	932
15	8	1.0	2.11	342	376.7	343	378.8	575	524	918	903
16	1	4.3	8.36	264	472.8	268.3	481.1	765	497	1033	978
16	2	4.4	7.62	234	462.3	238.4	469.9	716	518	954	988
16	4	6.3	3.12	194	190.9	200.3	194.1	808	523	1008	717
16	8	4.2	2.18	170	142.7	174.2	144.8	790	443	964	588
17	1	42.1	27.88	1287	1228.1	1329.1	1256.0	487	439	1816	1695
17	2	31.3	24.38	1235	1204.1	1266.3	1228.5	504	453	1770	1681
17	4	25.8	28.54	1218	1187.7	1243.8	1216.2	493	436	1737	1652
17	8	15.0	23.68	1109	1072.9	1124	1096.6	487	475	1611	1572
19	1	45.8	27.39	1799	976.4	1844.8	1003.8	563	538	2408	1542
19	2	38.4	24.63	1641	932.3	1679.4	956.9	587	522	2266	1479
19	4	35.6	21.08	1590	939.4	1625.6	960.4	588	524	2214	1484
19	8	31.9	16.2693	1550	937.034	1581.9	953.3	577	523.745	2159	1477.05
20	1	38.2	13.19	1251	933.6	1289.2	946.8	426	471	1715	1418
20	2	31.5	8.61	1166	926.2	1197.5	934.8	426	443	1624	1378
20	4	17.0	9.10	967	829.8	984	838.9	386	571	1370	1410
20	8	11.8	7.76	436	565.1	447.8	572.9	286	600	734	1173
23	1	27.5	11.22	1181	1113.1	1208.5	1124.3	718	675	1927	1799
23	2	16.8	8.23	765	984.2	781.8	992.4	707	672	1489	1665
23	4	10.3	5.36	628	477.1	638.3	482.4	726	614	1364	1096
23	8	9.8	5.73	502	1008.8	511.8	1014.5	758	723	1270	1737
24	1	7.0	0.72	662	226.8	669	227.5	591	477	1260	705
24	2	0.9	0.58	440	270.5	440.9	271.1	542	490	983	762
24	4	0.3	0.76	341	300.5	341.3	301.2	558	485	899	786
24	8	0.1	0.44	165	181.1	165.1	181.5	657	538	822	719
25	1	2.9	0.34	456	229.2	458.9	229.5	682	599	1141	829
25	2	0.9	1.04	348	220.3	348.9	221.3	657	587	1006	808
25	4	1.1	0.48	304	278.1	305.1	278.6	658	619	963	898
25	8	0.6	1.26	110	489.8	110.6	491.1	801	611	912	1102
27	1	5.2	2.50	1876	1057.2	1881.2	1059.7	724	533	2605	1593
27	2	2.4	1.60	1419	699.0	1421.4	700.6	515	454	1936	1155
27	4	0.5	0.35	723	309.3	723.5	309.7	487	474	1211	784
27	8	0.4	0.21	605	248.3	605.4	248.5	520	502	1125	751
	Mean	7.2	4.84	522	419.2	529.5	424.0	594	525	1123	949

Table 5-4. Direct Comparison of 1992 Total Phosphorus, Organic Matter, and Total Iron Measurements with Values Reported for the Same Locations by Ackerly (1983).

CORE NUMBER	DEPTH	TOTAL PHOSPHORUS			ORGANIC MATTER			TOTAL IRON		
	cm	1982 ug/g	1992 ug/g	Diff. ug/g	1982 %	1992 %	Diff. %	1982 ug/g	1992 ug/g	Diff. ug/g
1	1	1984	1090	-894	9.96	7.00	-2.96	34520	35856	-1336
1	2	1864	1077	-787	11.05	7.18	-3.87	30235	35986	-5751
1	4	1625	1115	-510	10.80	6.74	-4.06	30164	35961	-5797
1	8	1168	1183	15	8.62	4.84	-3.78	28259	35081	-6822
2	1	1407	944	-463	7.02	6.03	-0.99	27696	28051	-355
2	2	1338	877	-461	6.47	5.33	-1.14	23745	25326	-1581
2	4	1299	914	-385	6.53	5.58	-0.95	23407	25922	-2515
2	8	1194	801	-393	6.45	4.69	-1.76	25736	25770	-34
3	1	1171	995	-176	2.79	0.85	-1.94	16863	12376	4487
3	2	1191	948	-243	3.00	1.76	-1.24	13605	11674	1931
3	4	1176	868	-308	3.55	1.73	-1.82	14586	9794	4792
3	8	1063	669	-394	2.07	1.62	-0.45	10998	9612	1386
4	1	1086	1158	72	7.75	4.02	-3.73	30382	33430	-3048
4	2	972	1002	30	7.06	6.57	-0.49	27480	35140	-7660
4	4	931	1087	156	7.01	7.51	0.50	26187	33968	-7781
4	8	859	954	95	5.80	7.22	1.42	24109	30542	-6433
5	1	779	495	-284	3.75	1.78	-1.97	13217	8632	4585
5	2	460	397	-63	2.07	1.42	-0.65	9158	6983	2175
5	4	276	382	106	1.24	0.50	-0.74	6484	4626	1858
7	1	766	955	189	1.92	2.33	0.41	9270	14928	-5658
7	2	581	798	217	1.00	2.75	1.75	9068	11347	-2279
7	4	671	784	113	1.05	1.04	-0.01	9170	39457	-30287
7	8	683	824	141	2.18	0.92	-1.26	33353	44328	-10975
8	1	1707	1518	-189	10.97	9.49	-1.48	29933	30702	-769
8	2	1292	1115	-177	10.00	8.05	-1.95	26923	27349	-426
8	4	1082	915	-167	7.85	6.04	-1.81	26118	26988	-870
8	8	988	881	-107	4.83	3.42	-1.41	20970	20886	84
9	1	1418	619	-799	3.26	2.02	-1.24	14524	6710	7814
9	2	930	606	-324	8.43	1.67	-6.76	20010	6139	13871
9	4	862	542	-320	11.53	1.12	-10.41	25314	6663	18651
9	8	846	571	-275	8.25	4.88	-3.37	23807	17528	6279
10	1	1828	1283	-545	11.57	8.71	-2.86			
10	2	1716	1321	-395	11.35	8.32	-3.03	35961	37671	-1710
10	4	1541	1316	-225	9.37	6.93	-2.44	38489	37301	1188
10	8	1337	958	-379	7.53	4.59	-2.94	33198	34518	-1320
11	1	1726	588	-1138	5.65	1.91	-3.74	21306	13056	8250
11	2	1615	603	-1012	6.78	1.77	-5.01	24062	14629	9433
11	4	1346	566	-780	4.64	1.10	-3.54	35278	15029	20249
11	8	1039	479	-560	3.29	0.42	-2.87	58459	14287	44172
12	1	1660	1176	-484	10.46	7.63	-2.83	33689	34845	-1156
12	2	1373	1174	-199	10.40	6.01	-4.39	33224	44264	-11040
12	4	1287	1057	-230	10.09	7.30	-2.79	33051	31969	1082
12	8	1325	877	-448	8.49	4.85	-3.64	30812	27214	3598

Table 5-4. Continued.

CORE NUMBER	DEPTH	TOTAL PHOSPHORUS			ORGANIC MATTER			TOTAL IRON		
	cm	1982 ug/g	1992 ug/g	Diff. ug/g	1982 %	1992 %	Diff. %	1982 ug/g	1992 ug/g	Diff. ug/g
13	1	1061	702	-359	6.82	0.93	-5.89	16663	14223	2440
13	2	1051	624	-427	6.90	1.02	-5.88	23439	16516	6923
13	4	1028	595	-433	6.85	0.88	-5.97	23355	18117	5238
15	1	1465	1132	-333	8.30	5.98	-2.32			
15	2	1381	1227	-154	8.67	7.25	-1.42			
15	4	1305	1255	-50	7.48	6.83	-0.65			
15	8	1281	1156	-125	7.73	5.87	-1.86			
16	1	1185	1210	25	2.26	5.67	3.41			
16	2	1081	1187	106	2.33	5.04	2.71			
16	4	1109	790	-319	2.36	2.80	0.44			
16	8	1057	696	-361	1.88	1.86	-0.02			
17	1	2370	2136	-234	8.96	8.42	-0.54	23742	30578	-6836
17	2	2288	2108	-180	8.32	8.72	0.40	23885	28241	-4356
17	4	2344	2067	-277	8.33	8.30	-0.03			
17	8	2195	1941	-254	8.38	6.40	-1.98			
19	1	3255	1838	-1417	8.98	6.18	-2.80	24481	24040	441
19	2	2982	1809	-1173	8.42	8.37	-0.05	23775	22391	1384
19	4	2898	1826	-1072	8.27	8.32	0.05	24353	22392	1961
19	8	2752	1834	-918	7.76	8.70	0.94	22794	22986	-192
20	1	2565	1914	-651	16.60	10.00	-6.60	24591	30204	-5613
20	2	2444	1894	-550	17.54	9.47	-8.07	24647	29889	-5242
20	4	2248	1757	-491	17.26	7.97	-9.29	23981	27339	-3358
20	8	1378	1337	-41	24.26	3.18	-21.08	19053	18947	106
23	1	2530	2255	-275	6.02	2.80	-3.22			
23	2	1910	990	-920	4.40	1.68	-2.72			
23	4	1718	1257	-461	3.77	1.81	-1.96			
23	8	1558	1867	309	3.20	2.44	-0.76			
24	1	1658	1040	-618	8.23	6.25	-1.98	29264	29798	-534
24	2	1349	1070	-279	8.13	6.18	-1.95	28360	28478	-118
24	4	1185	1064	-121	7.15	5.15	-2.00	26235	26939	-704
24	8	1013	977	-36	4.99	2.91	-2.08	22185	23774	-1589
25	1	1238	1083	-155	5.49	5.70	0.21	20985	26181	-5196
25	2	1265	1058	-207	5.50	5.09	-0.41	22384	24679	-2295
25	4	1160	1116	-44	5.10	3.47	-1.63	20110	23340	-3230
25	8	957	1238	281	2.74	5.01	2.27	13677	24255	-10578
27	1	3234	2080	-1154	11.50	9.72	-1.78	48893	42759	6134
27	2	2248	1587	-661	8.51	7.97	-0.54	38174	37675	499
27	4	1507	1146	-361	9.08	6.05	-3.03	34329	34553	-224
27	8	1427	1023	-404	6.59	4.79	-1.80	33160	34287	-1127
	MEAN	1465	1126	-339	7.18	4.89	-2.29	25065	24853	212
	ST DEV	619.4	450.4	356.4	3.96	2.74	3.19	9081	10261	8783
	COUNT	82	82	82	82	82	82	67	67	67

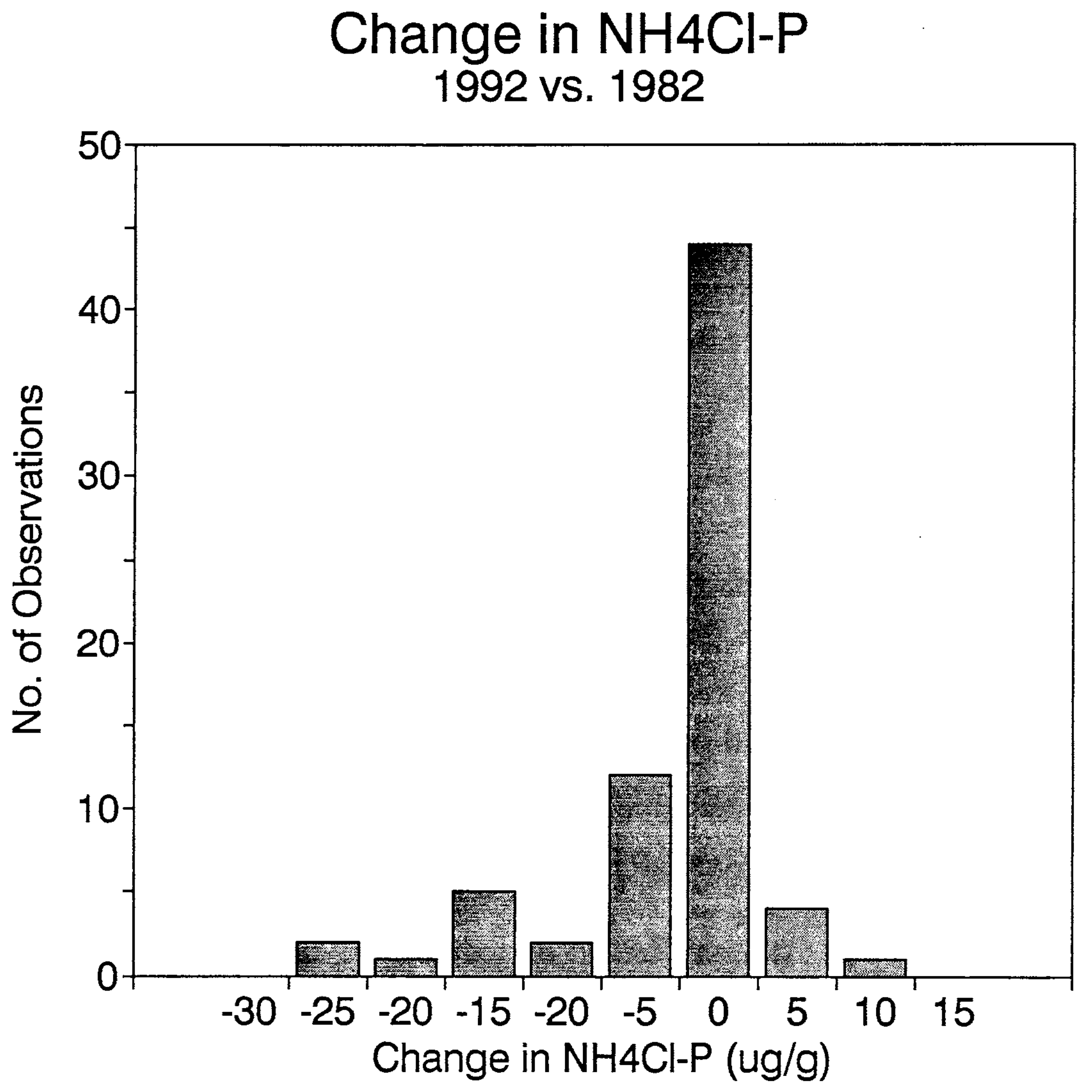

Figure 5-3. Frequency Distribution of Change in the NH_4Cl-P Fraction Between 1982 and 1992 in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

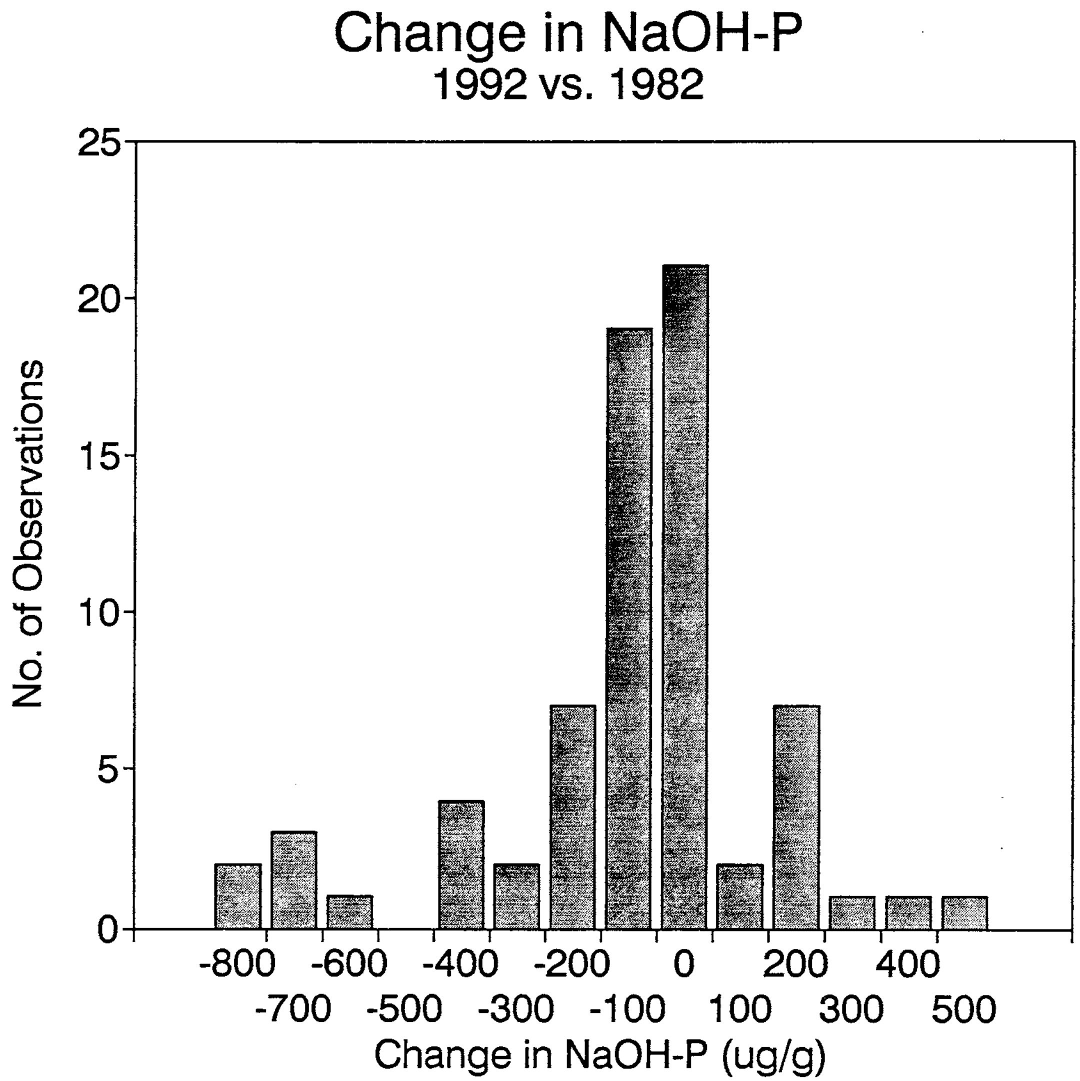

Figure 5-4. Frequency Distribution of Change in the NaOH-P Fraction Between 1982 and 1992 in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

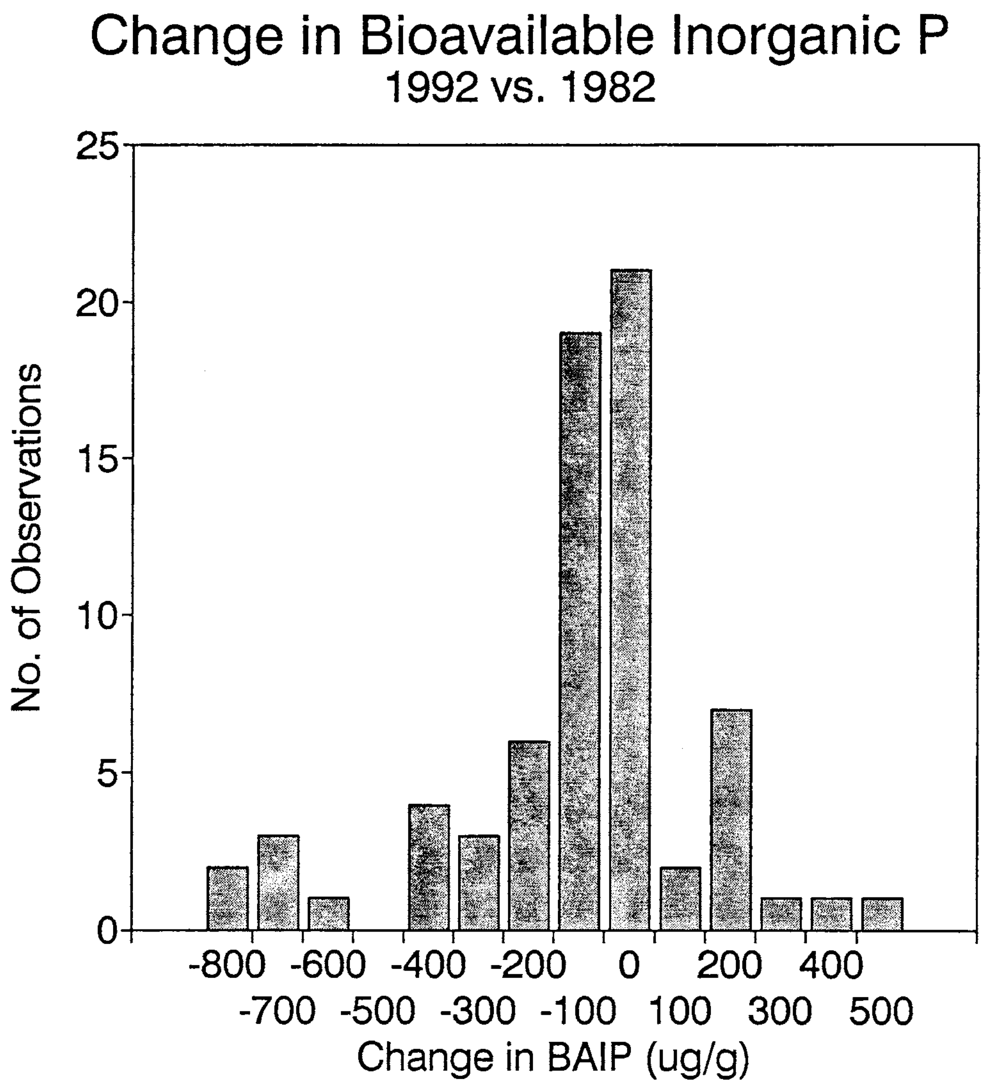

Figure 5-5. **Frequency Distribution of Change in the BAIP (NH_4Cl-P + NaOH-P) Fraction Between 1982 and 1992 in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.**

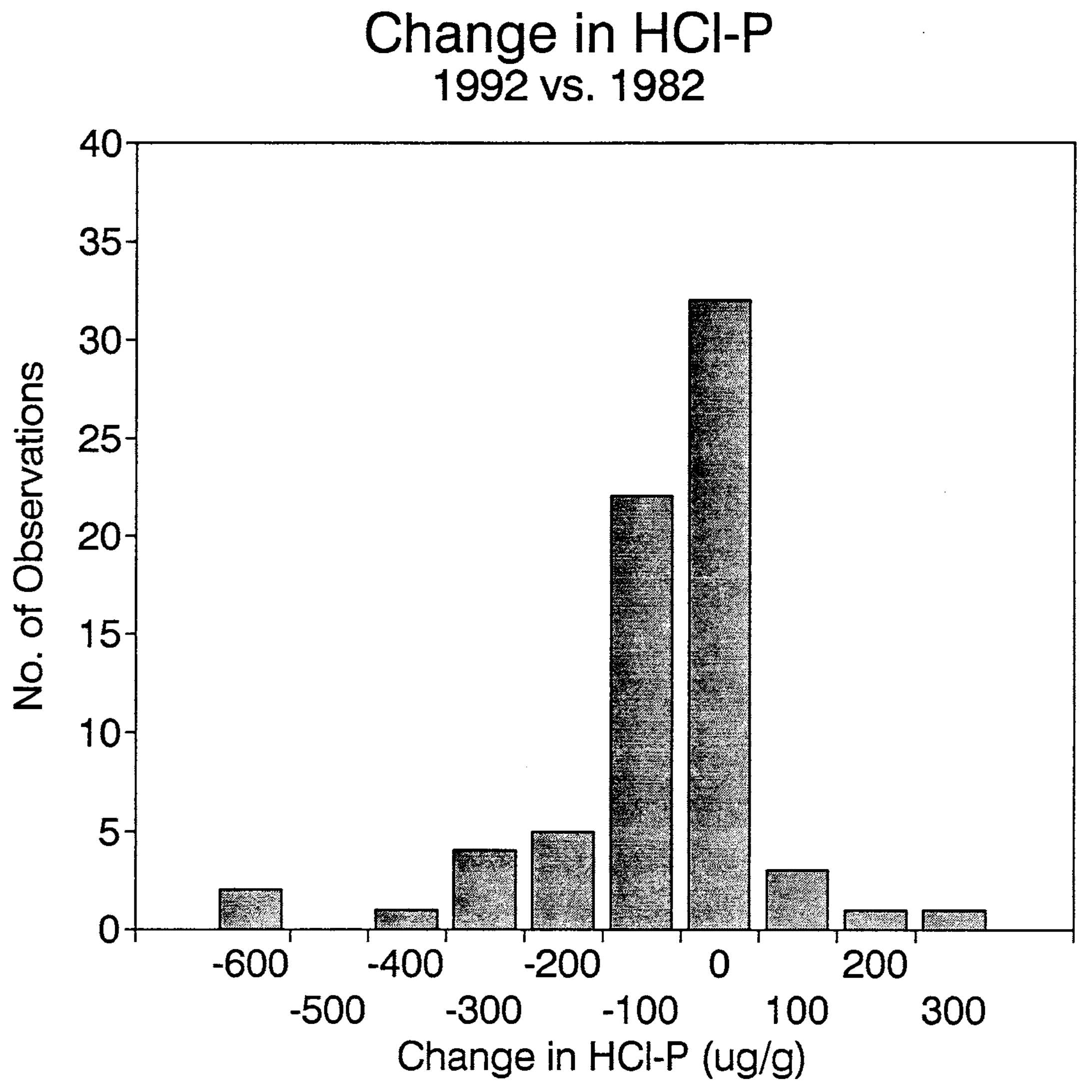

Figure 5-6. Frequency Distribution of Change in the HCl-P Fraction Between 1982 and 1992 in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

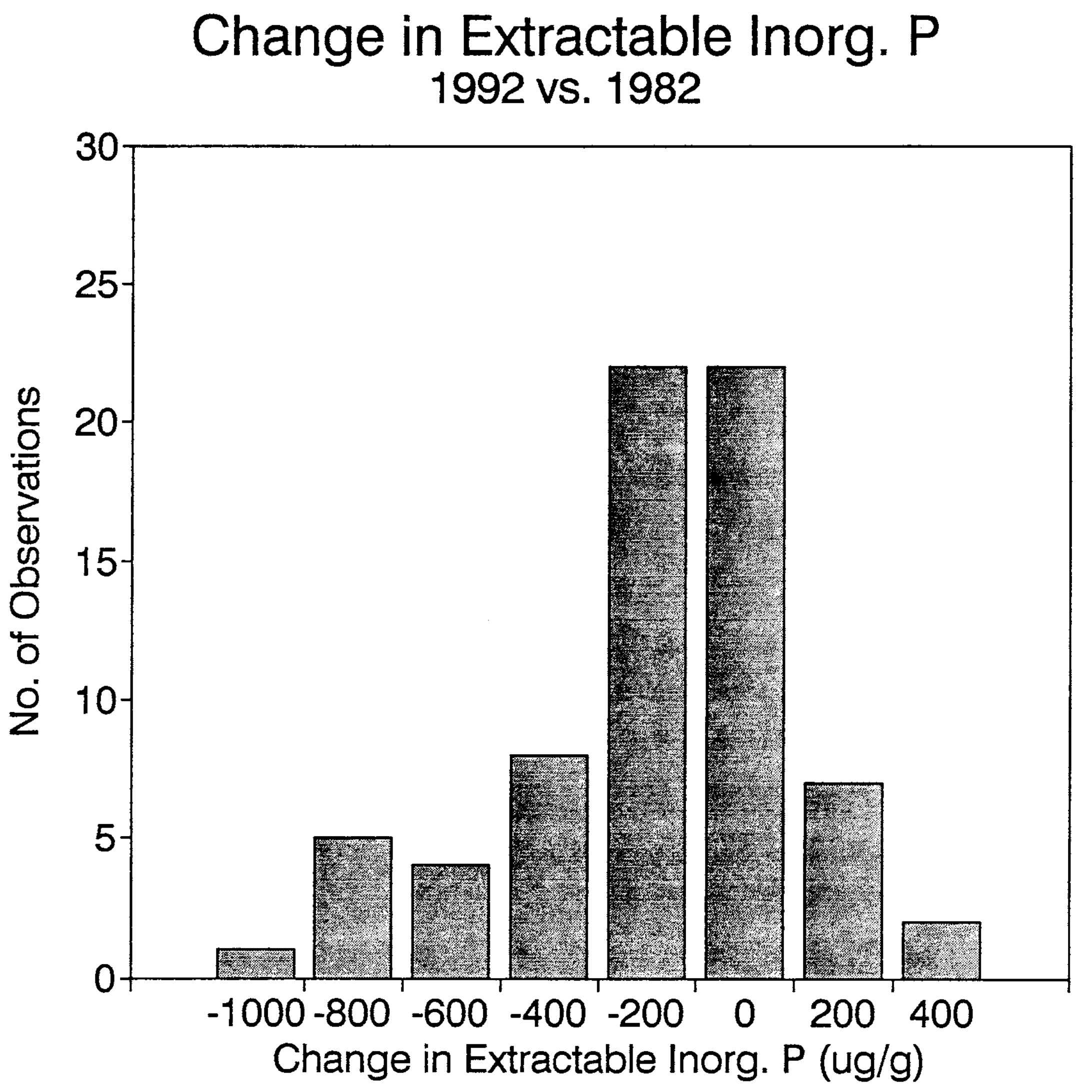

Figure 5-7. Frequency Distribution of Change in Total Extractable Inorganic Phosphorus (TEIP) Between 1982 and 1992 in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

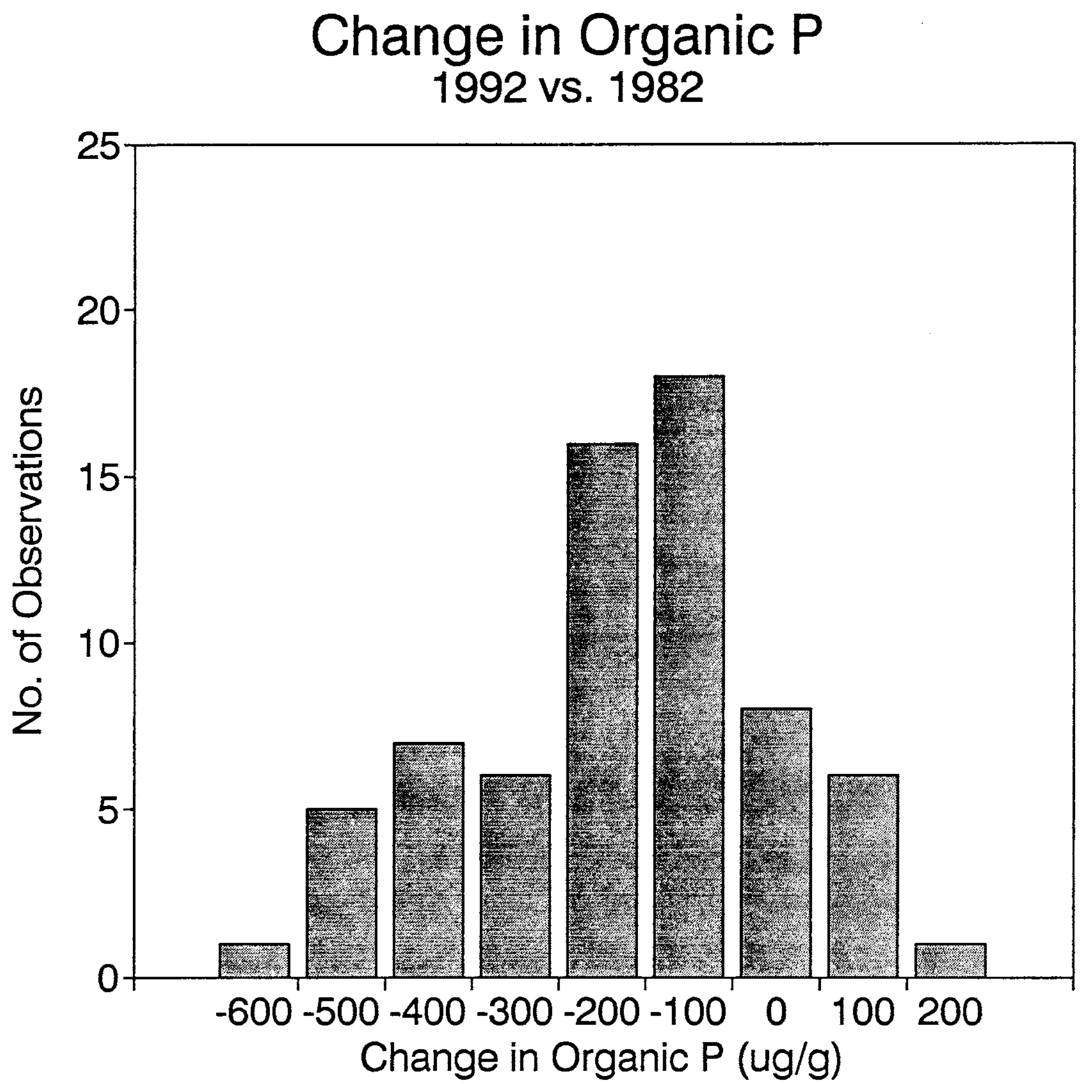

Figure 5-8. Frequency Distribution of Change in the Organic P (Total P - TEIP) Fraction Between 1982 and 1992 in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

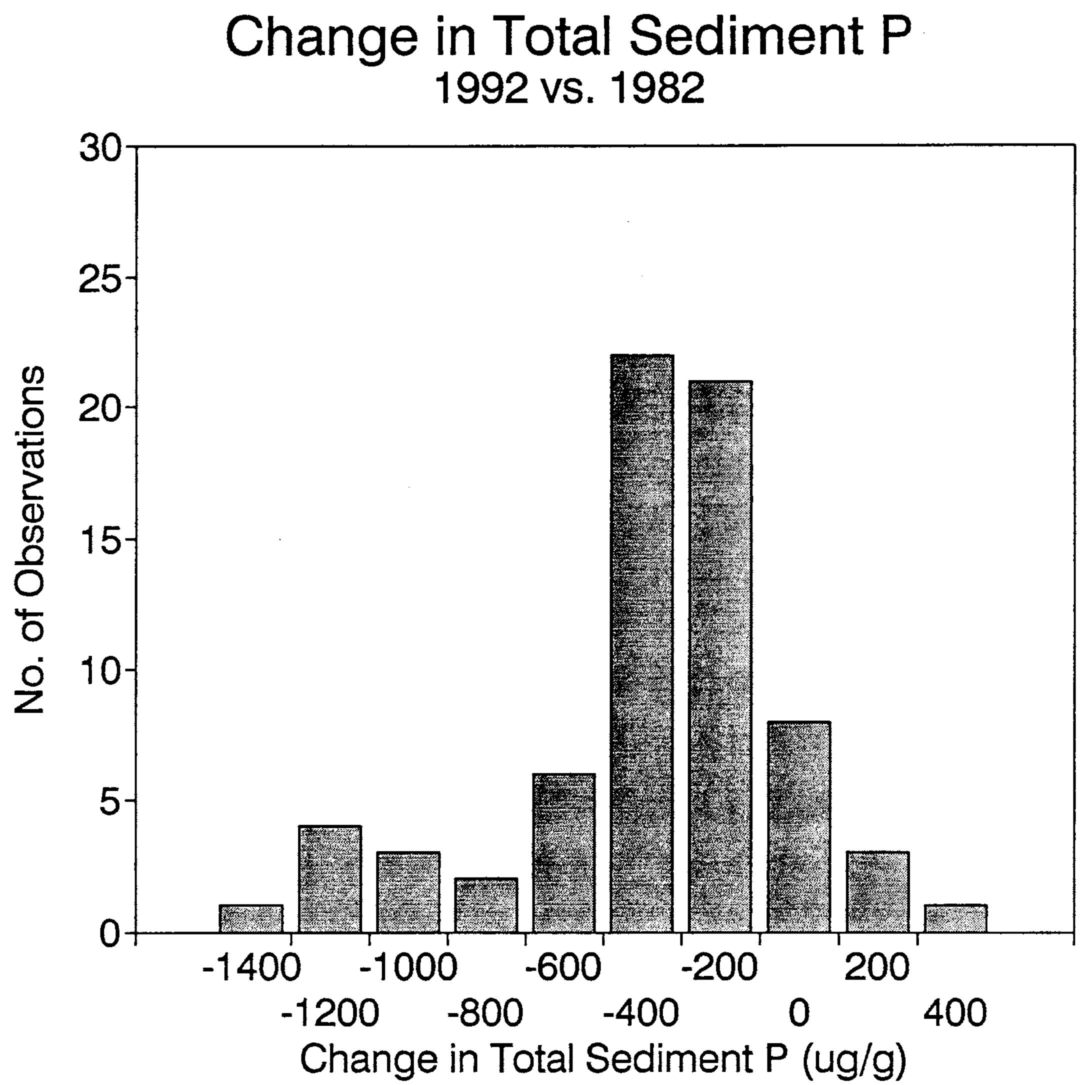

Figure 5-9. Frequency Distribution of Change in Total P Between 1982 and 1992 in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

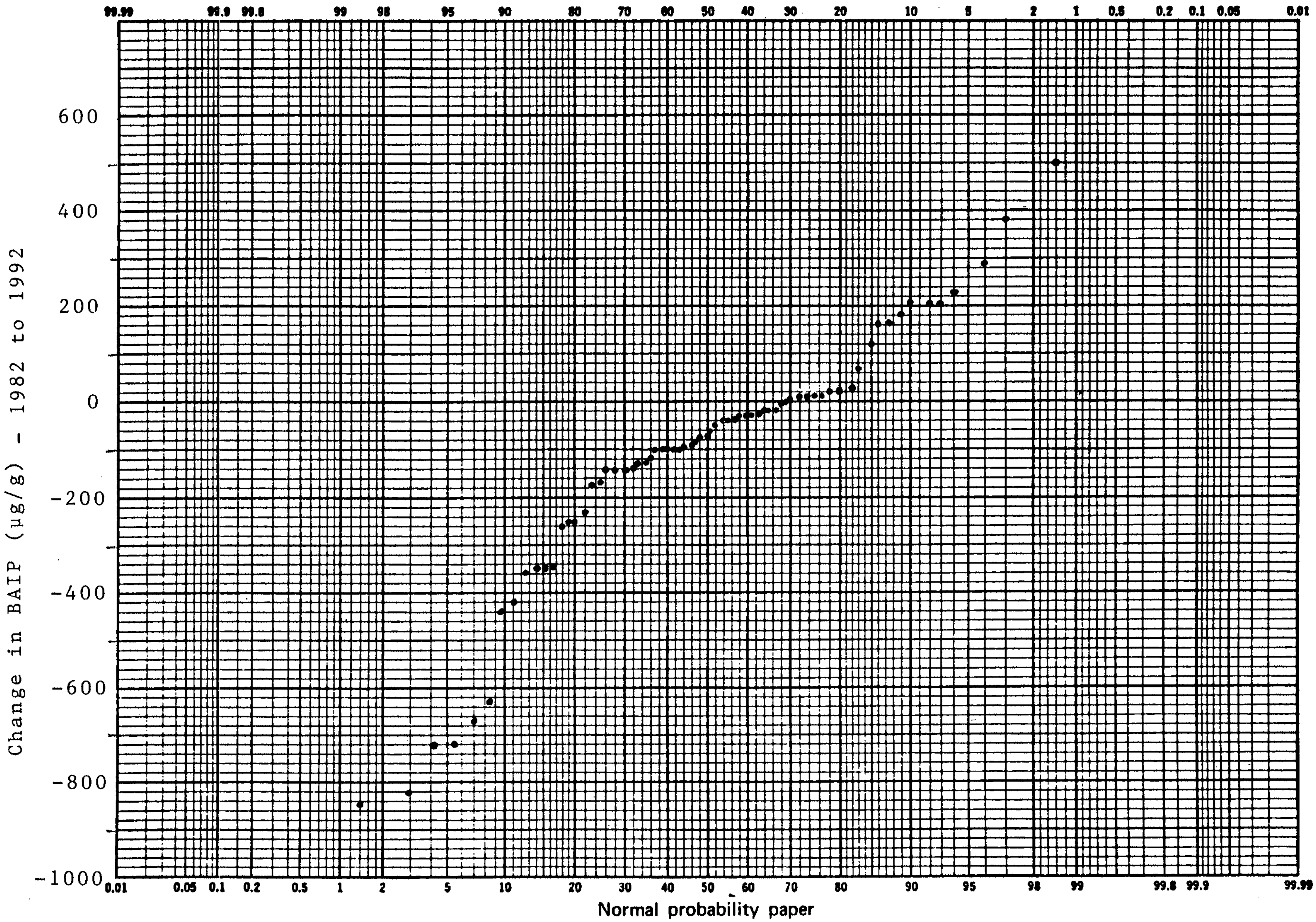

Figure 5-10. **Plot of ΔBAIP (1992 vs 1982; All Data) for St. Albans Bay and Stevens Brook Wetland Sediments on Normal Probability Paper.**

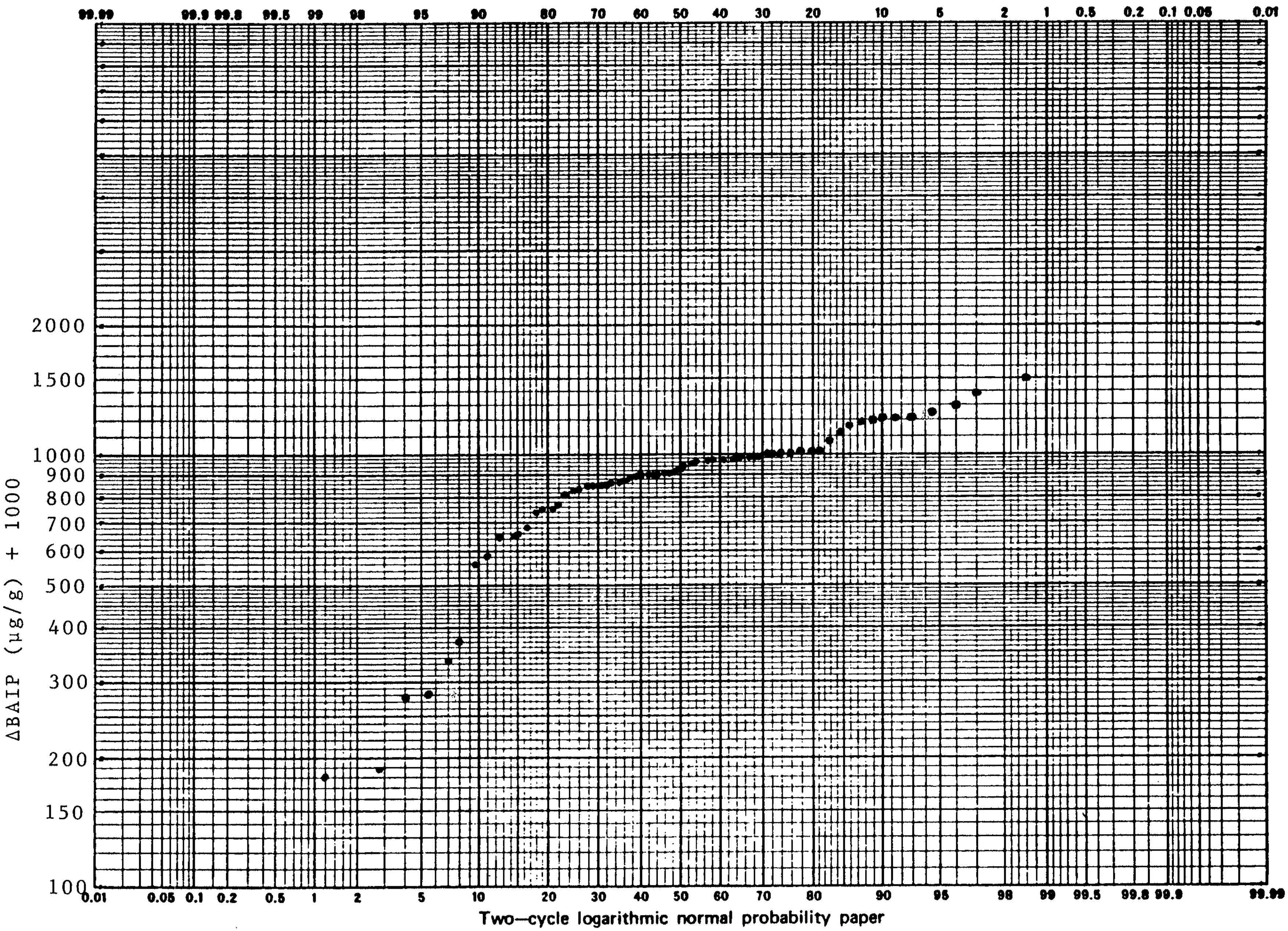

Figure 5-11. Plot of ΔBAIP (1992 vs 1982; All Data) for St. Albans Bay and Stevens Brook Wetland Sediments on Log-Normal Probability Paper.

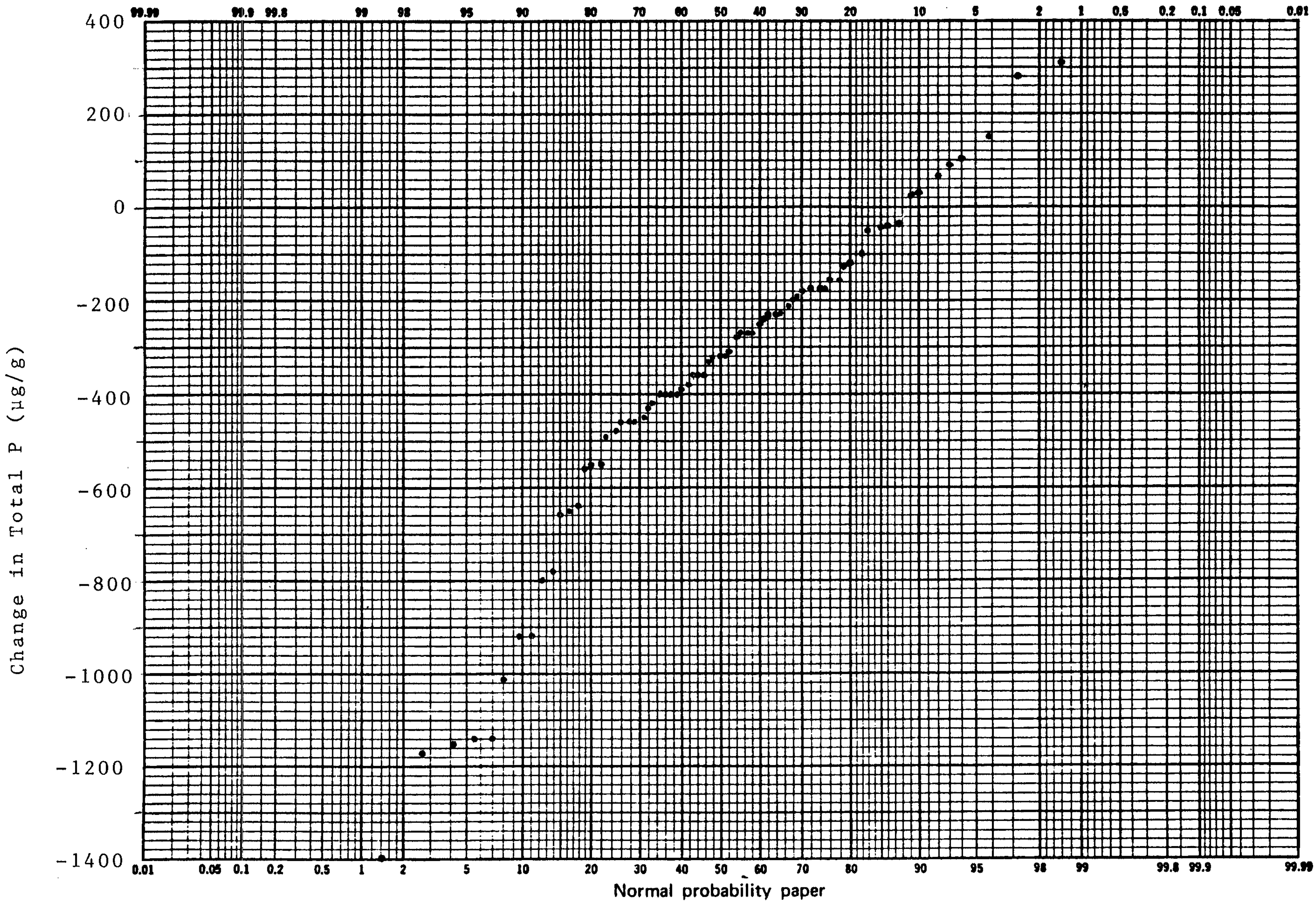

Figure 5-12. **Plot of ΔTotal P (1992 vs 1982; All Data) for St. Albans Bay and Stevens Brook Wetland Sediments on Normal Probability Paper.**

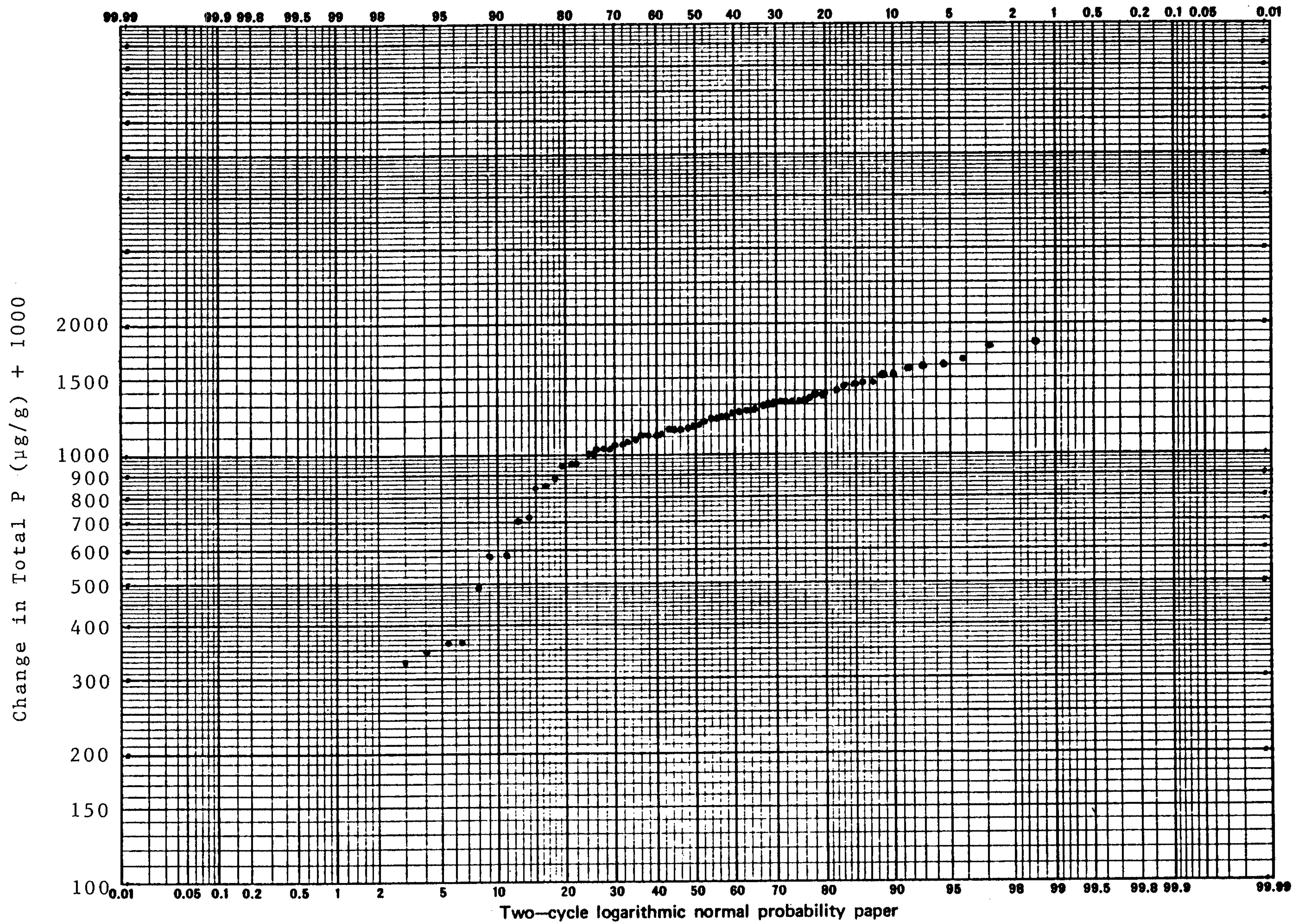

Figure 5-13. **Plot of ΔTotal P (1992 vs 1982; All Data) for St. Albans Bay and Stevens Brook Wetland Sediments on Log-Normal Probability Paper.**

Table 5-5. Results of T-Test for Paired Observations (1992 vs. 1982) of Chemical Parameters in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland (p = probability of zero difference between means).

Parameter	Data Set	No. Obs.	μg/g (except %OM)		p
			Mean Δ	Std Dev	
NH4Cl-P	All	71	-2.4	6.21	.0025
NaOH-P	All	71	-103.1	253.3	.0010
BAIP	All	71	-105.5	256.1	<.001
HCl-P	All	71	-68.7	142.5	<.001
TEIP	All	71	-174.2	289.7	<.001
Org P	All	68	-176.2	168.7	<.001
Total P	All	82	-339	356.4	<.001
%OM	All	82	-2.29	3.19	<.001
Total Fe	All	67	+212	8783	>.80

means is significant. Calculations performed using the entire data set are summarized in Table 5-5. All phophourus fractions show $p<0.10$; in fact, most show $p<.001$. This means there is only a 0.1% chance that the null hypothesis is valid, or conversely, a 99.9% probability that 1992 concentrations are lower than 1982 levels. For Total Fe, $p>0.8$, indicating that sediment iron levels have not changed since 1982.

An overall comparison of phosphorus fractions between 1982 and 1992, using means from samples at all locations and depths, is shown graphically in Figure 5-14. Of the 350.3 μg/g average decrease in total sediment P (for samples on which extractions were performed), 106 μg/g (30.3%) came from the BAIP fraction, 69 μg/g (19.7%) from HCl-P, and the remaining 175.3 μg/g (50.0%) from the Organic P fraction. The large contribution of the Organic P fraction is consistent with the sizeable decrease observed in % organic matter in the bottom sediments. Table 5-4 indicates that a 31.9% decrease occurred between 1982 and 1992. This suggests that, since the WWTF upgrade, organic matter is decomposing in the bottom sediments of the Wetland/Bay system at a much faster rate than it is being deposited from the water column. This, in turn, suggests that primary productivity has declined on an annual average basis.

A more rigorous evaluation of statistical significance was performed for ΔBAIP, ΔHCl-P, ΔOrganic P, and ΔTotal P by applying the t-test to data sorted by depth within the bottom sediments. The results are summarized in Table 5-6. The decreases in all of these fractions are

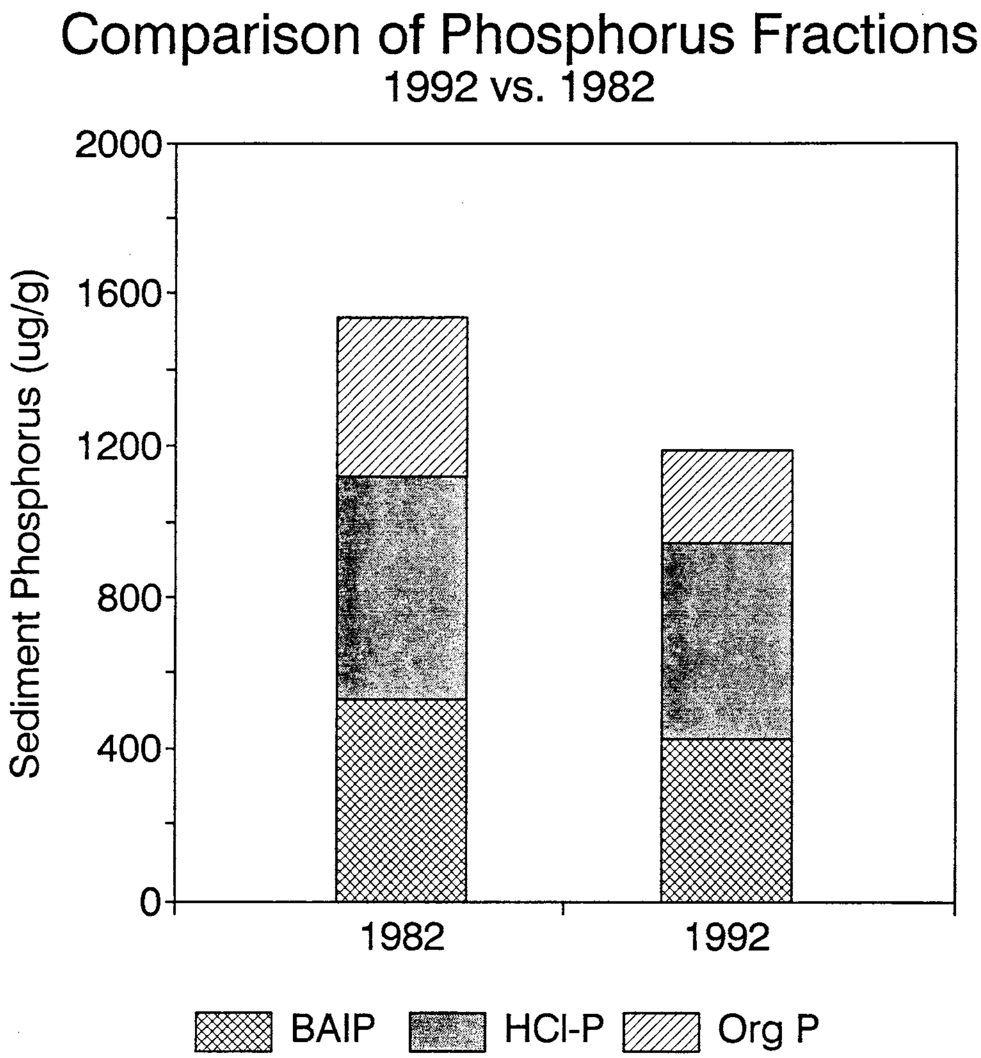

Figure 5-14. Comparison of Mean Contributions of BAIP, HCl-P, and Organic P to Total Sediment P for 1992 Versus 1982 in St. Albans Bay and Stevens Brook Wetland.

Table 5-6. Results of T-Test for Paired Observations (1992 vs. 1982) of BAIP, HCl-P, Organic P and Total P, Sorted by Depth, in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

Parameter	Data Set	No. Obs.	Units: µg/g		p
			Mean Δ	Std Dev	
BAIP	1 cm	18	-192.5	286.8	.0113
HCl-P	1 cm	18	-108.9	195.7	.0305
Organic P	1 cm	18	-192.7	181.4	<.001
Total P	1 cm	21	-470.6	411.4	<.001
BAIP	2 cm	18	-110.5	250.3	.0816
HCl-P	2 cm	18	-80.1	109.9	.0070
Organic P	2 cm	17	-158.6	153.5	<.001
Total P	2 cm	21	-374.1	357.8	<.001
BAIP	4 cm	18	-85.9	193.9	.0811
HCl-P	4 cm	18	-41.3	100.4	.0992
Organic P	4 cm	17	-196.2	164.0	<.001
Total P	4 cm	21	-294.3	284.0	<.001
BAIP	8 cm	17	-28.8	257.4	.653
HCl-P	8 cm	17	-42.9	132.3	.200
Organic P	8 cm	16	-154.9	169.5	.0031
Total P	8 cm	19	-203.0	298.7	.0087

p = probability of zero difference between 1982 and 1992 means.

significant at the $p<0.10$ level at 1 cm, 2 cm, and 4 cm. At 8 cm, ΔOrganic P and ΔTotal P are statistically significant ($p<0.10$), while ΔBAIP and ΔHCl-P are not ($p>0.10$). A graphical summary of the changes in phosphorus fractions as a function of depth is presented in Figure 5-15. The mean changes in BAIP, HCl-P, and Total P all decrease with increasing sediment depth, while the change in Organic P shows no clear trend. This is consistent with the expectation that accumulated phosphorus near the sediment-water interface will be released more rapidly than that deeper in the bottom sediments following a reduction in external loading. These findings also support the assertion made by Ackerly (1983) that bottom sediments below a depth of 8 cm have a limited impact on water quality in St. Albans Bay.

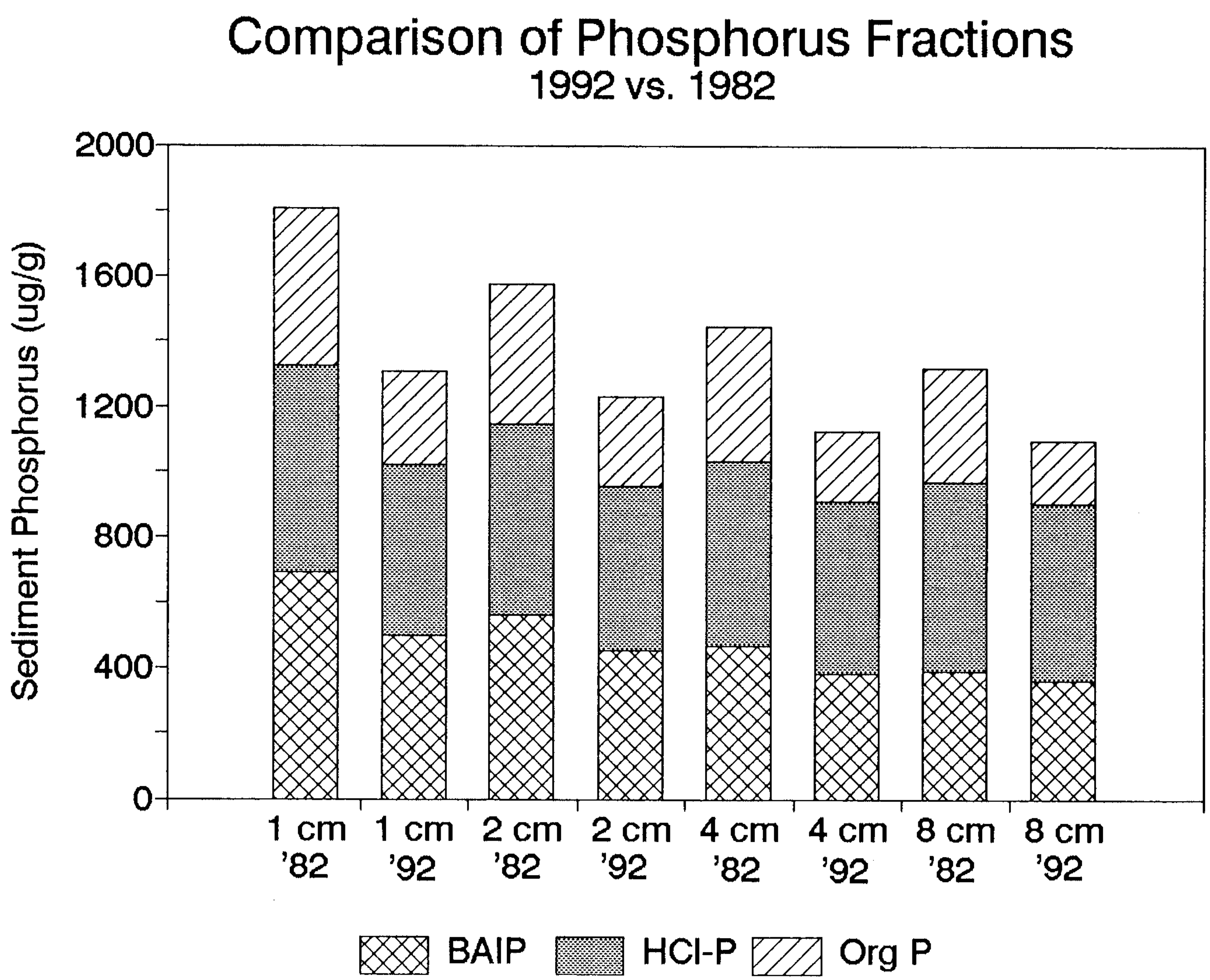

Figure 5-15. **Comparison of Phosphorus Fractionation Between 1982 and 1992 at Four Depths in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.**

The statistical significance of ΔBAIP, ΔHCl-P, ΔOrganic P, and ΔTotal P were also evaluated using analytical data sorted by location witthin the Bay/Wetland system. The results showed that ΔTotal P was significant at the $p<.001$ level in all segments. ΔBAIP was significant at the $p<0.01$ level in the Wetland, Middle Bay, and Outer Bay, but was not significant ($p>0.10$) in the Inner Bay. ΔHCl-P was significant at the $p<0.01$ level in all segments of St. Albans Bay, but was not significant ($p>0.10$) in the Wetland. And, ΔOrganic P was significant at the $p<0.01$ level in the Wetland, Inner Bay and Middle Bay, but was not significant ($p>0.01$) in the Outer Bay.

5.4 Correlations Among Measured Parameters

The main goal in investigating correlations among measured parameters was to find a regression equation that could be used to predict the concentrations of BAIP (i.e. NH_4Cl-P + NaOH-P), and other fractions if possible, for sediment cores where chemical extractions were not performed. Regression analyses were performed for BAIP against total sediment P, % organic matter, and total iron, lumping the entire data base together. The data are plotted and the regression lines shown in Figures 5-16 to 5-18, respectively. The strength of a correlation between two parameters can be determined by using the t-test to evaluate the probability, p, that a null hypothesis of no linear association is valid. Results of the t-tests are summarized in Table 5-7. For BAIP, the strongest correlation is with total P. This correlation is significant at the $p<0.001$ level. The correlation between BAIP and % organic matter is weaker, but also highly significant ($p<0.001$). The correlation of BAIP with total Fe is very weak and not statistically significant ($p=0.567$). Based on these results, it was determined that BAIP could be reliably estimated from regressions equations of BAIP versus total P.

The possibility that the relationship between BAIP and total P might vary with location in the Bay/Wetland system was investigated. The system was divided into four segments (Wetland, Inner Bay, Middle Bay, and Outer Bay) and data were sorted by zone. It was found that different regression coefficients were obtained for different segments. For example, plots for BAIP vs. total P are plotted in Figures 5-19 an 5-20 for Wetland and Inner Bay samples, respectively, using the same x and y axis ranges. Since all regressions for the individual segments were also significant at the $p<.001$ level, segment-specific regression equations were used to predict BAIP from total P. The regression coefficients are summarized in Table 5-7. Predicted values of BAIP are given in Table D-6 of Appendix D (numbers enclosed in boxes). These values were used in addition to direct measurements to more accurately map BAIP levels in bottom sediments of the Bay and Wetland.

Several other regression analyses were performed, and are summarized in Table 5-7. HCl-P was not correlated significantly with total P. A plot of HCl-P vs. total P with all data combined is shown in Figure 5-21. The regression line has a slope close to zero, indicating that HCl-P (in $\mu g/g$) tends to remain constant regardless of the total P level. Organic P is strongly correlated ($p<.001$) with both total P and % organic matter. Highly significant ($p<.001$) correlations were also observed between Organic P and both Total P and % Organic Matter in the bottom sediments. Regression coefficients for Organic P versus both of these parameters are presented in Table 5-7. Since the correlation with % Organic Matter was slightly stronger, additional regression analyses were performed against this parameter on data sorted by depth.

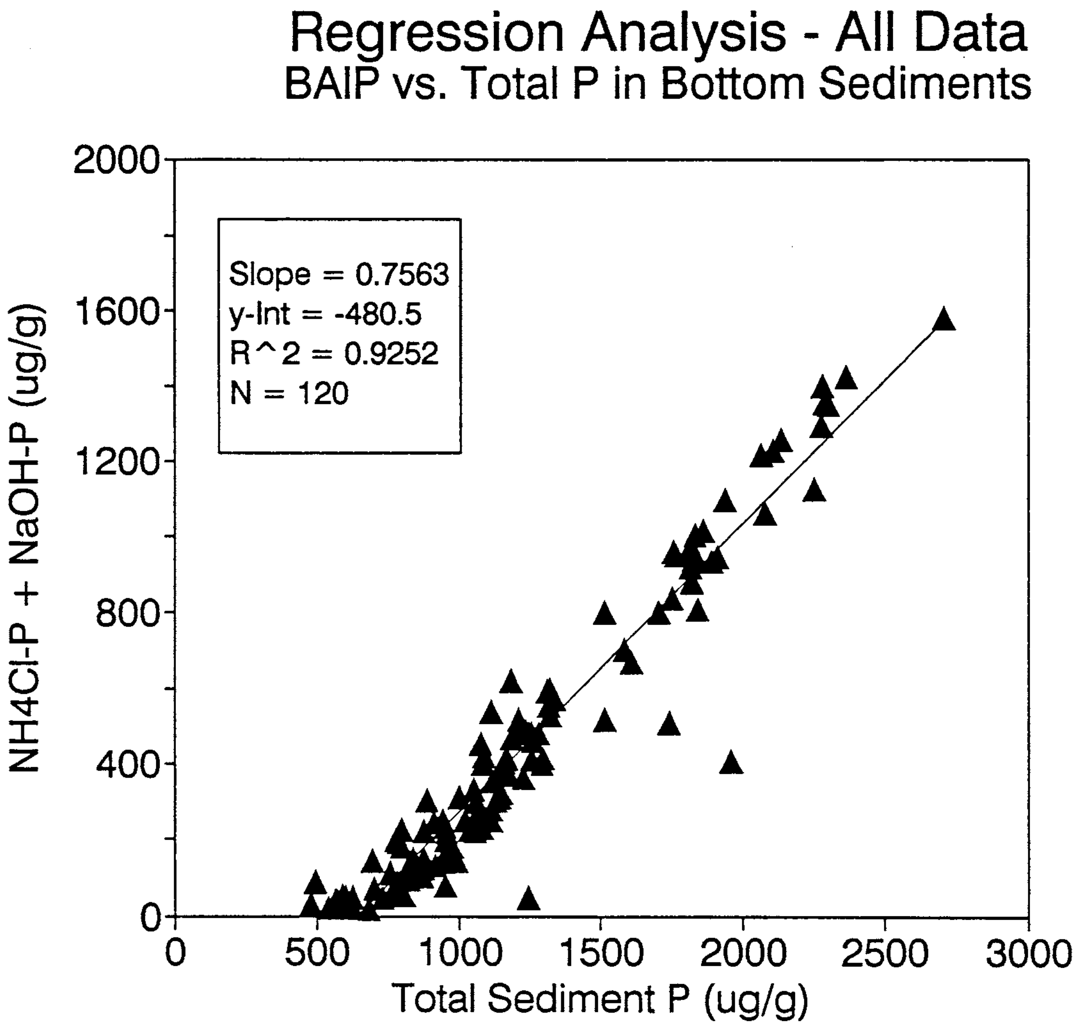

Figure 5-16. Regression Analysis for BAIP vs. Total P (All Data Included) in St. Albans Bay and Stevens Brook Wetland Bottom Sediments.

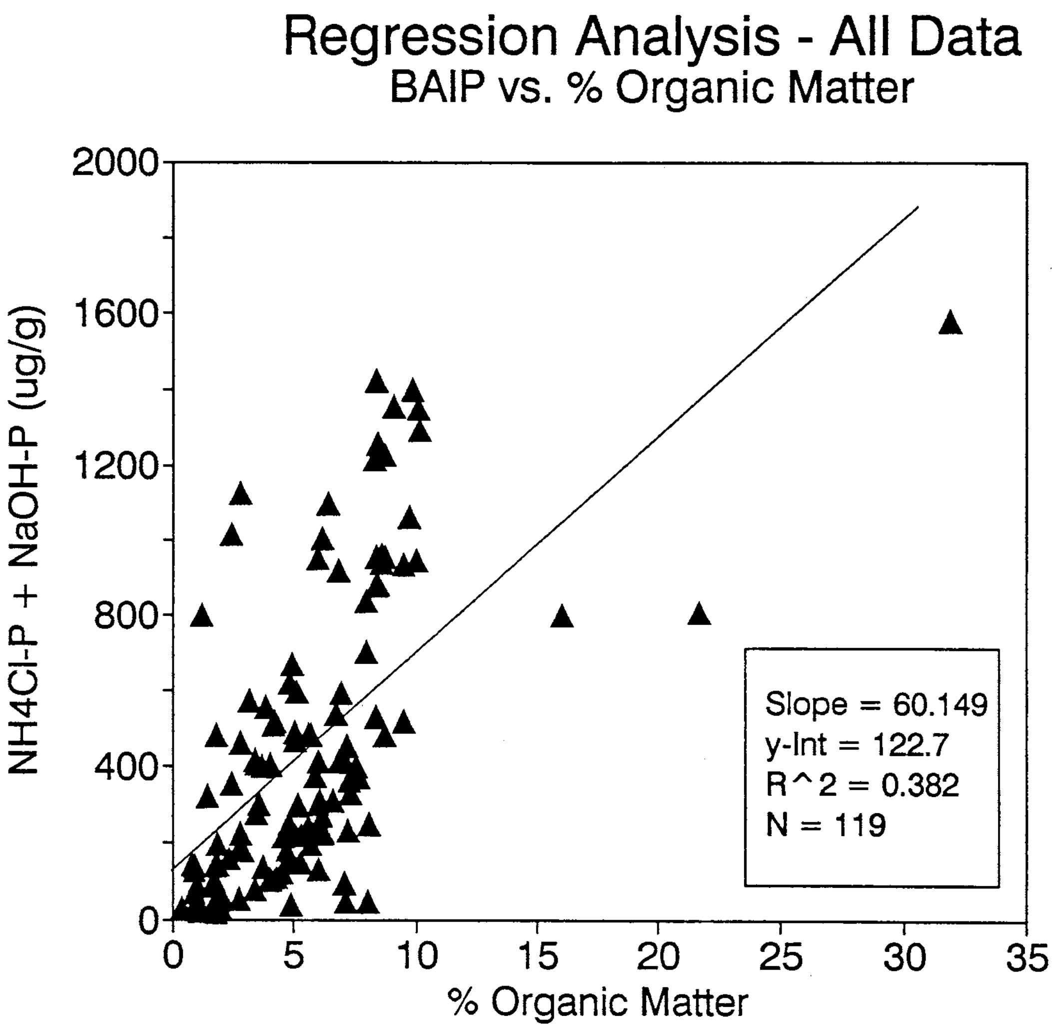

Figure 5-17. Regression Analysis for BAIP vs. % Organic Matter (All Data Included) in St. Albans Bay and Stevens Brook Wetland Bottom Sediments.

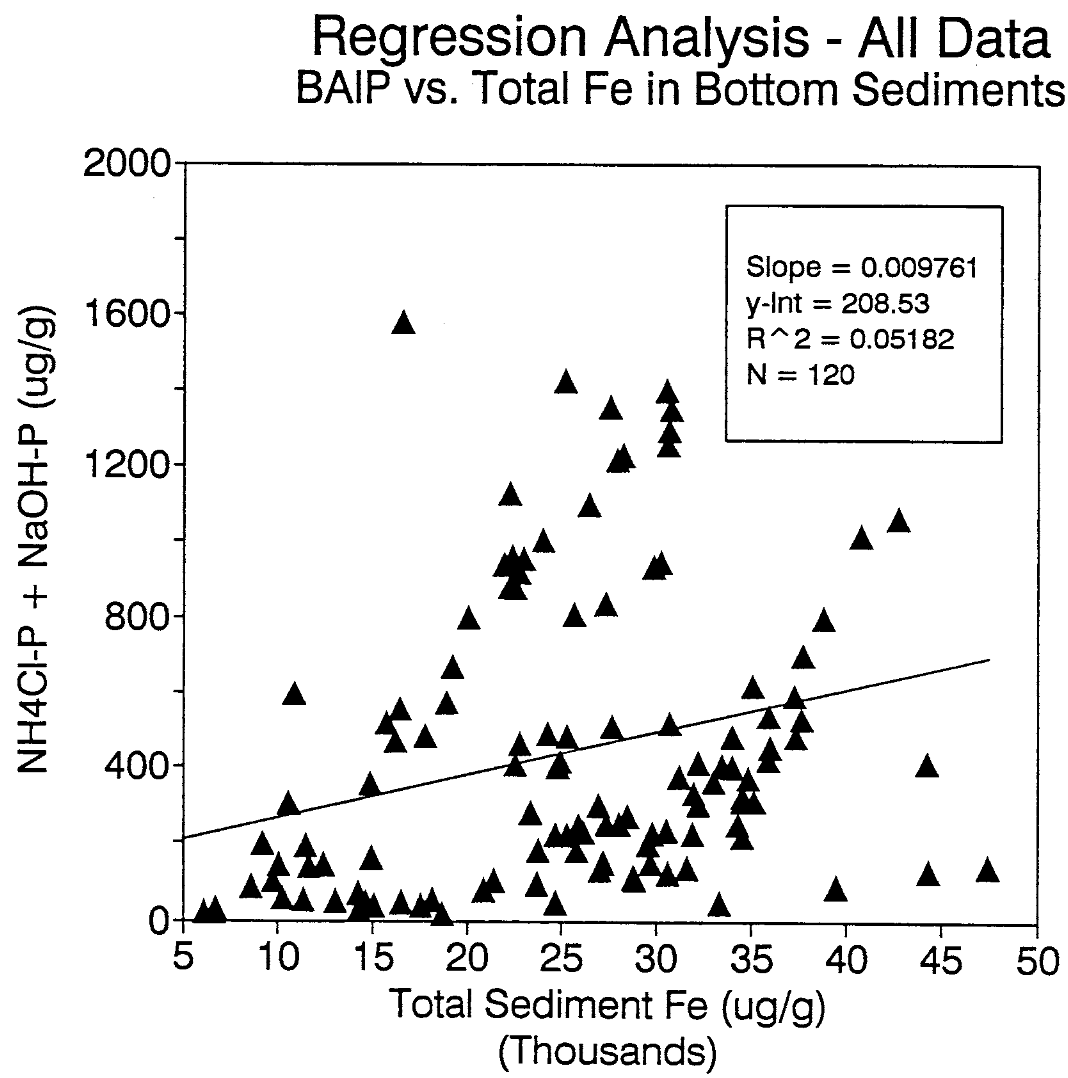

Figure 5-18. Regression Analysis for BAIP vs. Total Iron (All Data Included) in St. Albans Bay and Stevens Brook Wetland Bottom Sediments.

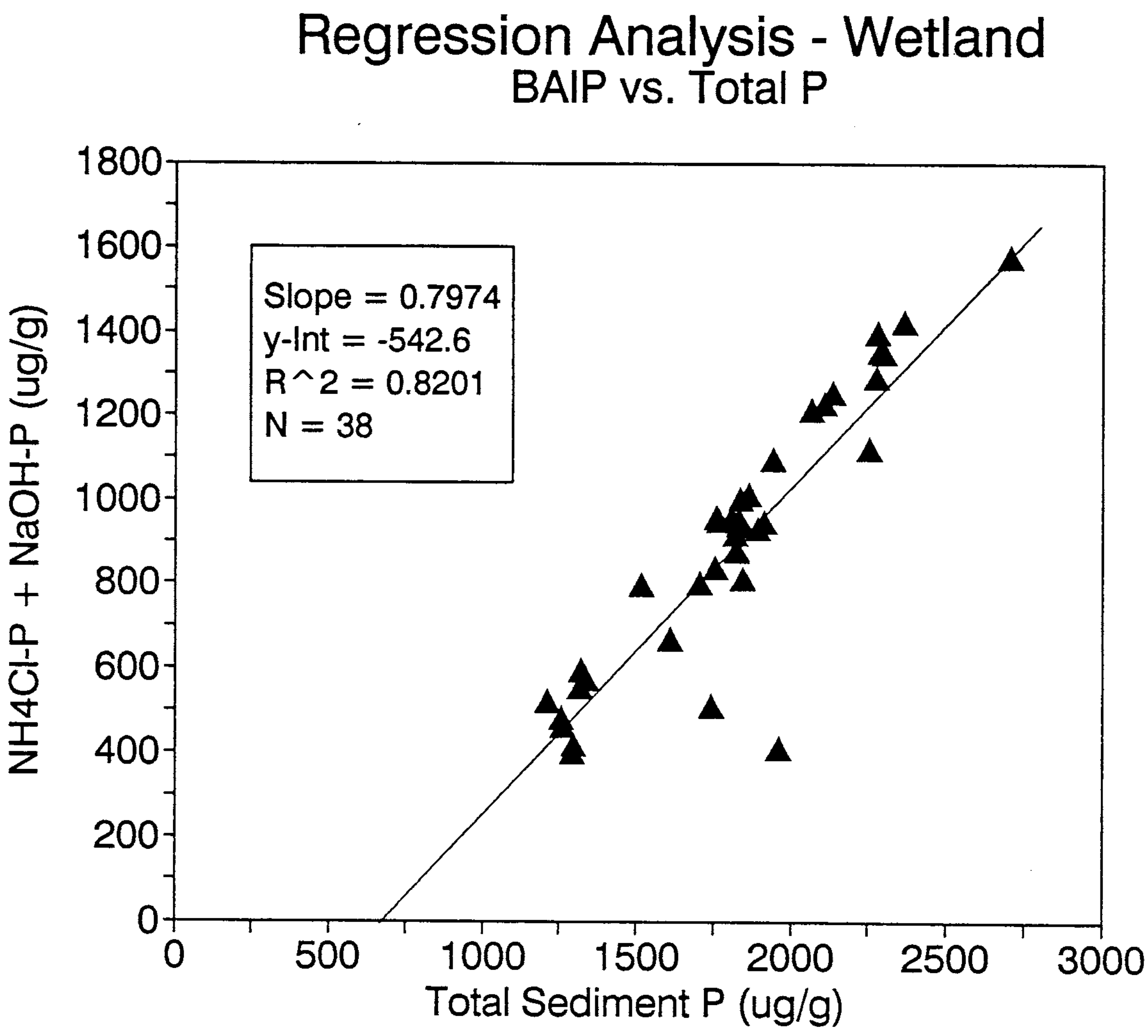

Figure 5-19. Regression Analysis for BAIP vs. Total P Stevens Brook Wetland Bottom Sediments.

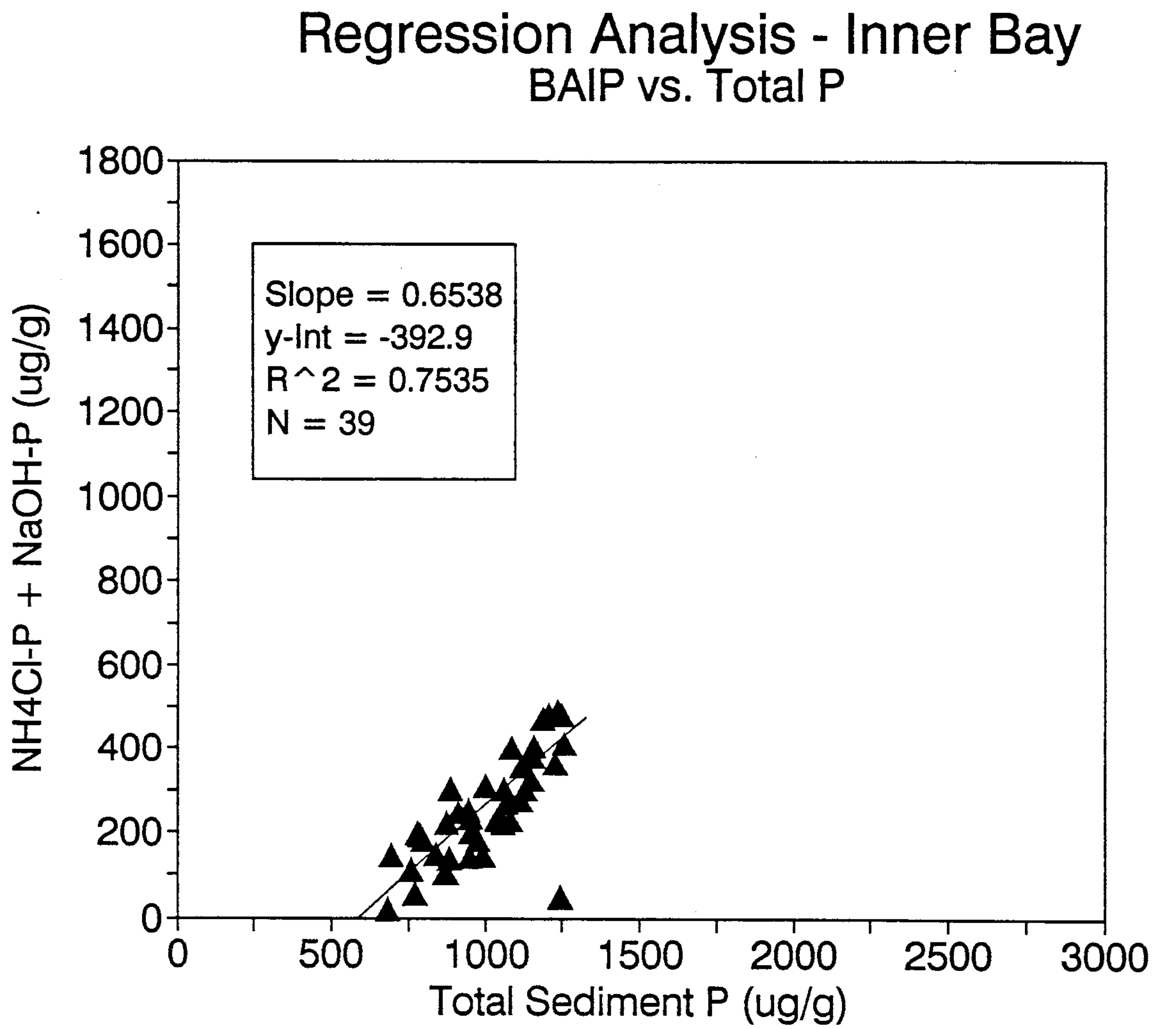

Figure 5-20. Regression Analysis for BAIP vs. Total P in Stevens Brook Wetland Bottom Sediments.

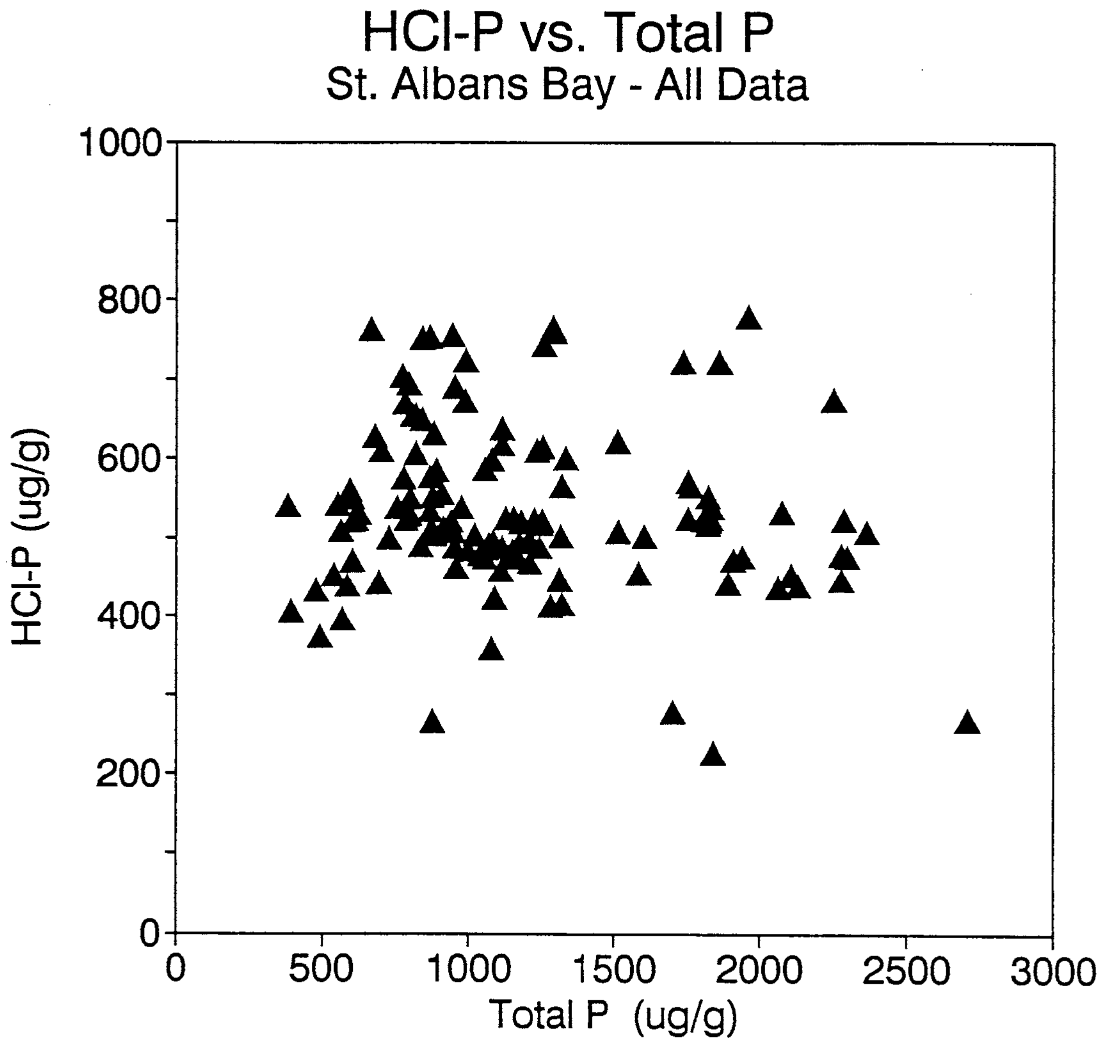

Figure 5-21. Regression Analysis for HCl-P vs. Total P (All Data Included) in St. Albans Bay and Stevens Brook Wetland Bottom Sediments.

Table 5-7. Summary of Regression and Correlation Analyses Involving Measured Phosphorus Fractions in St. Albans Bay Sediments.

Parameters	Data Set	N	Slope	y-Int	r^2	p
BAIP vs TP	All	120	0.756	-480.5	.925	<.001
BAIP vs %OM	All	119	60.15	122.7	.382	<.001
BAIP vs TotFe	All	120	.0098	208.5	.052	.567
HCl-P vs TP	All	120	-.0263	652.9	.016	.172
OrgP vs TP	All	120	0.270	-82.4	.577	<.001
OrgP vs %OM	All	120	33.75	65.0	.588	<.001
BAIP vs TP	Wetland	33	0.797	-542.6	.820	<.001
BAIP vs TP	Inner	39	0.654	-392.9	.754	<.001
BAIP vs TP	Middle	37	0.652	-368.3	.802	<.001
BAIP vs TP	Outer	5	0.790	-574.1	.998	<.001
OrgP vs %OM	Wetland	37	25.05	183.0	.551	<.001
OrgP vs %OM	Inner	39	33.57	41.6	.348	<.001
OrgP vs %OM	Middle	37	39.00	-4.69	.745	<.001
OrgP vs %OM	Outer	5	45.44	60.3	.973	<.001

The resulting equations were used to generate predicted values of Organic P for samples where it was not directly measured. These predicted values are also presented in Table D-6 of Appendix D (numbers enclosed in boxes).

5.5 Estimation of the Pool of Biologically Available Sediment Phosphorus

5.5.1 Contour Maps and Three-Dimensional Surface Plots of Phosphorus Fractions

The data collected in this study were used to develop contour maps of various phosphorus fractions in the bottom sediments of St. Albans Bay and Stevens Brook Wetland. All maps were developed with the SURFER software package, Version 4.13 (Golden Software). Contour maps for BAIP at 0-1 cm, 1-2 cm, 3-4 cm, 7-8 cm, and 11-12 cm depths in St. Albans Bay are presented in Figures 5-22 through 5-26. Three-dimensional versions of these maps were also developed - BAIP at 0-1 cm is shown in Figure 5-27. Contour maps of BAIP in the Wetland are presented in Figures 5-28 through 5-32. Two-dimensional contour maps of HCl-P, organic P, and total P at 0-1 cm depth are shown in Figures 5-33 through 5-35 for the Bay and 5-36 to 5-38 for the Wetland. The corresponding 3-D plots for St. Albans Bay are presented in Figures 5-39 to 5-41, respectively. Several additional Figures are presented in Appendix D, including:

1) 3-D surface plots of BAIP at depths of 1-2 cm, 3-4 cm, 7-8 cm, 11-12 cm in St. Albans Bay sediments (Figures D-1 to D-4).
2) Contour maps of Total P at 1-2 cm, 3-4 cm, 7-8 cm and 11-12 cm in:
    a) St. Albans Bay (Figures D-5 to D-8);
    b) Stevens Brook Wetland (Figures D-9 to D-12);
3) 3-D surface plots of total phosphorus at depths of 1-2 cm, 3-4 cm, 7-8 cm, 11-12 cm in St. Albans Bay sediments (Figures D-13 to D-16); and
4) 3-D surface plots of phosphorus fractions at a depth of 0-1 cm in Stevens Brook Wetland:
    a) BAIP (Figure D-17)
    b) HCl-P (Figure D-18)
    c) Organic P (Figure D-19)
    d) Total P (Figure D-20).

5.5.2 Estimates of Phosphorus Mass in Bottom Sediments

There are several approaches that could be taken to estimate the mass of phosphorus in St. Albans Bay bottom sediments. A "high-tech" approach would be to use the capabilities of the SURFER program to calculate contour areas or 3-D volumes from the various maps presented in section 5.5.1. Alternatively, measured or estimated phosphorus concentrations at each sampling station can be considered to represent conditions over equal bottom sediment surface areas. In this study, there is no reason to believe that the "high tech" approach would yield any greater accuracy, so the second approach was taken. First, the Bay and Wetland were divided into the same four segments used in previous analyses. Then, the BAIP, Organic P, and Total P concentrations (both measured and predicted) from Table D-6 were averaged within each segment. The resulting values are presented in Table 5-8, along with means computed for 1982 by sorting data from Ackerly (1983) by depth and segment. The total mass of these three sediment phosphorus components stored in the bottom sediments of each segment was calculated by Equation 5-1.

$$M = \sum_{z=0}^{8cm} P_i A_s \Delta z \, (1-\phi) \, X 2600 X 10^{-6} \qquad \textbf{(5-1)}$$

where:

P_i = mean sediment P concentration in segment, μg/g;
A_s = projected bottom sediment surface area, m^2;
z = depth within bottom sediments, m;
ϕ = porosity;
2600 = assumed density of solid matter composing bottom sediments, kg/m^3; and
10^{-6} = conversion factor from μg to g.

BAIP CONCENTRATION – ST. ALBANS BAY SEDIMENTS, 1992

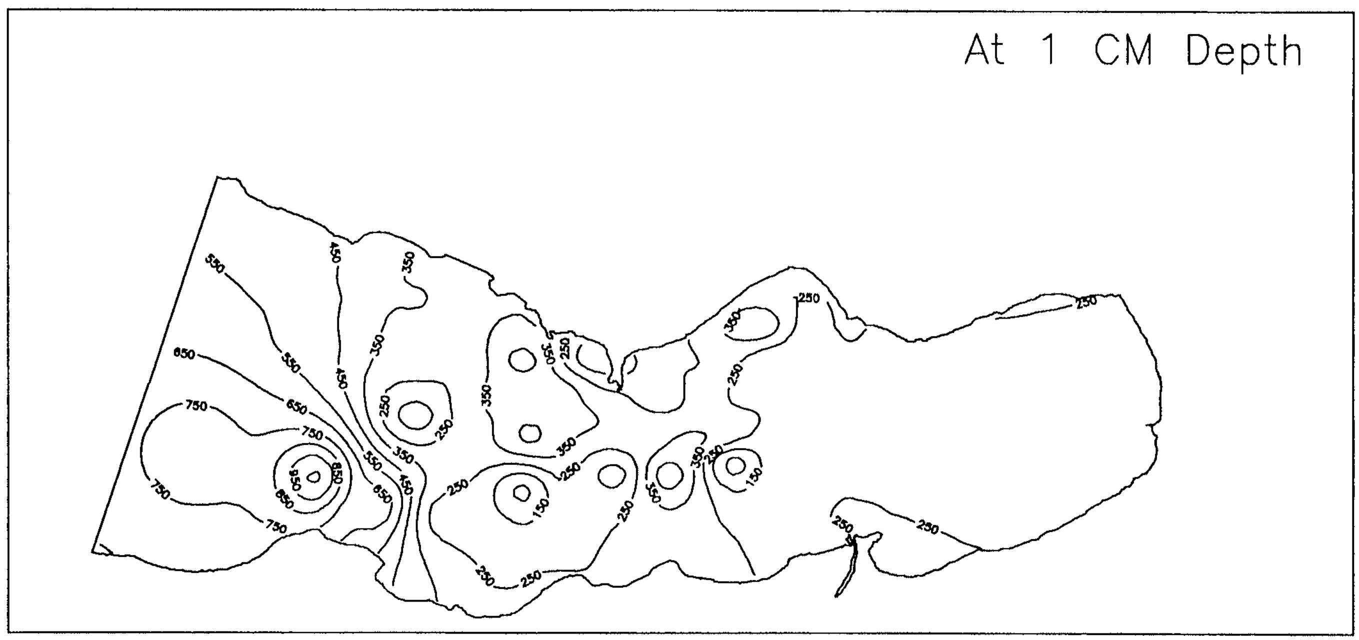

Figure 5-22. Contour Map of BAIP ($\mu g/g$) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.

BAIP CONCENTRATION – ST. ALBANS BAY SEDIMENTS, 1992

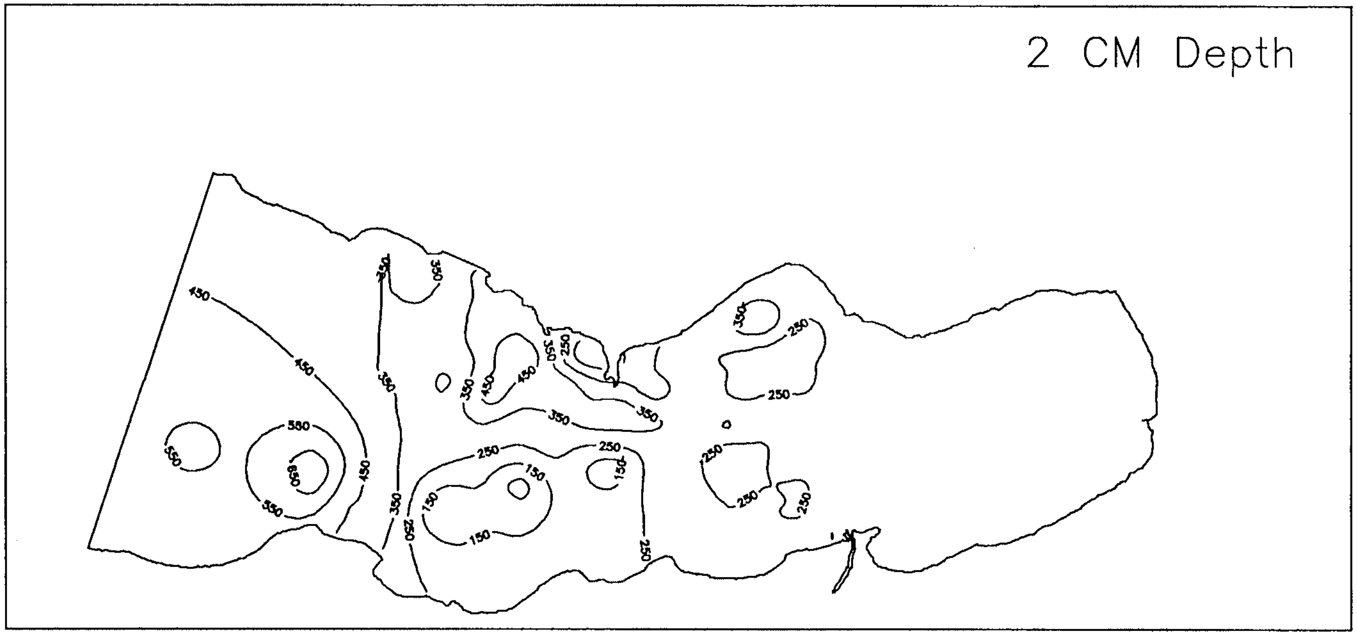

Figure 5-23. Contour Map of BAIP ($\mu g/g$) at 1-2 cm Depth in St. Albans Bay Bottom Sediments.

BAIP CONCENTRATION – ST. ALBANS BAY SEDIMENTS, 1992

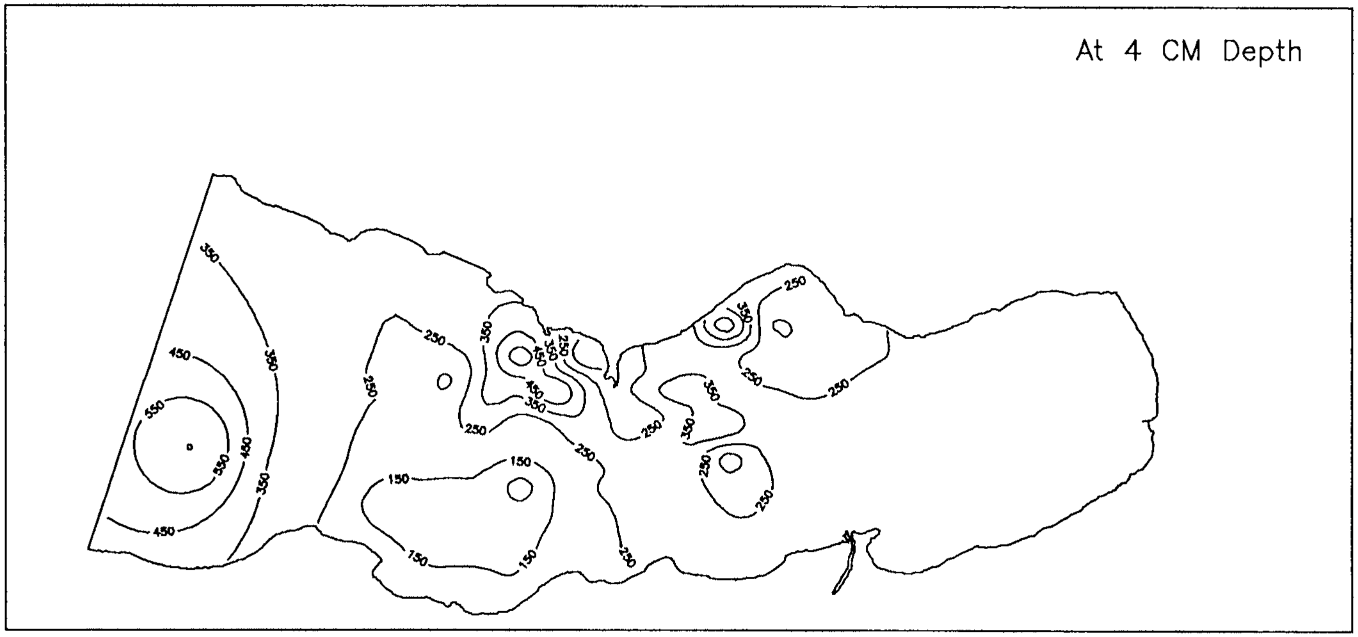

Figure 5-24. Contour Map of BAIP ($\mu g/g$) at 3-4 cm Depth in St. Albans Bay Bottom Sediments.

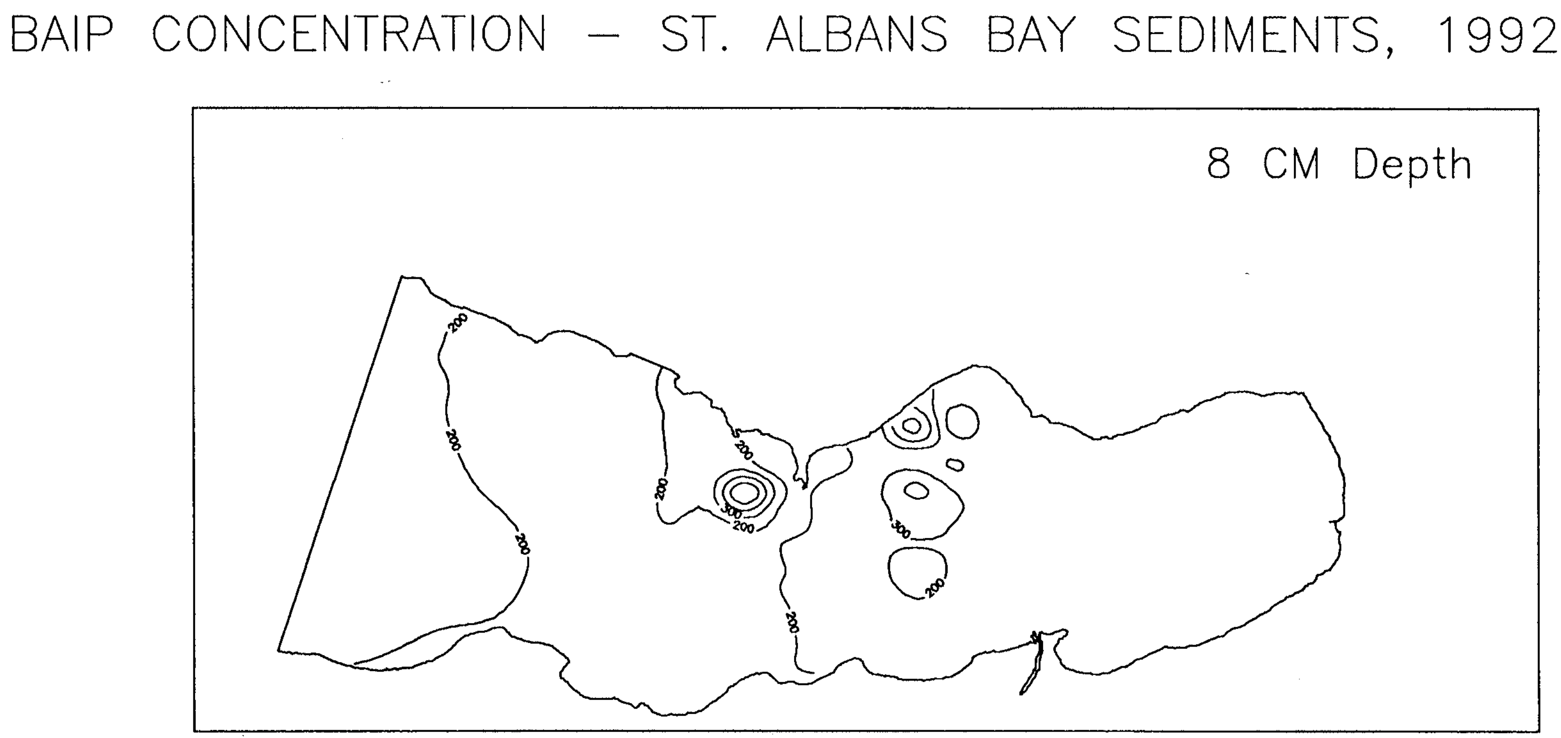

Figure 5-25. Contour Map of BAIP ($\mu g/g$) at 7-8 cm Depth in St. Albans Bay Bottom Sediments.

BAIP CONCENTRATION – ST. ALBANS BAY SEDIMENTS, 1992

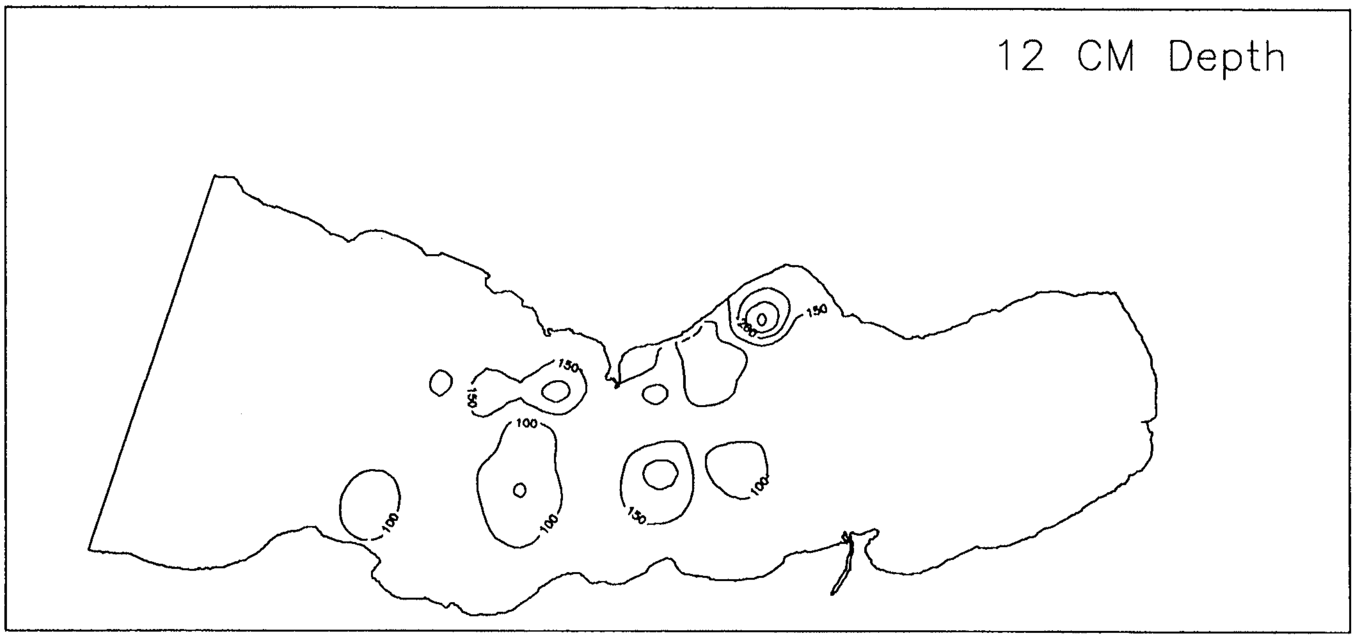

Figure 5-26. Contour Map of BAIP ($\mu g/g$) at 11-12 cm Depth in St. Albans Bay Bottom Sediments.

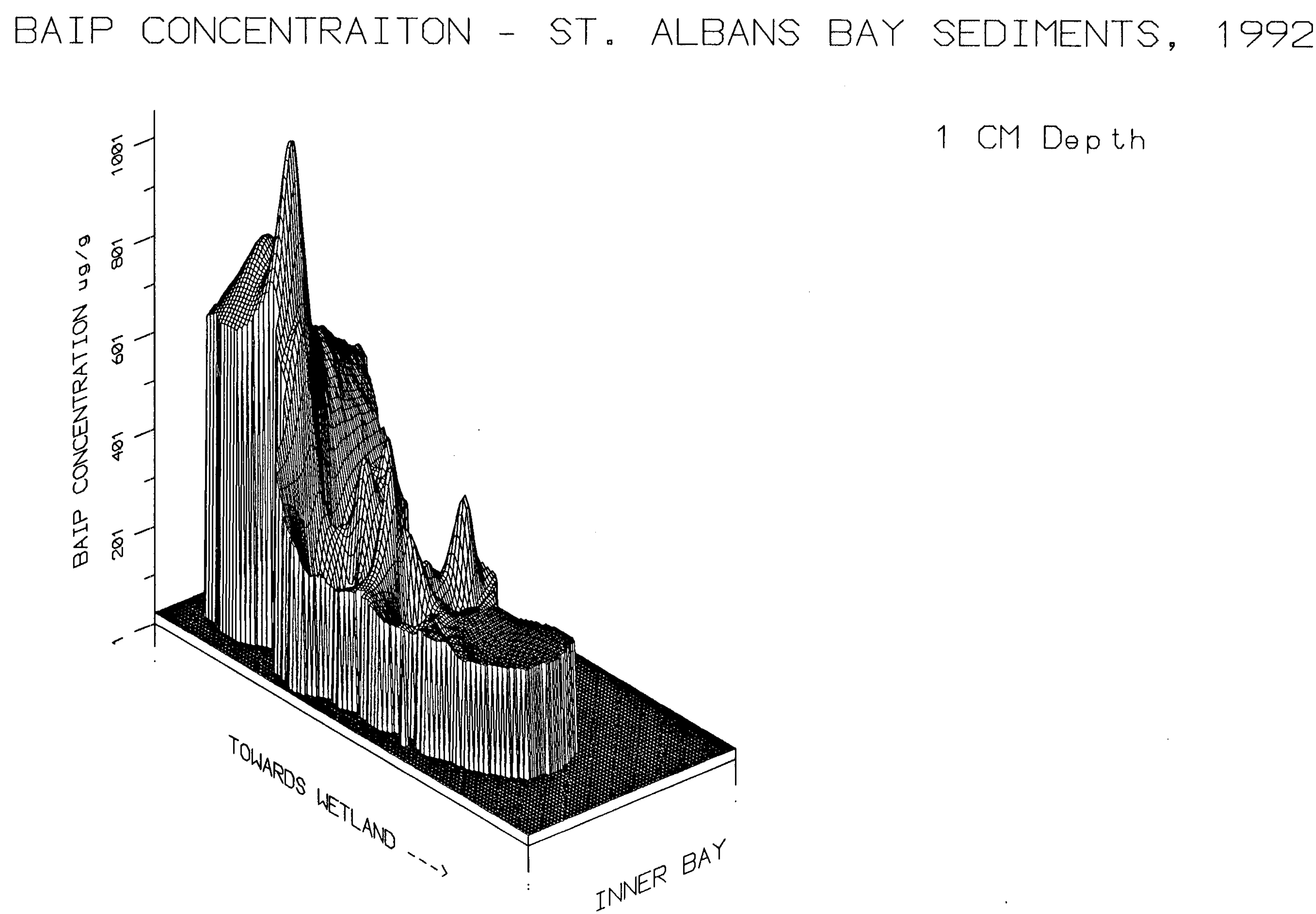

Figure 5-27. **Three-Dimensional Surface Plot of BAIP (μg/g) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.**

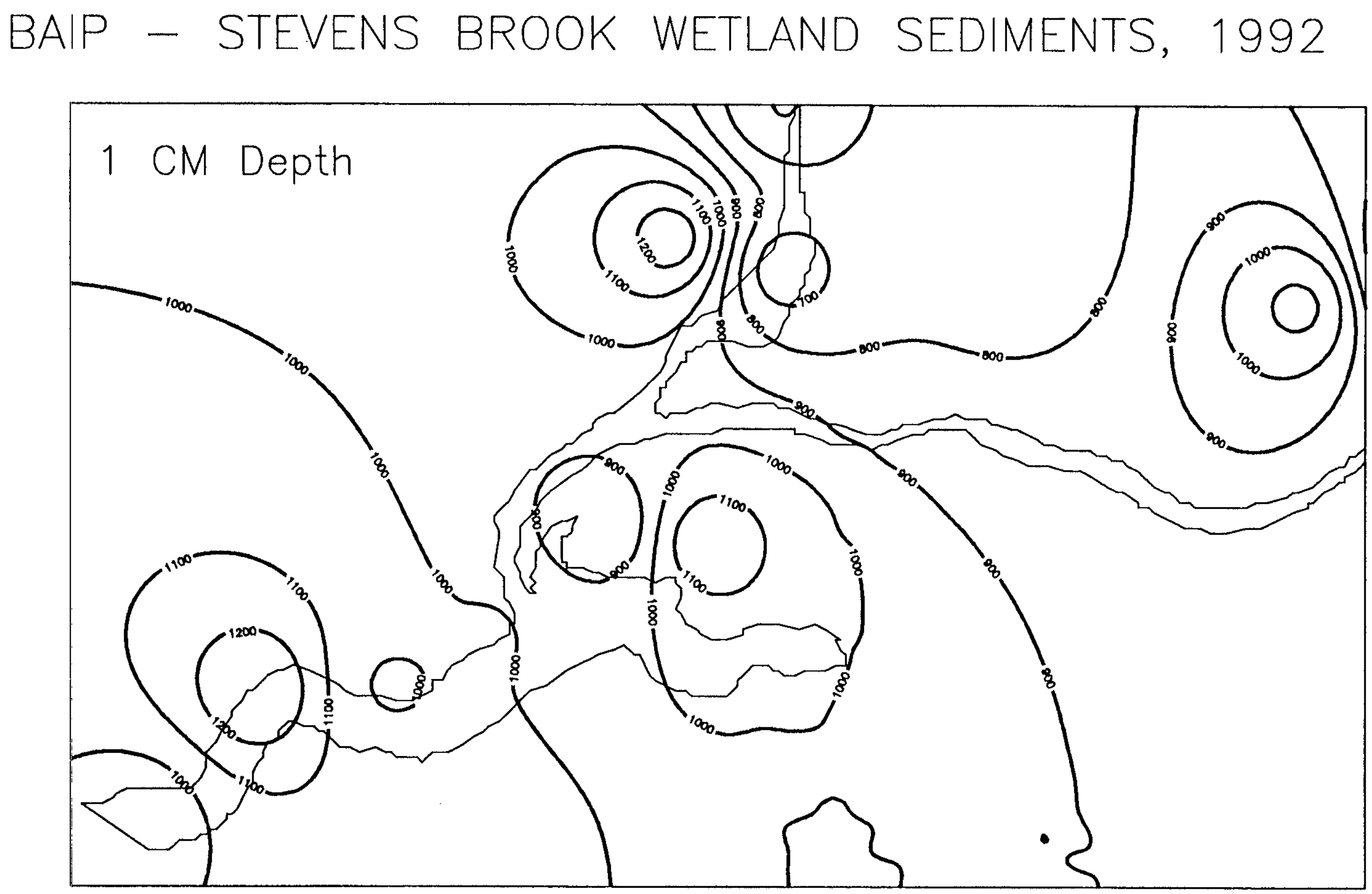

Figure 5-28. Contour Map of BAIP ($\mu g/g$) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.

BAIP – STEVENS BROOK WETLAND SEDIMENTS, 1992

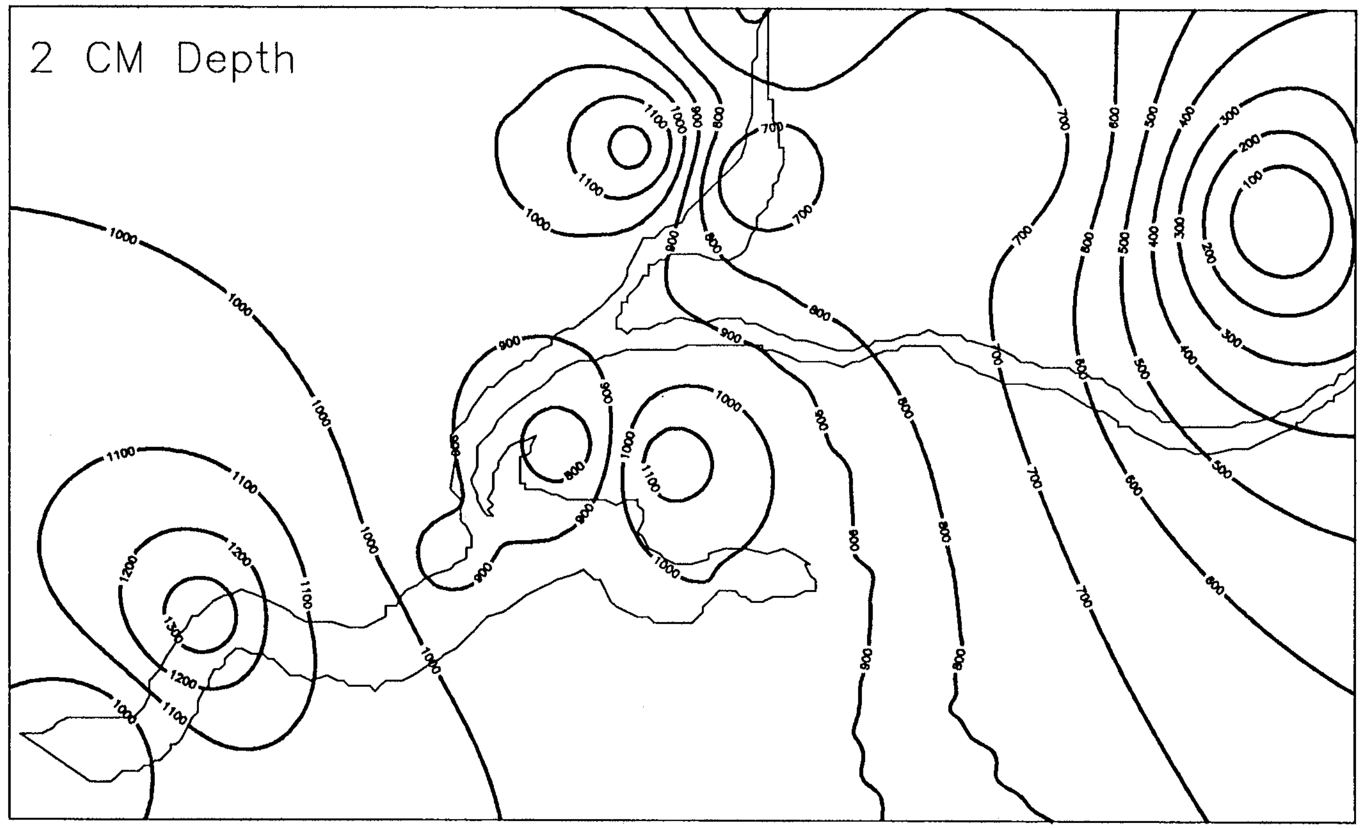

Figure 5-29. Contour Map of BAIP ($\mu g/g$) at 1-2 cm Depth in Stevens Brook Wetland Bottom Sediments.

BAIP – STEVENS BROOK WETLAND SEDIMENTS, 1992

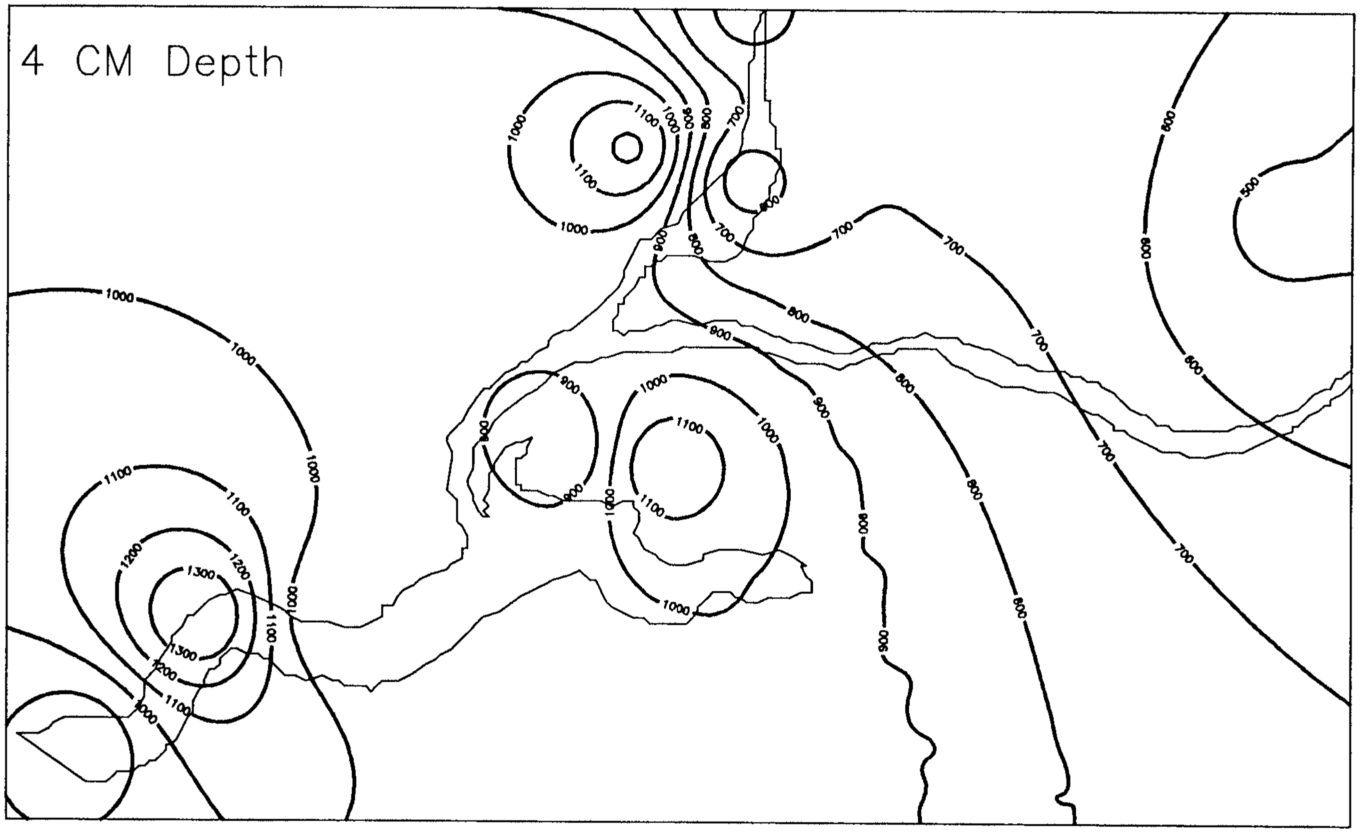

Figure 5-30. Contour Map of BAIP ($\mu g/g$) at 3-4 cm Depth in Stevens Brook Wetland Bottom Sediments.

BAIP – STEVENS BROOK WETLAND SEDIMENTS, 1992

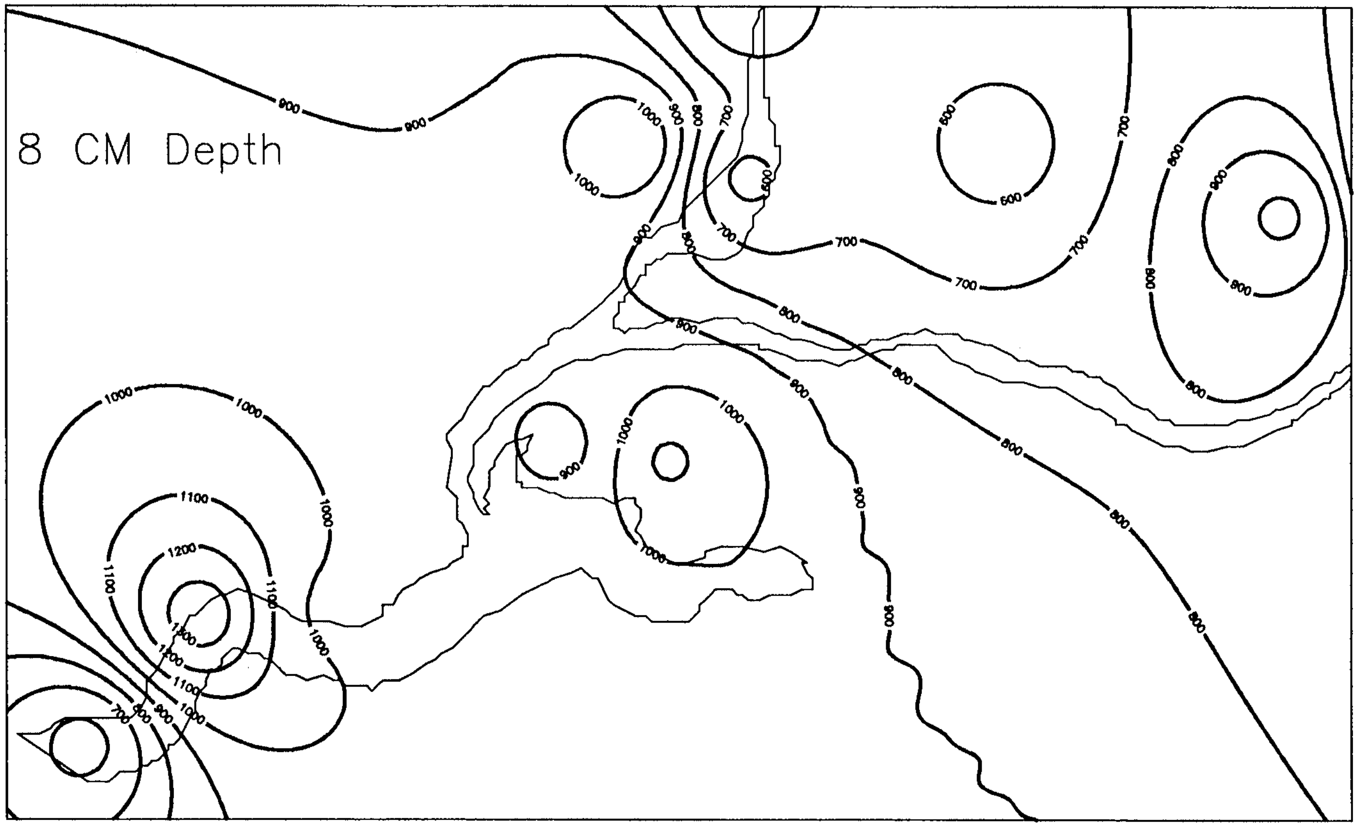

Figure 5-31. **Contour Map of BAIP ($\mu g/g$) at 7-8 cm Depth in Stevens Brook Wetland Bottom Sediments.**

BAIP – STEVENS BROOK WETLAND SEDIMENTS, 1992

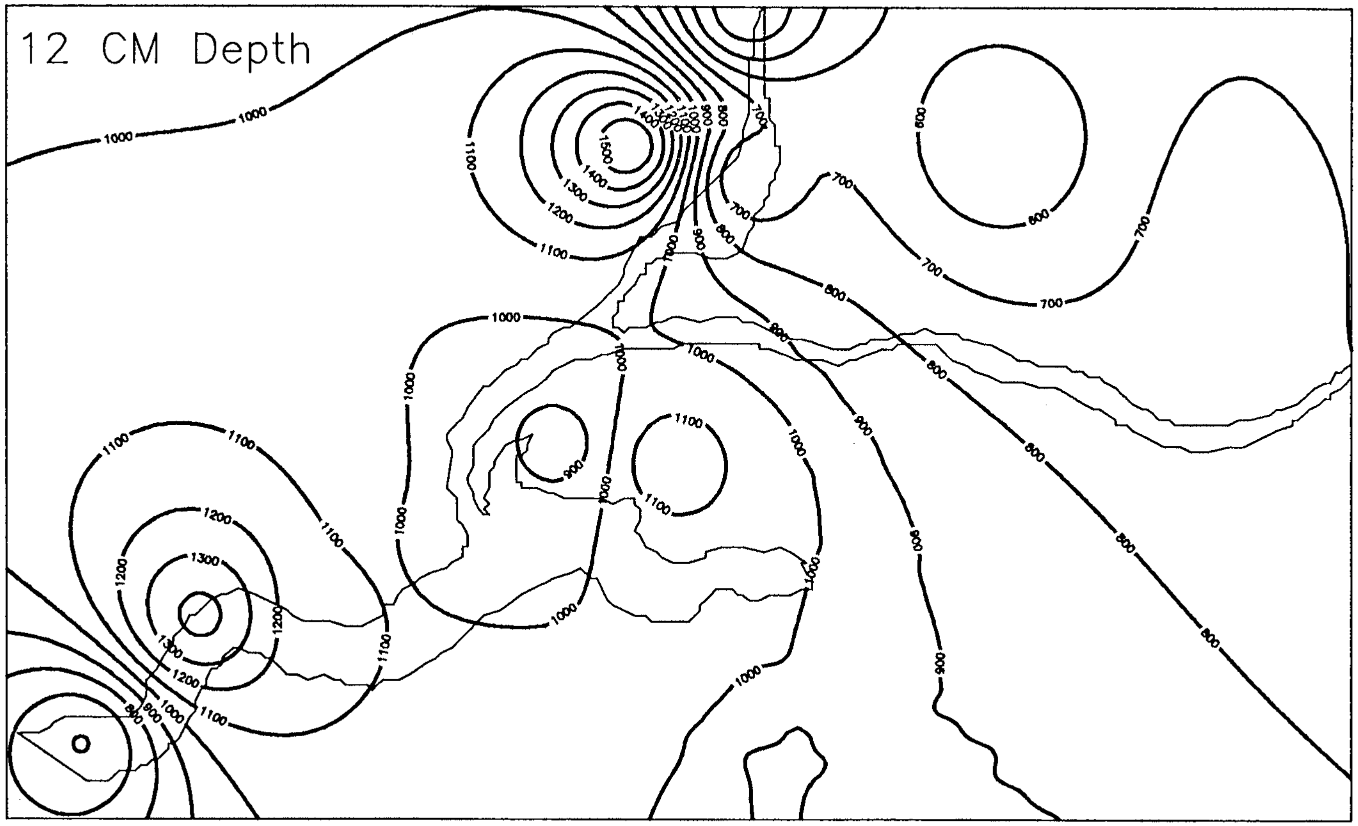

Figure 5-32. Contour Map of BAIP ($\mu g/g$) at 11-12 cm Depth in Stevens Brook Wetland Bottom Sediments.

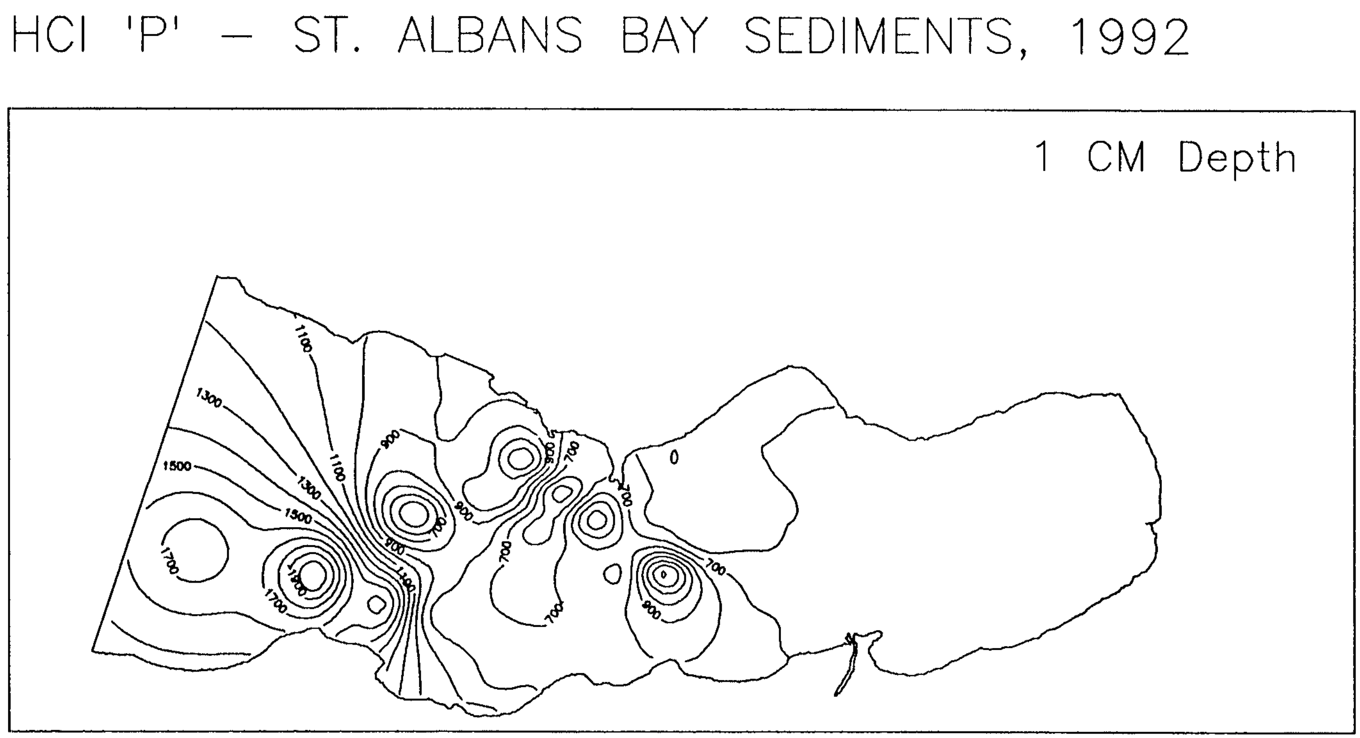

Figure 5-33. Contour Map of HCl-P ($\mu g/g$) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.

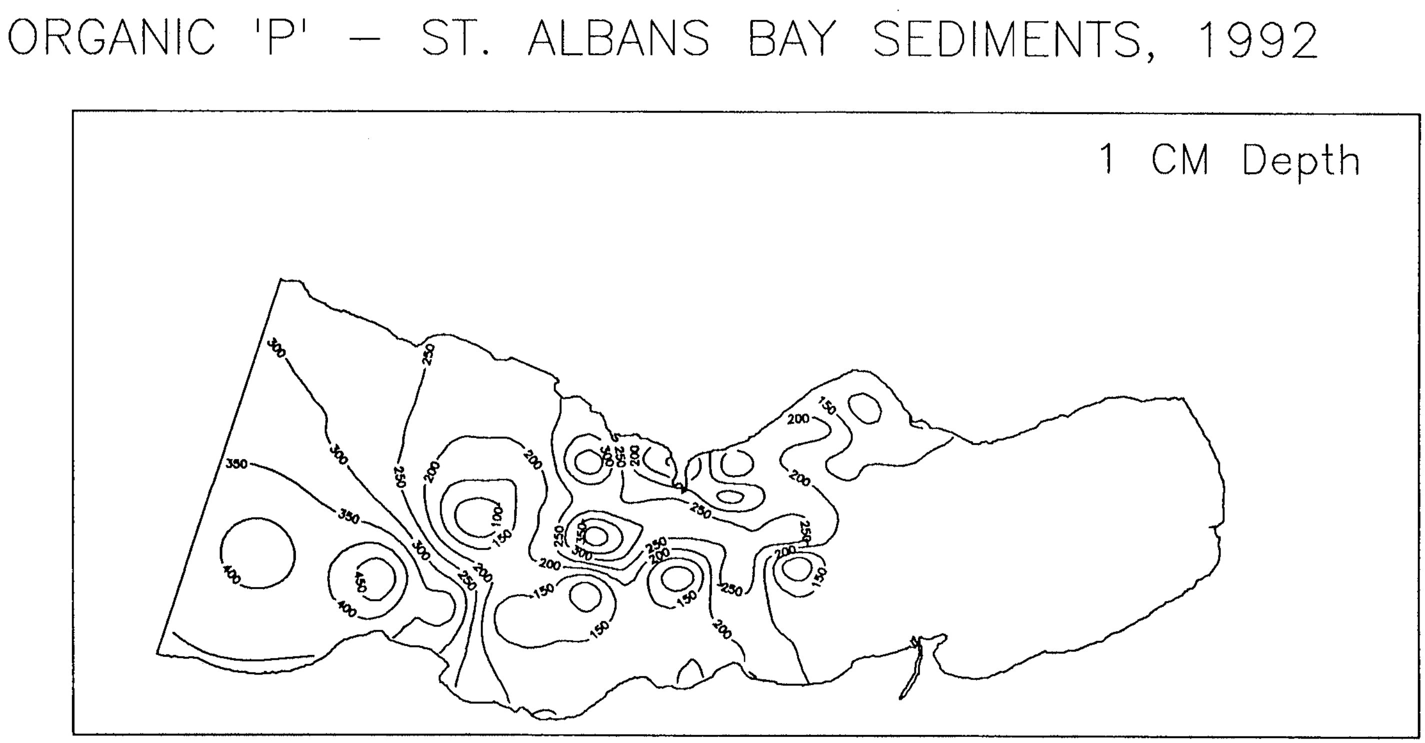

Figure 5-34. Contour Map of Organic P ($\mu g/g$) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.

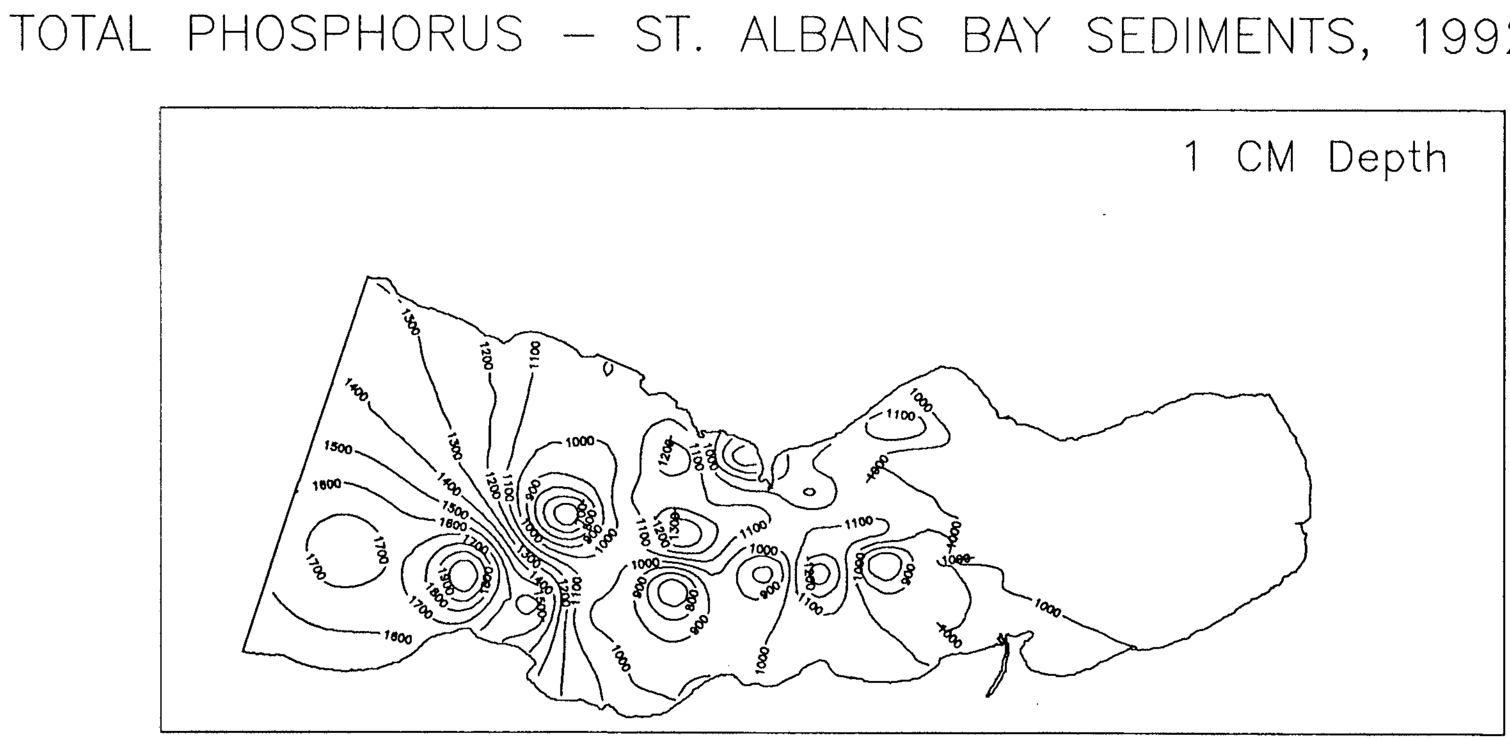

Figure 5-35. Contour Map of Total P (μg/g) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.

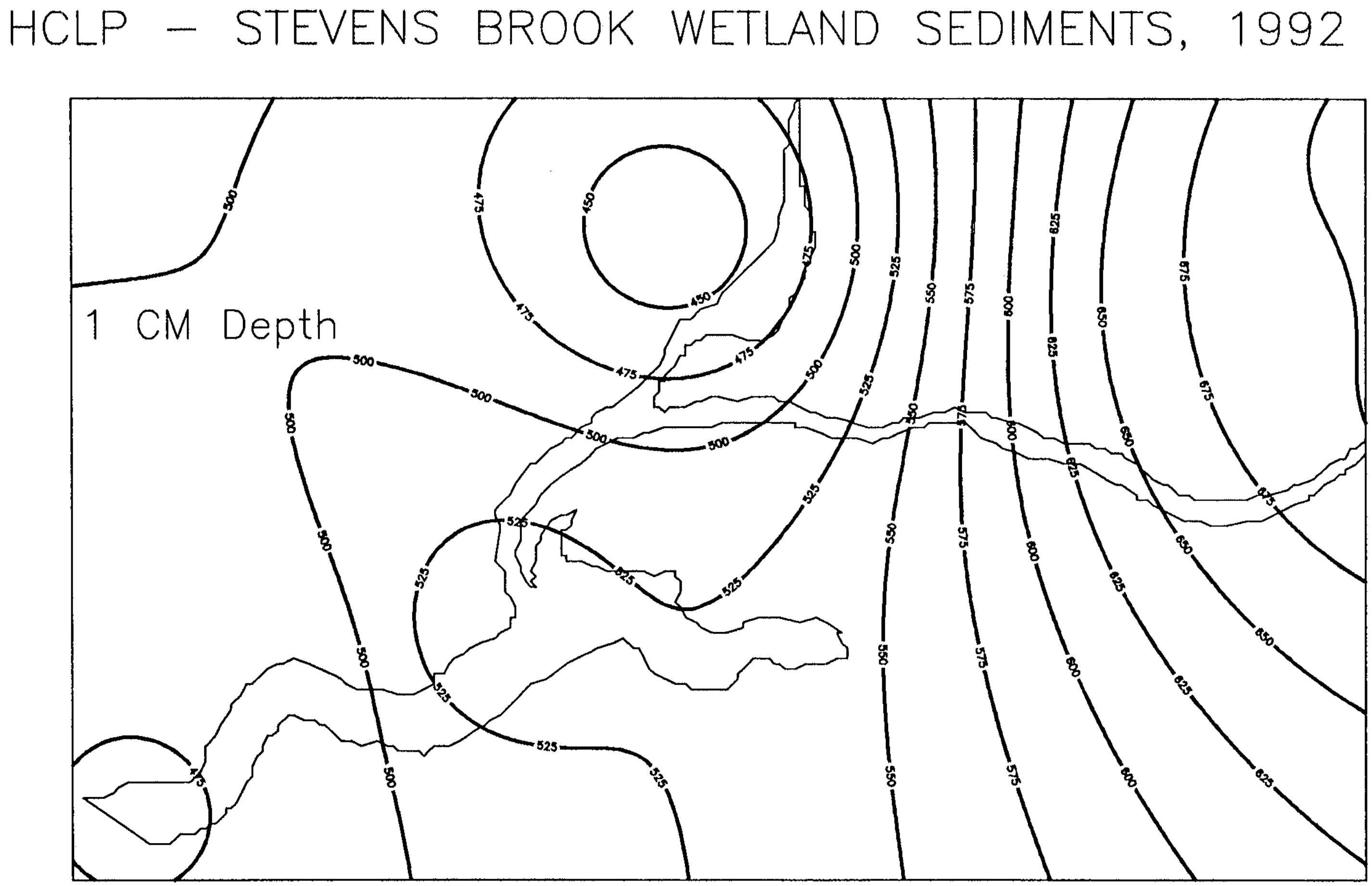

Figure 5-36. **Contour Map of HCl-P ($\mu g/g$) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.**

ORGANIC 'P' – STEVENS BROOK WETLAND SEDIMENTS, 1992

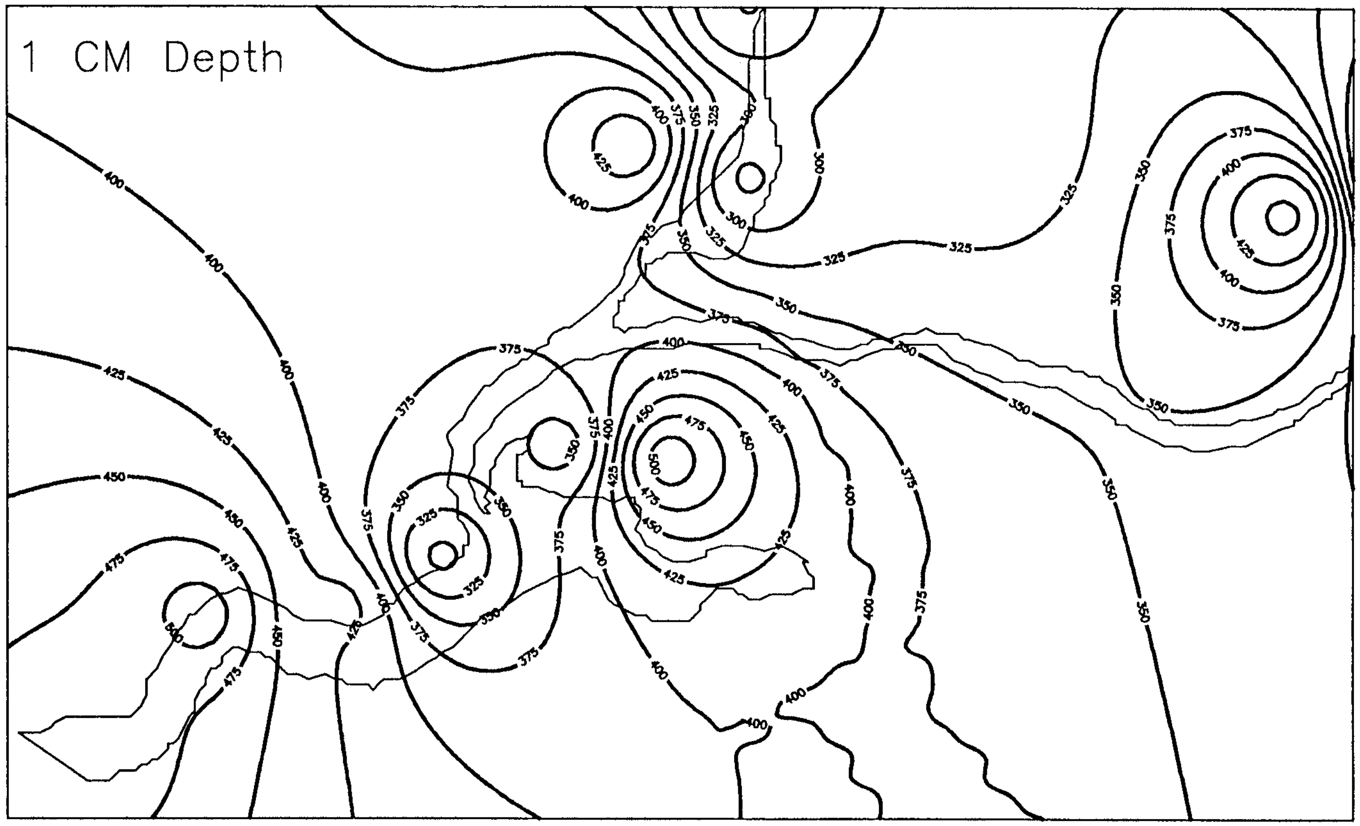

Figure 5-37. Contour Map of Organic P ($\mu g/g$) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.

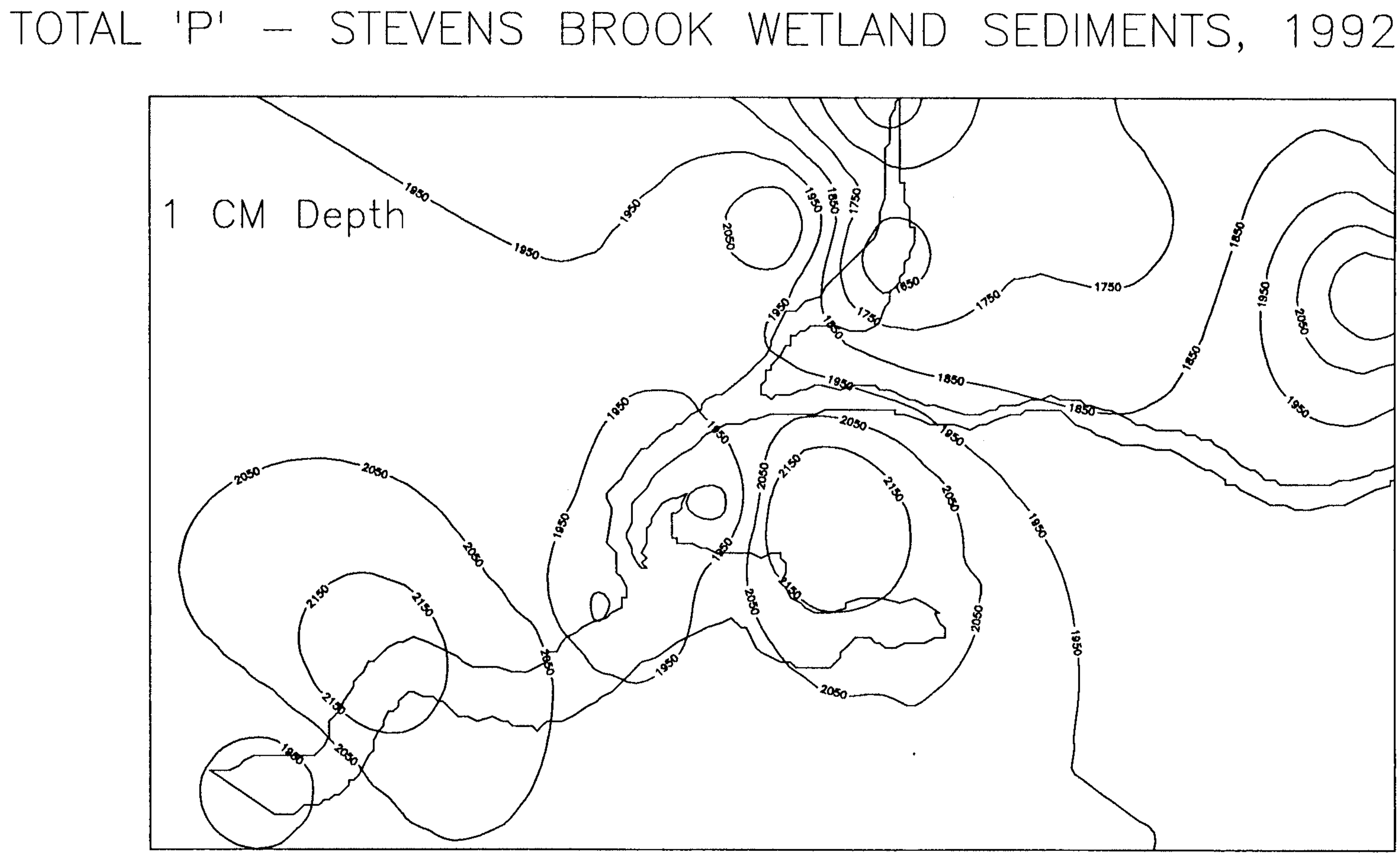

Figure 5-38. Contour Map of Total P (μg/g) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.

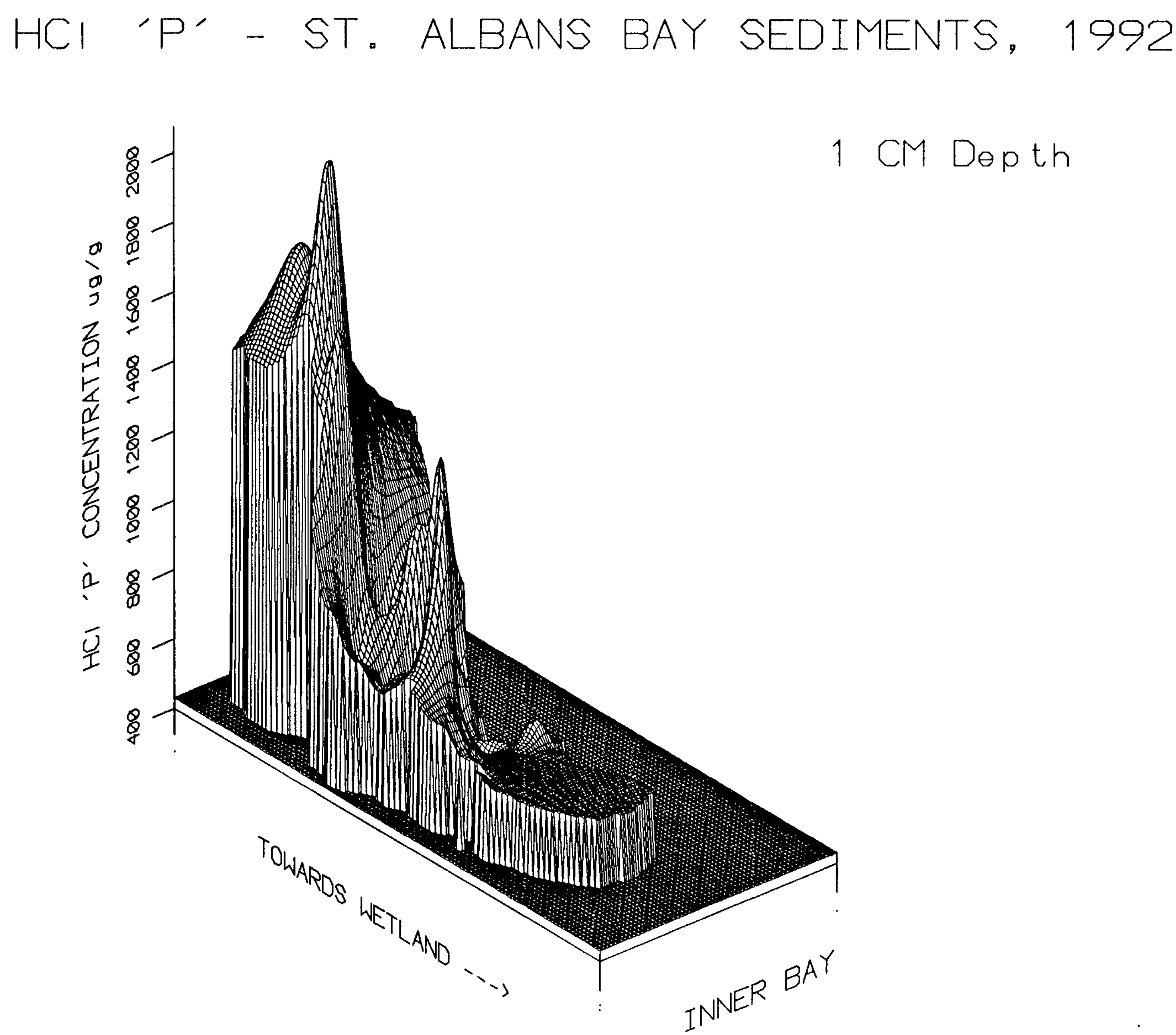

Figure 5-39. Three-Dimensional Surface Plot of HCl-P (μg/g) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.

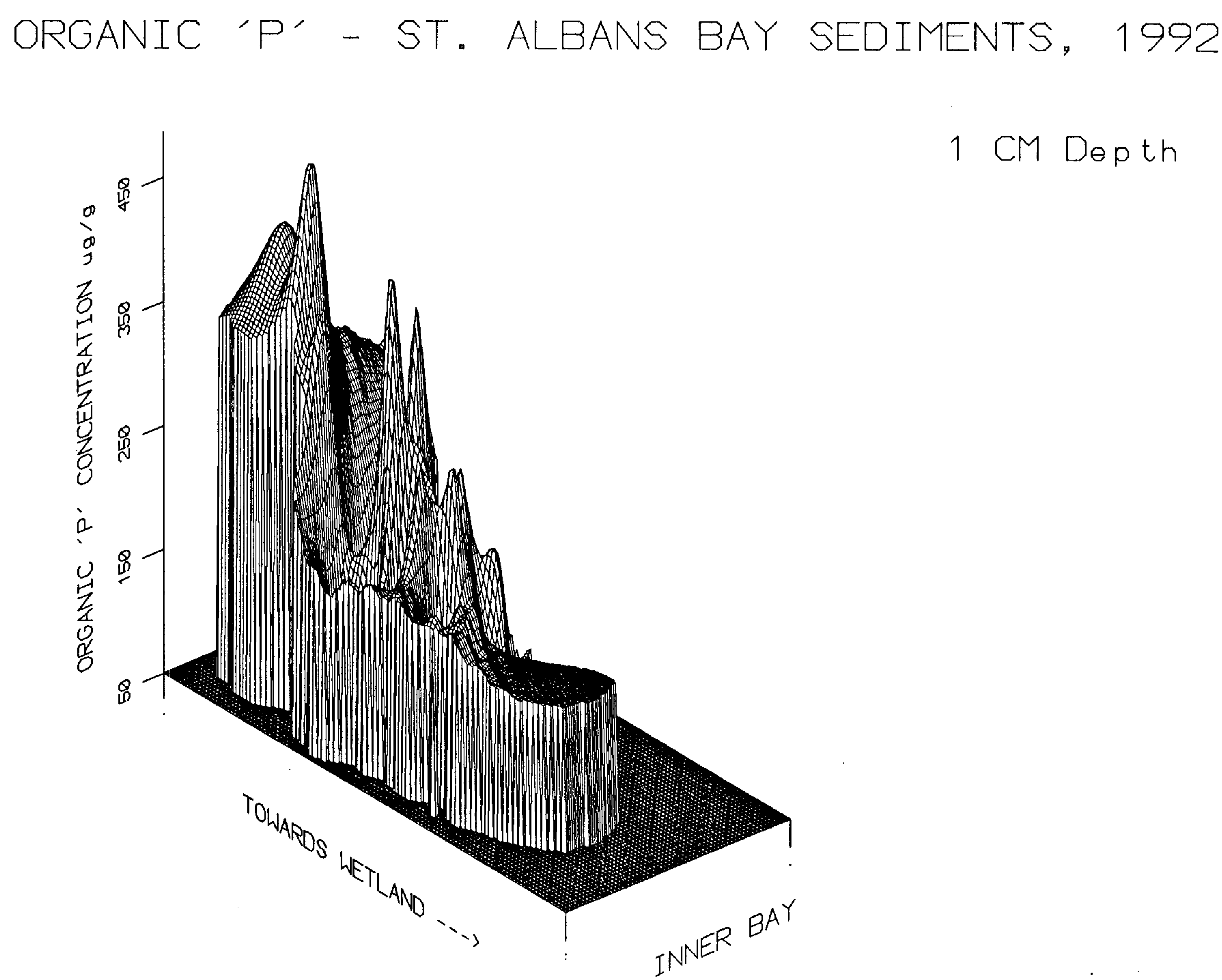

Figure 5-40. **Three-Dimensional Surface Plot of Organic P ($\mu g/g$) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.**

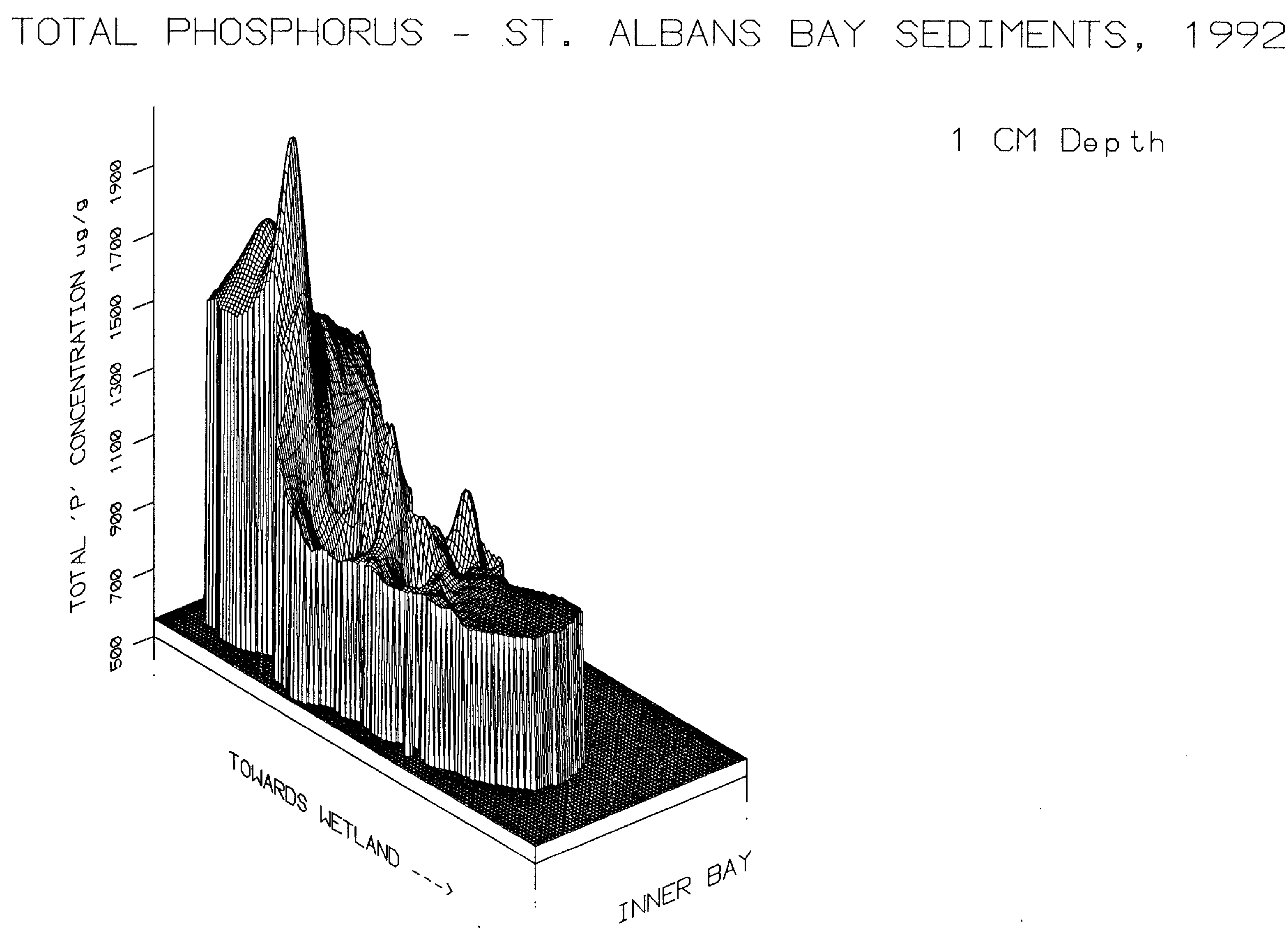

Figure 5-41. Three-Dimensional Surface Plot of Total P (μg/g) at 0-1 cm Depth in St. Albans Bay Bottom Sediments.

Table 5-8. Average Concentrations of BAIP, Organic P, and Total P in Bottom Sediments as Functions of Location and Depth.

Location	Depth (cm)	BAIP (ug/g) 1992 Mean	BAIP (ug/g) 1982 Mean	Org P (ug/g) 1992 Mean	Org P (ug/g) 1982 Mean	Total P (ug/g) 1992 Mean	Total P (ug/g) 1982 Mean
Stevens Brook Wetland	0-1	947.8	1417.5	400.2	713.6	1883.0	2680.0
	1-2	925.3	1266.7	384.5	617.8	1826.6	2406.0
	3-4	862.7	1122.9	339.6	630.8	1721.7	2302.0
	7-8	843.4	916.4	408.8	527.4	1779.5	1970.8
	11-12	918.1		430.7		1842.6	
Inner St. Albans Bay	0-1	254.6	387.6	238.3	302.7	1001.0	1315.7
	1-2	282.6	307.4	239.4	306.7	1022.7	1225.3
	3-4	289.2	266.6	207.0	274.4	1037.2	1166.4
	7-8	258.7	184.1	198.7	208.6	980.9	1060.6
	11-12	135.6		147.5		830.3	
Middle St. Albans Bay	0-1	280.2	306.0	225.9	445.6	991.9	1336.1
	1-2	265.9	234.0	223.7	419.2	973.4	1151.8
	3-4	259.0	200.9	178.1	381.2	928.0	1045.5
	7-8	189.9	175.9	159.0	319.4	851.7	947.1
	11-12	136.1		156.9		821.3	
Outer St. Albans Bay	0-1	858.7	1881.2	456.2	629.0	1817.4	3234.0
	1-2	560.9	1421.4	400.0	312.0	1427.5	2248.0
	3-4	380.5	723.5	335.8	297.0	1217.0	1507.0
	7-8	181.6	605.4	254.8	302.0	950.1	1427.0
	11-12	105.3		229.9		862.1	

Segment surface areas were obtained from Smeltzer (1993), while mean porosity for each segment was taken from Table 5-2. Calculations were performed for phosphorus in the top 8 cm of the sediments. The results of these calculations are presented in Tables 5-9 (for 1992) and 5-10 (for 1982). It is estimated that the present (1992) pools of Total P stored in the bottom sediments are: 1.617 X 10^4 kg in Stevens Brook Wetland; 1.106 X 10^5 kg in Inner St. Albans Bay; 2.313 X 10^5 kg in the Middle Bay; and 2.500 X 10^5 kg in the Outer Bay. While the reservoir of Total P in the Wetland is roughly an order of magnitude smaller that any of the Bay segments, over 70% of this is present as BAIP or Organic P. Thus, the potential impact of phosphorus releases from Wetland sediments on water quality in the Bay should not be overlooked.

5.6 Estimation of Recovery Times for Bottom Sediments

Based on the estimated pools of phosphorus in the Bay and Wetland bottom sediments, predictions can be made of the time required for depletion of the accumulated phosphorus. A simple preliminary calculation was performed based on the assumption that the excess Total P above some "pristine" background level is lost from the bottom sediments at a first order rate. Total P was chosen for this calculation, rather than BAIP or (BAIP + Organic P), because results presented in Section 5.3 suggest that significant amounts of sediment phosphorus were lost from all chemical fractions (including HCl-P) between 1982 and 1992. For these calculations, it was assumed that sediment phosphorus levels began to decline in 1982, when substantial point source loading reductions occurred (see Table 3-3), possibly as a delayed result of the 1978 Vermont Phosphorus Detergent Ban (Hyde et al., 1993) It was also assumed that the mean Total P level of 535 μg/g reported by Corliss and Hunt (1973) in Lapan Bay could be used to approximate "pristine" conditions. The mass of Total P in each segment under these (pristine) conditions would be: 4.862 X 10^3 kg in the Wetland, 5.844 X 10^4 kg in the Inner Bay, 1.344 X 10^5 kg in the Middle Bay, and 1.072 X 10^5 kg in the Outer Bay.

Considering the mass of Total P in the entire Bay/Wetland system as a whole, comparison of Tables 5-9 and 5-10 indicates that 22.5% of the Total P pool was lost between 1982 and 1992. However, this represents a depletion of 36.8% of the accumulated "excess" Total P above the "pristine" background level. This corresponds to a first-order loss rate of 0.046 yr^{-1}. Using this loss rate, the times required (starting in 1982) for depletion of 50%, 75%, and 90% of the accumulated excess Total P in the bottom sediments were estimated as follows:

50% depletion	-	15.1 years
75% depletion	-	30.1 years
90% depletion	-	50.1 years

If it is assumed that the internal phosphorus loading rate from the bottom sediments is roughly proportional to the "excess" Total P present at any given time, then it can be reasoned that a 36.8% reduction in internal loading (from the 1982 peak) has already been achieved, a 50% reduction will be achieved by the year 1997, a 75% reduction by the year 2012, and a 90% reduction by the year 2032. Since much of the decrease in the sediment P pool may have occurred after the St. Albans WWTF upgrade in 1987, the first-order loss rate may actually be higher, and the phosphorus release more rapid, than indicated here. A more sophisticated analysis of sediment phosphorus recycle is presented in Section 6.

Table 5-9. Estimated Masses of Phosphorus in Top 8 cm of Bottom Sediments, Based on 1992 Measurements from This Study.

Mass of Phosphorus in Top 8 cm of Bottom Sediments - 1992					
Segment	P Fraction	Depth Ave. Mean Conc. (ug/g)	Surface Area (sq m)	Porosity	P Pool (kg)
Wetland	BAIP	879.04	1.776E+05	0.754	7.988E+03
	Organic P	377.21	1.776E+05	0.754	3.428E+03
	Total P	1779.22	1.776E+05	0.754	1.617E+04
Inner Bay	BAIP	274.11	2.587E+06	0.797	2.994E+04
	Organic P	214.39	2.587E+06	0.797	2.342E+04
	Total P	1012.36	2.587E+06	0.797	1.106E+05
Middle Bay	BAIP	241.35	4.330E+06	0.721	6.065E+04
	Organic P	186.66	4.330E+06	0.721	4.690E+04
	Total P	920.66	4.330E+06	0.721	2.313E+05
Outer Bay	BAIP	411.94	7.030E+06	0.863	8.252E+04
	Organic P	337.57	7.030E+06	0.863	6.762E+04
	Total P	1248.11	7.030E+06	0.863	2.500E+05

Table 5-10. Estimated Masses of Phosphorus in Top 8 cm of Bottom Sediments, Based on 1982 Measurements by Ackerly (1983).

Mass of Phosphorus in Top 8 cm of Bottom Sediments - 1982					
Segment	P Fraction	Depth Ave. Mean Conc. (ug/g)	Surface Area (sq m)	Porosity	P Pool (kg)
Wetland	BAIP	1122.16	1.776E+05	0.754	1.020E+04
	Organic P	606.40	1.776E+05	0.754	5.511E+03
	Total P	2265.25	1.776E+05	0.754	2.059E+04
Inner Bay	BAIP	263.60	2.587E+06	0.797	2.879E+04
	Organic P	263.43	2.587E+06	0.797	2.878E+04
	Total P	1163.04	2.587E+06	0.797	1.270E+05
Middle Bay	BAIP	212.43	4.330E+06	0.721	5.338E+04
	Organic P	377.06	4.330E+06	0.721	9.475E+04
	Total P	1071.01	4.330E+06	0.721	2.691E+05
Outer Bay	BAIP	962.16	7.030E+06	0.863	1.927E+05
	Organic P	342.87	7.030E+06	0.863	6.869E+04
	Total P	1836.80	7.030E+06	0.863	3.680E+05

SECTION 6

LONG-TERM MASS BALANCE MODEL OF PHOSPHORUS IN ST. ALBANS BAY AND STEVENS BROOK WETLAND

6.1 Modeling Approach

A variation of the total phosphorus (TP) model of Chapra and Canale (1991) was applied for St. Albans Bay and Stevens Brook Wetland in order to gain a better understanding of phosphorus dynamics and develop a tool for predicting long-term trends in phosphorus concentrations. This portion of the project was divided into four phases - model development and programming; hydrodynamic calibration; model calibration for total phosphorus; and model application.

6.2 Model Development and Programming

Chapra and Canale's (1991) model was chosen for this study because it accounts for the effects of sediment phosphorus recycle on water column concentrations by explicitly modeling phosphorus in the bottom sediments. The processes included in the mass balance equations are: external loading, outflow, settling, recycle and burial. Their model was developed for lakes where spatial gradients in phosphorus levels can be neglected and the water body can be treated as one completely mixed spatial segment. Since this is certainly not the case in St. Albans Bay, modification of the model was necessary. The Wetland and Bay were divided into a total of nine spatial segments, based on observed water quality gradients; the segmentation is shown in Figures 6-1 and 6-2, respectively. Morphometric characteristics of the Wetland were provided by Smeltzer (personal communication, 1992), while those for the Bay were obtained by digitizing a NOAA bathymetric chart and performing calculations with the SURFER software package (Version 4.13, Golden Software). Bottom sediment segments were assumed to have a depth of 0.1 m (10 cm) and a projected surface area equal to that of the overlying water column segment. The morphometry is summarized in Table 6-1.

Application of the model to a multi-segment system requires that terms accounting for inflow from upstream segments and dispersive exchanges with adjacent segments be added to the water column mass balance equation. Accordingly, model equations 6-1 and 6-2 were applied for total phosphorus in the water column and bottom sediments, respectively, of each segment.

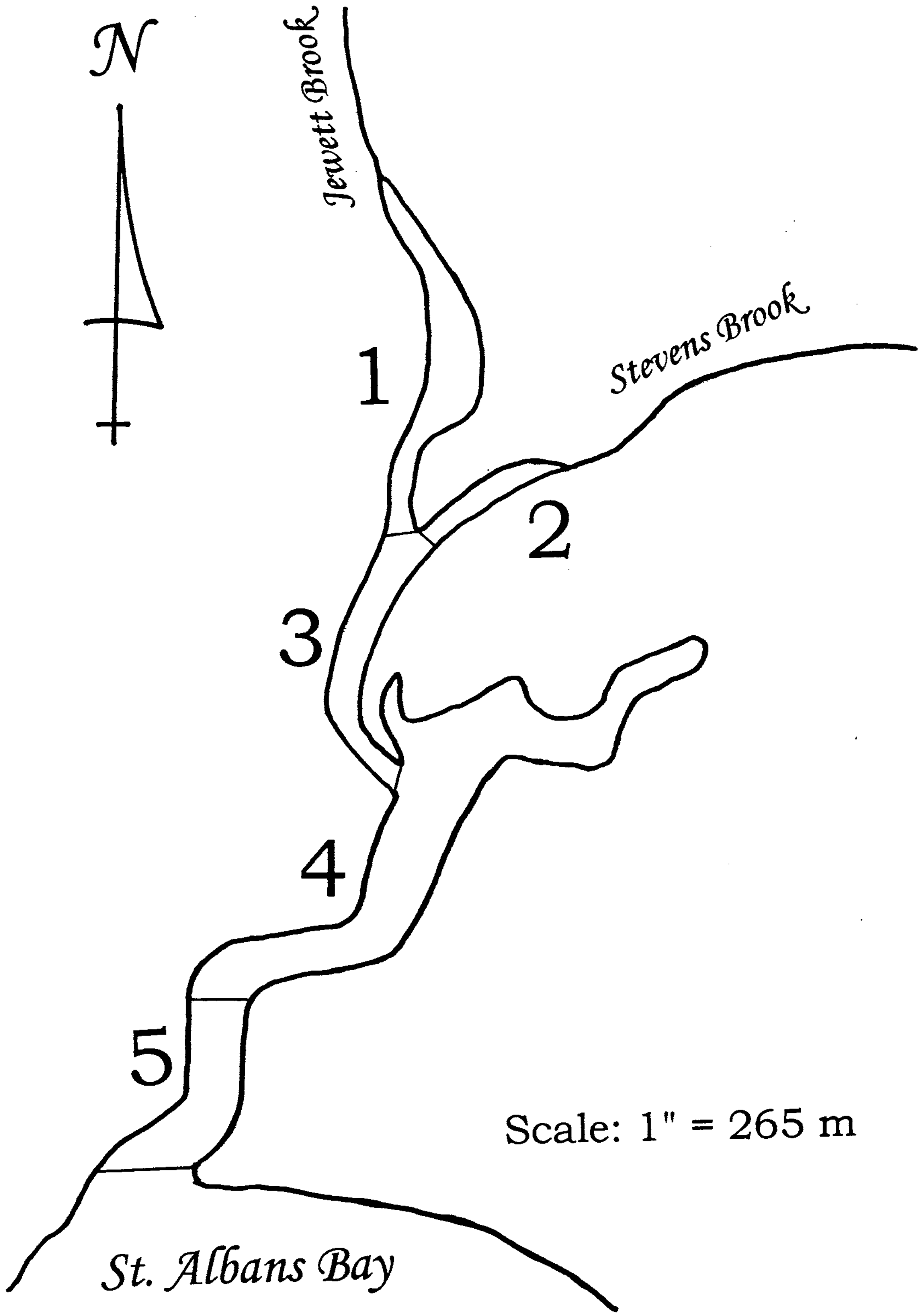

Figure 6-1. Spatial Segmentation for Models of Chloride and Total Phosphorus in Stevens Brook Wetland.

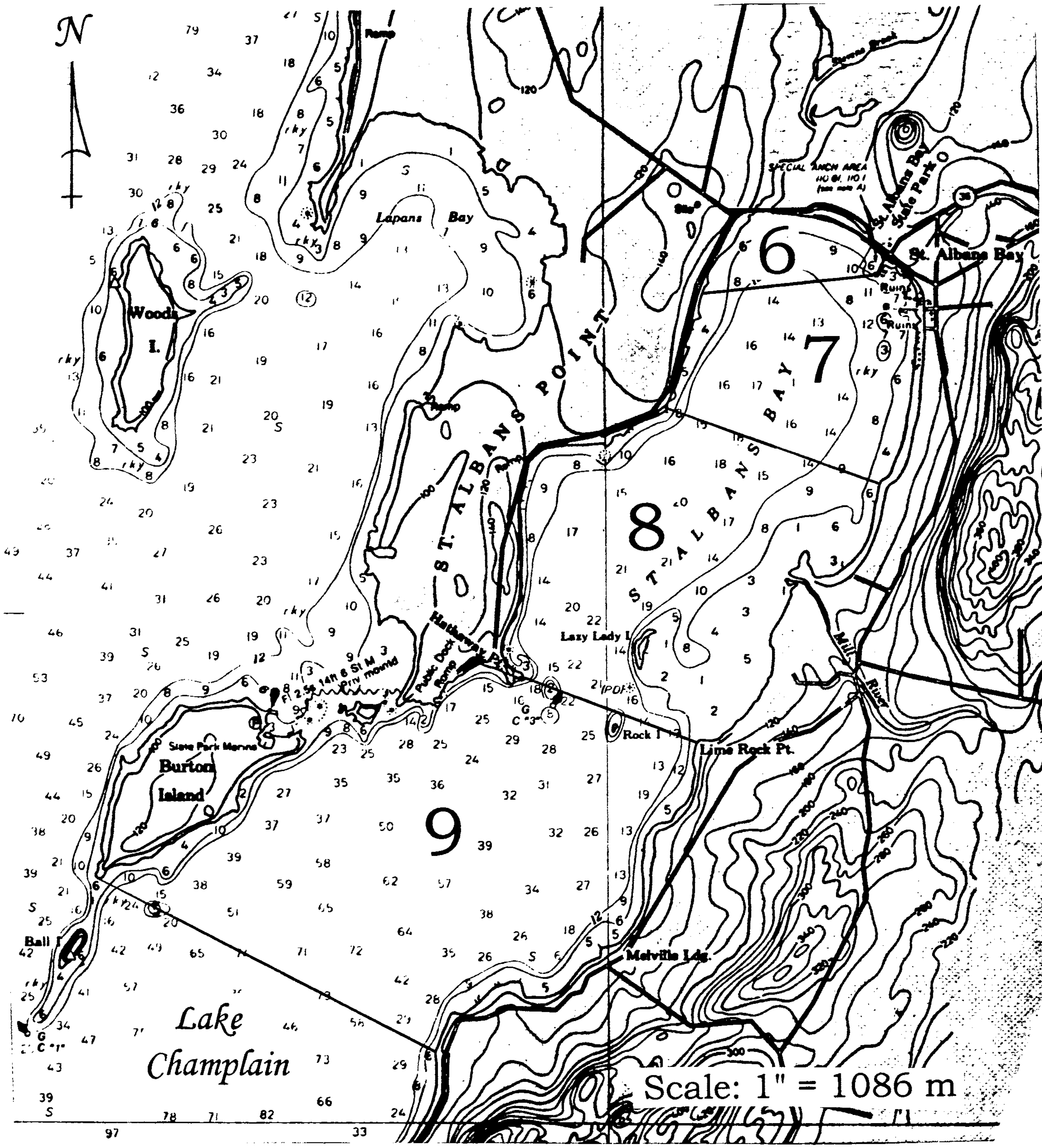

Figure 6-2. Spatial Segmentation for Models of Chloride and Total Phosphorus in St. Albans Bay.

Table 6-1. Morphometry of St. Albans Bay Model Segments.

Segment	Volume (m^3)	Surface Area (m^2)	Mean Depth (m)
1	5.98×10^4	7.48×10^4	0.80
2	9.98×10^3	1.25×10^4	0.80
3	4.00×10^4	5.34×10^4	0.75
4	7.93×10^4	9.32×10^4	0.85
5	4.44×10^4	3.06×10^4	1.45
6	1.21×10^6	6.42×10^5	1.88
7	8.08×10^6	2.46×10^6	3.29
8	1.78×10^7	5.26×10^6	3.38
9	8.28×10^7	8.20×10^6	10.10

TP in Water Column of Segment i:

$$V_{1i}\frac{dP_{1i}}{dt} = W_i + \sum_{j=1}^{m}(Q_{ji}P_{1j}) - (\sum_{j=1}^{m} Q_{ji})P_{1i} + \sum_{k=1}^{n} E_{ik}(P_{1k}-P_{1i}) - v_{si}A_{1i}P_{1i} + v_{ri}A_{2i}P_{2i} \qquad (6\text{-}1)$$

TP in Bottom Sediments Under Segment i:

$$V_{2i}\frac{dP_{2i}}{dt} = v_{si}A_{1i}P_{1i} - v_{ri}A_{2i}P_{2i} - v_{bi}A_{2i}P_{2i} \qquad (6\text{-}2)$$

where:

V_{1i}, V_{2i} = volume of water column segment i and underlying bottom sediment segment, m^3;

P_{1i}, P_{2i} = total phosphorus (TP) conc. in water column segment i and underlying bottom sediment segment, mg/m^3;

W_i = external loading rate of TP to water column seg. i, mg/d;
m = number of upstream segments flowing into segment i;
Q_{ji} = flow from segment j to segment i, m^3/d;
P_{1j} = TP conc. in water column of upstream segment j, mg/m^3;
n = number of segments adjacent to (i.e. sharing a boundary with) segment i;
E_{ik} = exchange (dispersive) flow between segs. i and k, m^3/d;
P_{1k} = TP conc. in adjacent segment k, mg/m^3;
v_{si} = settling velocity of TP in water column of seg. i, m/d;
A_{1i}, A_{2i} = surface area of water column and bottom sediments in segment i, m^2;
v_{ri} = resuspension velocity of bottom sediments in seg. i, m/d;
v_{bi} = burial velocity of bottom sediments in segment i, m/d.

Although sediment focusing can result in $A_2 < A_1$, for this study these areas were both considered equal to the surface area of the water column segment. These coupled differential equations were solved using a fourth-order Runge-Kutta algorithm. The computer program used to read input data, perform calculations and print output files, was written in QuickBASIC (Version 4.5, Microsoft). The model program was named "TPM" (Total Phosphorus Model). A spreadsheet preprocessor was also developed (using Quattro Pro, Version 3.0, Borland International) to construct input data files for the model.

6.3 Hydrodynamic Calibration Using Chloride

The hydrodynamic component(s) of finite-segment water quality models for bays are frequently calibrated using chloride as a conservative tracer (e.g. Richardson, 1974, for Saginaw Bay; Martin et al., 1993, for Green Bay). This approach was taken to estimate the dispersive exchange rate between adjacent segments in the St. Albans Bay/Stevens Brook Wetland system. Chloride was modeled for the years 1983 to 1992. Loading estimates for all years were obtained (for Stevens Brook, Jewett Brook, the St. Albans WWTF, and Mill River) from the product of gaged flow rates and the average of monthly chloride concentrations reported by Smeltzer et al. (1993). These values are summarized in Table 6-2. Trends in the boundary concentration of chloride in Lake Champlain (just outside of St. Albans Bay) were approximated based on Vermont DEC studies in 1982 (Smeltzer, 1983), 1986 and 1988 (Smeltzer, 1991), and 1992 SABDFS data from Stations 10 and 11 (Table 3-6). The boundary concentration ranged from 7.7 mg/L in 1983 to 9.65 mg/L in 1992. Dispersive exchange rates were set initially to the average of monthly values reported by Smeltzer et al. (1993), and then adjusted to provide the best possible fit to 1992 SABDFS data (Table 3-6).

Table 6-2. Estimated Chloride Loadings to St. Albans Bay, 1983-1992.

Assumed Chloride Concs.: (Based on SABDFS Data)		
Jewett:	30	mg/L
Stevens:	90	mg/L
Mill:	35	mg/L
WWTF:	80	mg/L

	Jewett	Brook	Stevens	Brook	Mill	River	WWTF	
Year	Flow cu m/d	Load kg/d	Flow cu m/d	Load kg/d	Flow cu m/d	Load kg/d	Flow cu m/d	Load kg/d
1983	33652	1009.6	37061	3335.5	126747	4436.1	6684	534.7
1984	27123	813.7	30634	2757.1	169274	5924.6	6368	509.4
1985	10014	300.4	11534	1038.1	63155	2210.4	6498	519.8
1986	11177	335.3	30946	2785.1	161477	5651.7	6293	503.4
1987	14012	420.4	14859	1337.3	61839	2164.4	8403	672.2
1988	5239	157.2	13329	1199.6	45214	1582.5	8518	681.4
1989	9910	297.3	20224	1820.2	79937	2797.8	10428	834.2
1990	17391	521.7	33793	3041.4	227270	7954.5	13401	1072.1
1991	16643	499.3	25518	2296.6	116042	4061.5	8425	674.0
1992	17500	525.0	16500	1485.0	48700	1704.5	6500	520.0

The chloride profile predicted by the calibrated model is compared with the measured concentrations in Figure 6-3. Agreement is excellent in the lower reaches of the Wetland and in the Bay (Segments 4-9), where dispersion is very active. Here the predicted concentrations are heavily influenced by the boundary concentration in Lake Champlain. In the upper reaches of the Wetland (Sections 1-3), predicted chloride levels were slightly low. Since the hydrodynamics of these sections are dominated by advection, the only possible explanation for this discrepancy is uncertainty in the estimates of chloride loading. The calibrated dispersive exchange rates between adjacent segments are as follows:

1-3: 1.000×10^4 m^3/d
2-3: 0.0 m^3/d
3-4: 1.000×10^5 m^3/d
4-5: 1.000×10^4 m^3/d
5-6: 3.000×10^4 m^3/d
6-7: 4.000×10^5 m^3/d
7-8: 2.880×10^6 m^3/d
8-9: 6.480×10^6 m^3/d
9-Lake: 1.742×10^7 m^3/d

Segments 3 and 4 were effectively treated as one segment by setting the dispersion rate between them at a relatively high value.

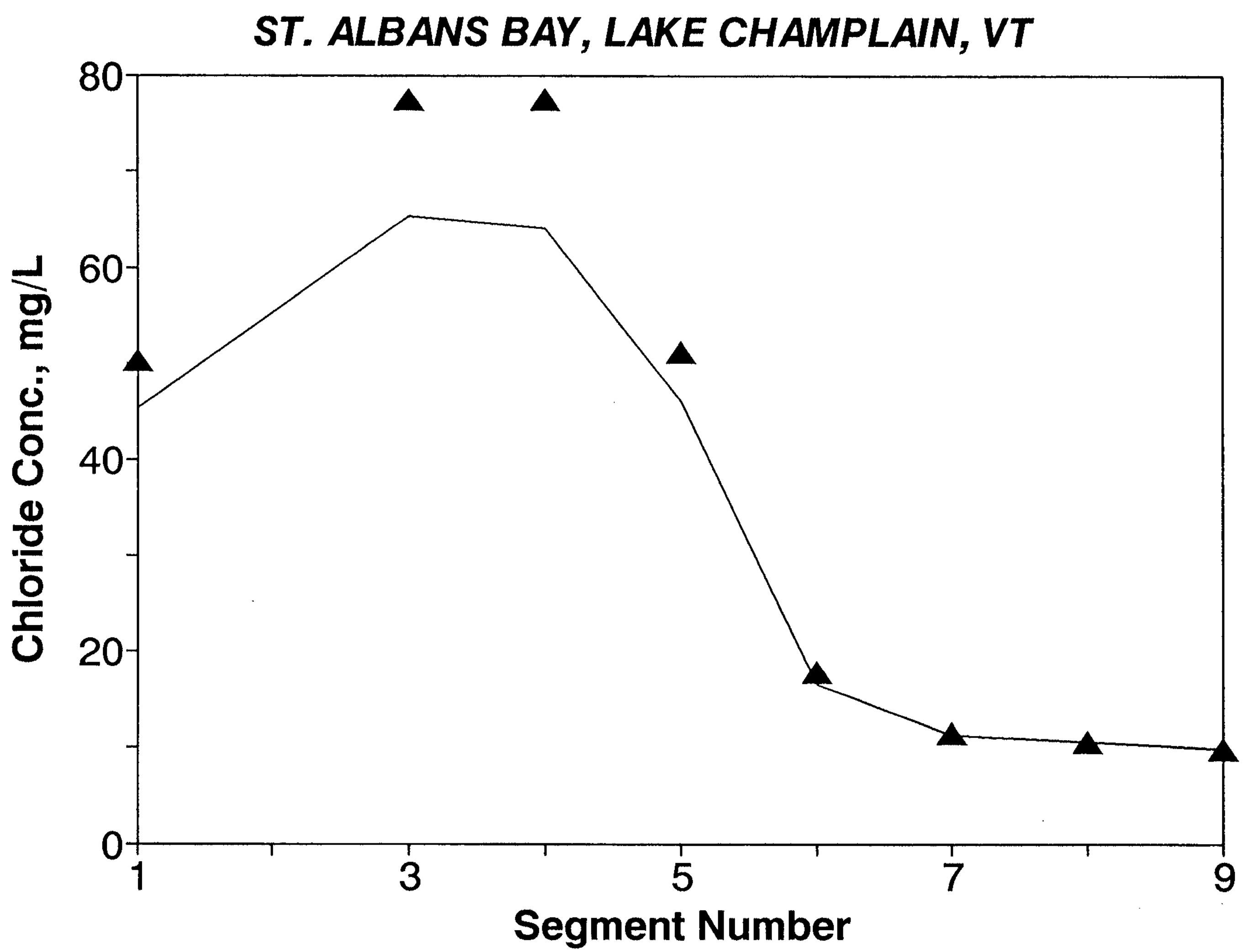

Figure 6-3. Comparison of Calibrated Model Predictions for Cloride and Average Measured Concentrations in All Segments (from 1992 SABDFS).

6.4 Calibration of Total Phosphorus Model

The total phosphorus model was calibrated by applying it for the 93 year period from 1900 to 1992. It is necessary to use a long time period for calibration in order to properly simulate the historical buildup of phosphorus in the bottom sediments. The parameters required as model input are: initial conditions; boundary concentrations in Lake Champlain; inflows and total phosphorus loadings from tributaries and point sources; and kinetic coefficients (settling, resuspension, and burial rates). The model was calibrated by adjusting the kinetic coefficients within reasonable ranges (based on Bowie et al., 1985) to obtain agreement between the model predictions and available data on water column and bottom sediment phosphorus data.

6.4.1 Initial Conditions

Obviously, no phosphorus measurements are available from the early 1900s. However, Hyde et al. (1993) have estimated that, by this time, both point and nonpoint source phosphorus loadings to the Bay/Wetland system had already increased significantly over undeveloped background conditions. It was assumed that water column phosphorus concentrations in the year 1900 were 50-60% lower than measured 1992 levels (Table 3-6) in the Wetland and 30-40% lower in the Bay. The one exception to this is Segment 2 (Stevens Brook), where the TP concentration 1900 was assumed to be 35-40% greater than in 1992 due to greater point source loading from the St. Albans WWTF. Initial TP levels in the bottom sediments were assumed to be about 50% less than measured 1992 concentrations (Table 5-2). The Bay values are comparable to those reported by Corliss and Hunt (1973) for Lapan Bay. The initial conditions applied at the start of the simulation period are summarized in Table 6-3.

6.4.2 Boundary Conditions in Lake Champlain

Boundary conditions for total phosphorus in Lake Champlain were based on data collected at Vermont Lay Monitoring Program station #16 from 1979 to 1991 (Table 3-4). Concentrations were assumed to increase linearly from 10.0 mg/m^3 in 1900 to 18.5 mg/m^3 in 1985, then decrease linearly to 13.5 mg/m^3 in 1990 and remain constant after that.

6.4.3 Tributary and WWTF Flows

Flow rates for Jewett Brook, Stevens Brook, Mill River, and the City of St. Albans WWTF were gaged from 1982 to 1990 as part of the Rural Clean Water Program (RCWP). Intermittent gaging has continued to the present day; Smeltzer et al. (1993) reported flows for 1992. The mean flows from these studies are listed in Table 6-4. For the tributaries, measured flows were used as model input when available, and the nine-year RCWP means were used for all other years. WWTF flows were assumed to increase linearly from zero in 1900 to the RCWP mean of 8425 m^3/d in 1930, and then remain constant until 1982. After 1982, measured flows were used, except for 1991 when the RCWP average was used.

Table 6-3. Initial Conditions Used for Total Phosphorus Model Calibration.

Segment No.	Initial TP Water Column (mg/m^3)	Initial TP Bottom Sediments (mg/m^3)
1	300	6.4 X 10^5
2	400	6.4 X 10^5
3	120	6.4 X 10^5
4	100	6.4 X 10^5
5	50	6.4 X 10^5
6	25	3.2 X 10^5
7	20	3.2 X 10^5
8	15	3.6 X 10^5
9	10	2.8 X 10^5

6.4.4 Total Phosphorus Loading Rates

Total phosphorus loadings for the period 1900-1981 were taken from Hyde et al. (1993) (Table A-2). Loading inputs were kept constant for each decade during this period. For 1982-1989, loading estimates from the Rural Clean Water Program (Table 3-3) were used. Combining the information in Tables 3-3 (TP loads) and 6-4 (flows), the yearly flow-weighted average total phosphorus concentrations were calculated for each source. The results are presented in Table 6-5. To estimate tributary loadings for 1990, the gaged flow rates were multiplied by the eight-year mean TP concentrations from the RCWP. WWTF loading rate was estimated from the product of gaged flow and the two-year (1988-89) post-upgrade mean TP concentration. For 1991, loading rates were obtained by multiplying the mean RCWP flows (Table 6-4) by the appropriate mean RCWP TP concentrations (from Table 6-5). Loading rates for 1992 were taken from Smeltzer et al. (1993). The TP loading rates used for 1990-1992 are summarized in Table 6-6.

6.4.5 Calibration Data

Total phosphorus data for St. Albans Bay are available from various studies performed over the past 15 years. These were described earlier in Section 3.4 (Tables 3-4 through 3-6 and Figures 3-1 through 3-7). The sampling stations located within the various spatial segments used in this modeling study are listed below:

Table 6-4. Measured Inflows to St. Albans Bay, from Rural Clean Water Program (Meals, Personal Communication, 1992) and Smeltzer (1993).

Year	Jewett Brook m^3/d	Stevens Brook m^3/d	Mill River m^3/d	St. Albans WWTF m^3/d
1982	21266	37284	109464	9234
1983	33652	37061	126747	6684
1984	27123	30634	169274	6368
1985	10014	11534	63155	6498
1986	11177	30946	161477	6293
1987	14012	14859	61839	8403
1988	5239	13329	45214	8518
1989	9910	20224	79937	10428
1990	17391	33793	227270	13401
Mean	16643	25518	116042	8425
1992	17500	16500	48700	6500

Segment 1: SABDFS-16
Segment 2: SABDFS-17
Segment 3: SABDFS-15
Segment 4: SABDFS-14
Segment 5: SABDFS-13
Segment 6: RCWP-14; RCWP-12; SABDFS-1; SABDFS-2
Segment 7: LCDFS-41; SABDFS-3; SABDFS-4
Segment 8: LCDFS-40; SABDFS-5; SABDFS-6; SABDFS-7
Segment 9: RCWP-11; LCDFS-37; SABDFS-8; SABDFS-9

Where two or more stations from a particular study were located within a given spatial segment, the mean annual measured concentrations were averaged for comparison with model predictions. A summary of all water column data used for calibration is presented in Table 6-7. Lay Monitoring Program data was not used since sampling was conducted only during the summer months.

To calibrate the model for total phosphorus in the bottom sediments, 1982 data from Ackerly (1993) and 1992 data from this study were used. Measured concentrations in $\mu g/g$ (or mg/kg) were converted to mg/m^3 by equation 6-3.

Table 6-5. Yearly Flow-Weighted Average Total Phosphorus Concentrations in St. Albans Bay Inflows, from Rural Clean Water Program Data.

Year	Flow-Weighted Average TP (mg/m^3)			
	Jewett	Stevens	Mill	WWTF
1982	1378.5	536.6	320.8	6385.5
1983	714.1	591.0	144.9	5011.7
1984	1075.6	706.4	481.9	4442.7
1985	1099.1	705.9	238.2	5064.3
1986	924.1	926.8	641.6	4212.6
1987	1254.7	640.7	368.0	1876.3
1988	1166.2	712.0	274.9	436.8
1989	1608.4	570.2	339.2	393.3
Mean	1153.0	674.0	340.0	3478.0

Table 6-6. Phosphorus Loading Estimates for 1990-1992 Used in Model Calibration.

Year	Estimated TP Loading Rate (kg/d)			
	Jewett	Stevens	Mill	WWTF
1990	20.05	22.77	77.28	5.56
1991	19.19	17.20	39.44	3.50
1992	6.70	2.00	8.40	3.30

$$C_s = P(1-\phi)\,X\,2600 \qquad \text{(6-3)}$$

where:

C_s = volumetric TP concentration in bottom sediments, mg/m^3;
P = measured TP concentration in bottom sediments, mg/kg;
ϕ = porosity of bottom sediments;
2600 = assumed denstiy of solid matter in bottom sediments, kg/m^3.

Table 6-7. Mean Total Phosphorus Concentrations Used for Model Calibration.

Data Source	Year	Annual Mean TP Concentration (mg/m^3)			
		Segment 6	Segment 7	Segment 8	Segment 9
RCWP	1981	95.1			21.1
	1982	115.1			26.1
	1983	70.4			22.9
	1984	93.7			45.7
	1985	143.9			45.0
	1986	103.1			42.2
	1987	104.6			75.9
	1988	80.6			72.8
	1989	76.0			40.0
	1990	113.1			56.8
LCDFS	1990		25.8	24.7	14.6
	1991		25.4	20.6	16.0
SABDFS	1992	68.6	30.5	22.2	15.9

The data from all sediment cores taken in each spatial segment were averaged; a summary is presented in Table 6-8.

6.4.6 Discrepancies Between Data Sets

There appear to be some serious discrepancies between the data collected by the Rural Clean Water Program (RCWP) and that collected by the Lake Champlain and St. Albans Bay Diagnostic Feasibility Studies (LCDFS and SABDFS, respectively). For example, total phosphorus levels reported at RCWP-11 for 1990 are more than twice those reported at LCDFS-40, even when samples were collected on the same date. Since RCWP-11 is further from the mouth of Stevens Brook, the TP concentrations should actually be **less than** those measured at LCDFS-40. This could be partly attributed to differences in the sampling methods. However, there are also dramatic differences in the estimates of nonpoint source loadings from the tributaries. Estimates of the total nonpoint loading via Jewett and Stevens Brooks and Mill River for 1991 (LCDFS; Smeltzer, personal communication, 1993) and 1992 (SABDFS; Smeltzer et al., 1993) are only about 24% of the eight-year (1982-89) mean RCWP estimates. The combined 1992 loading estimate for these

Table 6-8. Calibration Data for Total Phosphorus in Bottom Sediments of St. Albans Bay and Stevens Brook Wetland.

Segment No.	Bottom Sediment TP Concentration (mg/m^3)	
	1982 (Ackerly, 1983)	1992 (this study)
1	1.316×10^6	1.026×10^6
2	1.104×10^6	0.880×10^6
3	No data	0.971×10^6
4	1.699×10^6	1.171×10^6
5	1.236×10^6	1.129×10^6
6	0.987×10^6	0.760×10^6
7	0.494×10^6	0.520×10^6
8	0.786×10^6	0.621×10^6
9	0.635×10^6	0.404×10^6

three tributaries is about 40% less than the lowest yearly estimate (for 1988) obtained by the RCWP. Possible explanations for the differences in loading estimates include:

1) Real reductions in nonpoint source loads;
2) Natural year-to-year variability in loadings;
3) Differences in sampling methods;
4) Differences in temporal coverage of the sampling programs;
5) Differences in approaches to loading computations; and
6) Analytical or sampling errors.

During the RCWP, an effort was made to reduce the spreading of manure on frozen ground within the St. Albans Bay watershed. This was designed to minimize the export of nutrients, bacteria, and organic matter to the Bay with spring runoff. If manure runoff were a major contributor to the annual phosphorus loading, one would expect extremely high TP levels in the tributaries and inner Bay during the spring months. However, Figure 3-5 shows that measured TP was relatively low in March-May during the RCWP years. So, changes in manure application practices most likely have not brought about substantial reductions in phosphorus loadings. Year-to-year variability in nonpoint phosphorus loadings typically parallel differences in rainfall and runoff. Loadings are generally high during wet years and low during dry years, as shown in Figure 6-4. Annual average tributary flow estimates for 1992 were below the RCWP means in Stevens Brook and Mill River, but above the RCWP mean in Jewett Brook. Estimated 1992 flows were above the 1988 RCWP low flows in all tributaries. Thus, the discrepancy in loadings cannot be attributed to unusual climatic conditions.

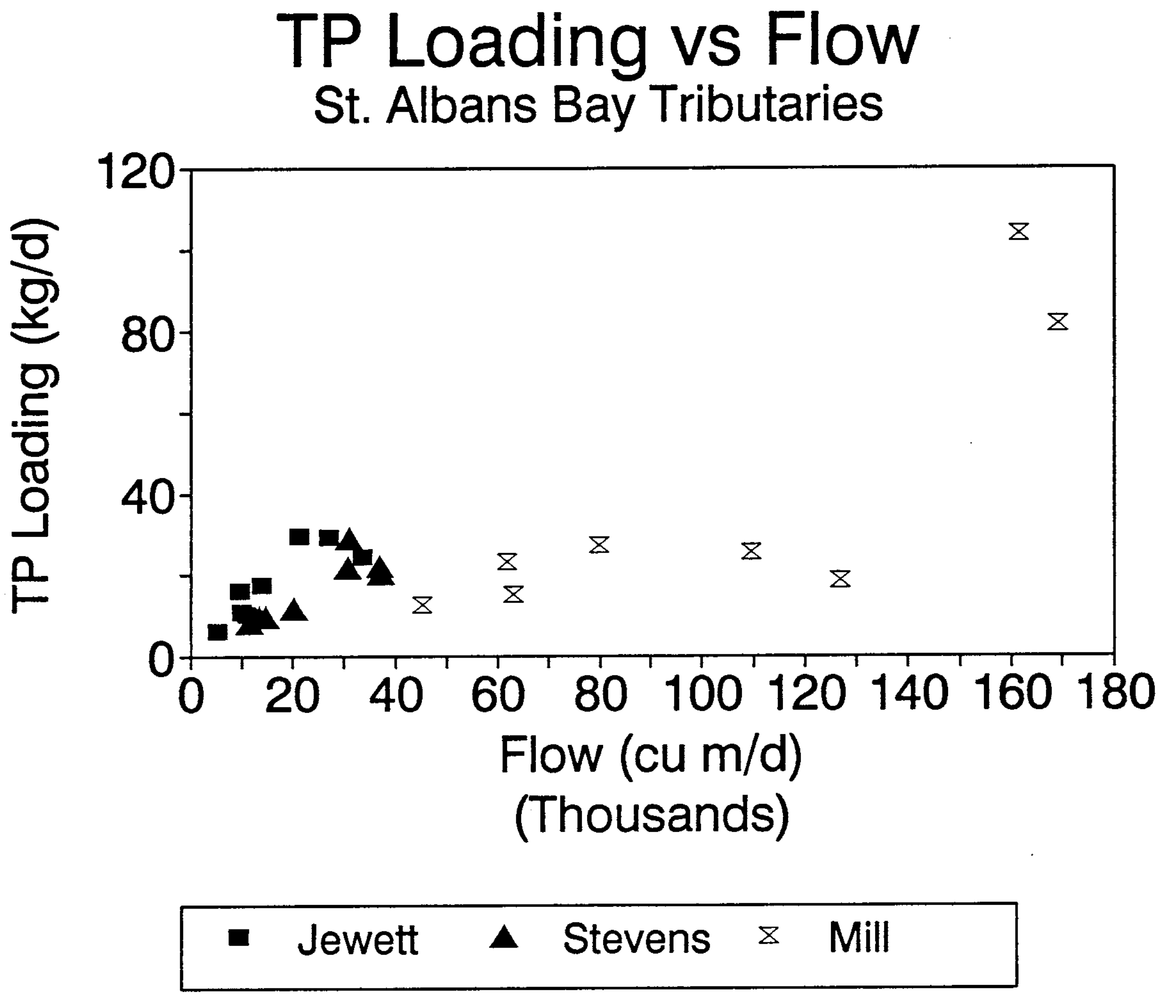

Figure 6-4. **Annual Average Total Phosphorus Loading Rates Versus Flow for Tributaries to St. Albans Bay.**

It seems unlikely that any significant analytical bias could occur in any of the studies cited, since they all were subject to strict QA/QC requirements. However, it is possible that sampling protocols yielded samples that do not accurately represent ambient water quality conditions. This is certainly the case for RCWP data on TP in St. Albans Bay. Annual average TP levels reported at Station 11 in the outer Bay (see Table 6-7) are often extremely high (mean 1987 and 1988 concentrations exceed 70 mg/m^3), and cannot possibly be representative of the entire water column. For tributary sampling, the RCWP used a fixed intake in the center of the stream channel, while the 1992 SABDFS used vertically-integrating samplers. The latter approach is certainly superior. However, the RCWP approach should have yielded reasonably representative samples as long as the intake was properly maintained and was not located too close to the bottom of the channel.

The RCWP monitoring program was much more intensive temporally than more recent studies. Samples were collected continuously (every 8 hours) with an automatic sampler (ISCO Model 1680), and three composite samples (two 48-hour and one 72-hour composites) were analyzed each week throughout the year (RCWP, 1991). For the LCDFS and SABDFS, regressions of TP concentration versus flow were used to estimate loadings for dates when measured concentrations were not available. Use of such regression equations usually results in a significant level of uncertainty in loading estimates.

In summary, SABDFS and LCDFS data on TP in St. Albans Bay is probably more reliable than RCWP data. However, with the information available, it is not possible to identify inaccuracies in the TP loading estimates with any degree of certainty.

6.4.7 Results of Model Calibration

To begin the model calibration process, values of the settling, resuspension, and burial velocities were set to those used by Chapra and Canale (1991) for Shagawa Lake. These were then adjusted to obtain reasonable agreement between model predictions and measured TP concentrations in both the water column and bottom sediments of the Bay and Wetland. The model's numerical algorithm was run with a time step of 0.5 days. Tests showed that the solution was numerically stable, and produced exactly the same results as runs with shorter time steps (0.2 and 0.1 days). The 93-year (1900-1992) simulation results are shown for the Stevens Brook Wetland (Segments 1-5) water column in Figure 6-5. An expanded view of the model output for 1980-1992 is shown in Figure 6-6. Results are shown for the St. Albans Bay (Segments 6-9) water column in Figure 6-7, while those for the Wetland and Bay bottom sediments are presented in Figures 6-8 and 6-9, respectively. The calibrated model output is compared with mean annual measured concentrations in the St. Albans Bay water column in Figures 6-10 (Segment 6), 6-11 (Segment 8), and 6-12 (Segment 9). The simulation results deviate considerably from the RCWP data from the 1980's, but agree well with the LCDFS and SABDFS data for 1990-1992.

A profile plot comparing the 1992 model predictions with SABDFS data for all nine segments is shown in Figure 6-13. Agreement is excellent except in Segment 1. The mean TP concentration measured at SABDFS Station 16 (in Segment 1) was considerably higher than at Station JEWE02 (in Jewett Brook) because sampling at the latter location was

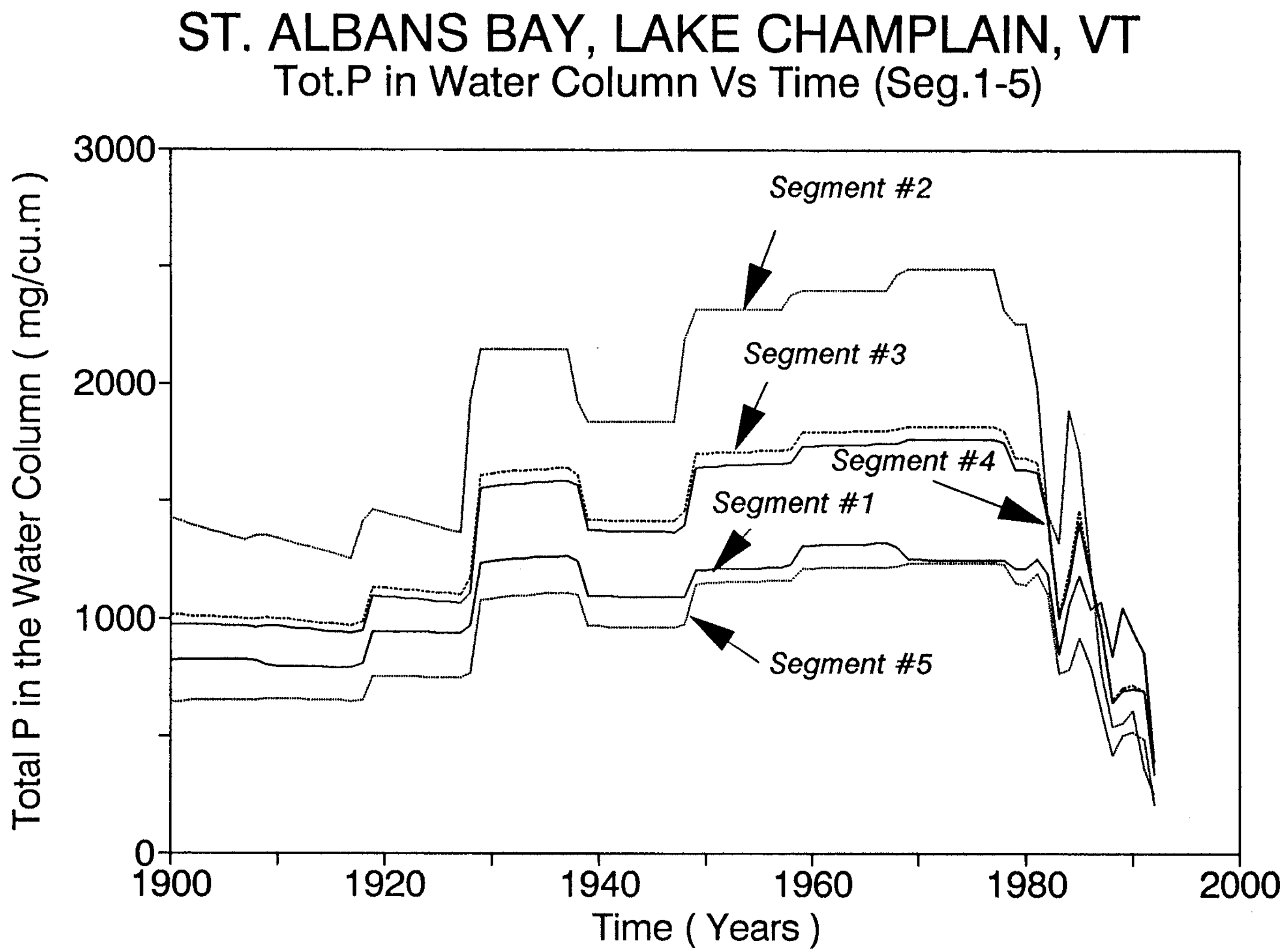

Figure 6-5. **Calibrated Model Simulation Results for Total Phosphorus in Water Column Segments of Stevens Brook Wetland, 1900-1992.**

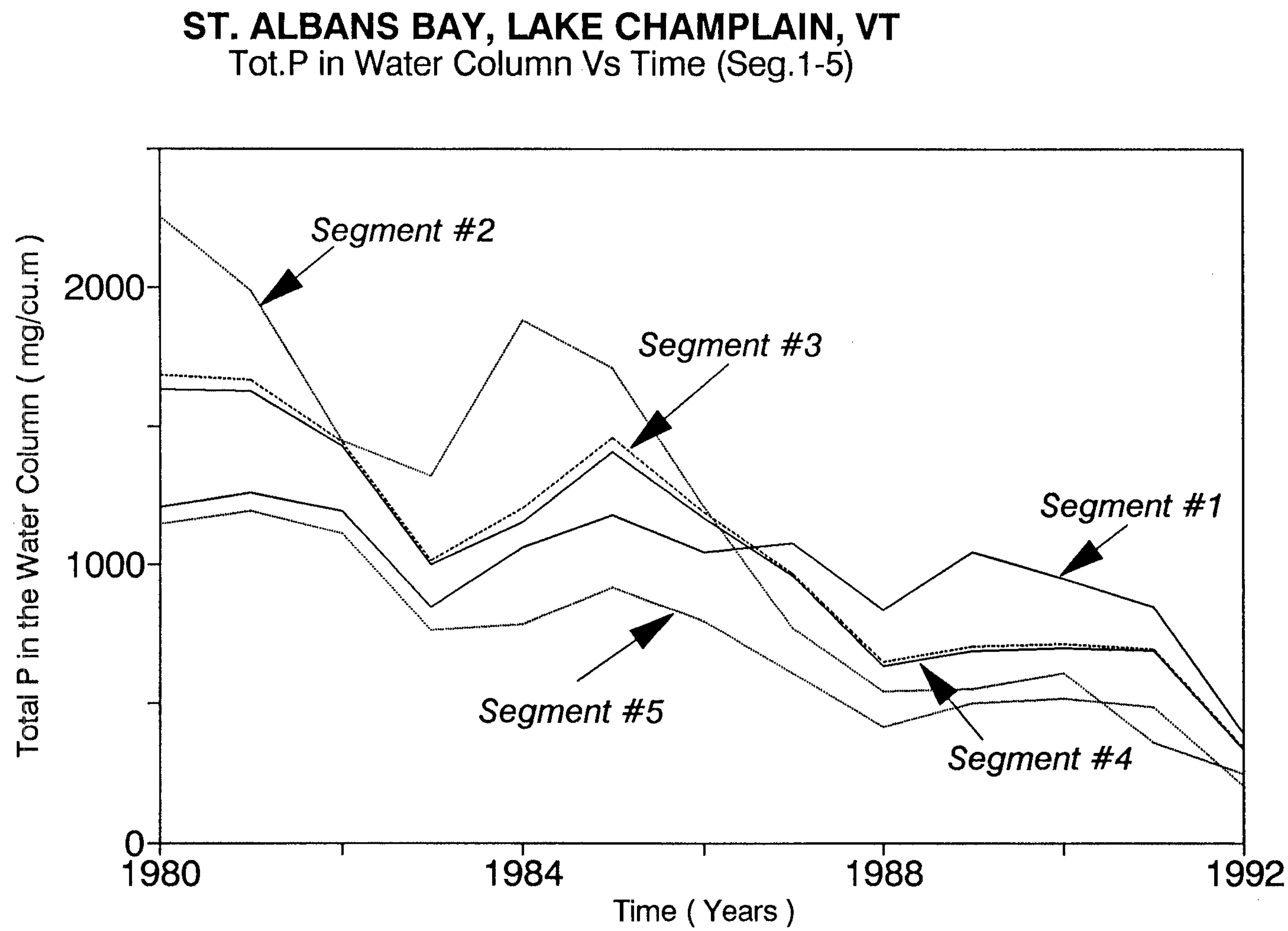

Figure 6-6. **Expanded View of Calibrated Model Simulation Results for Total Phosphorus in Water Column Segments of Stevens Brook Wetland, 1980-1992.**

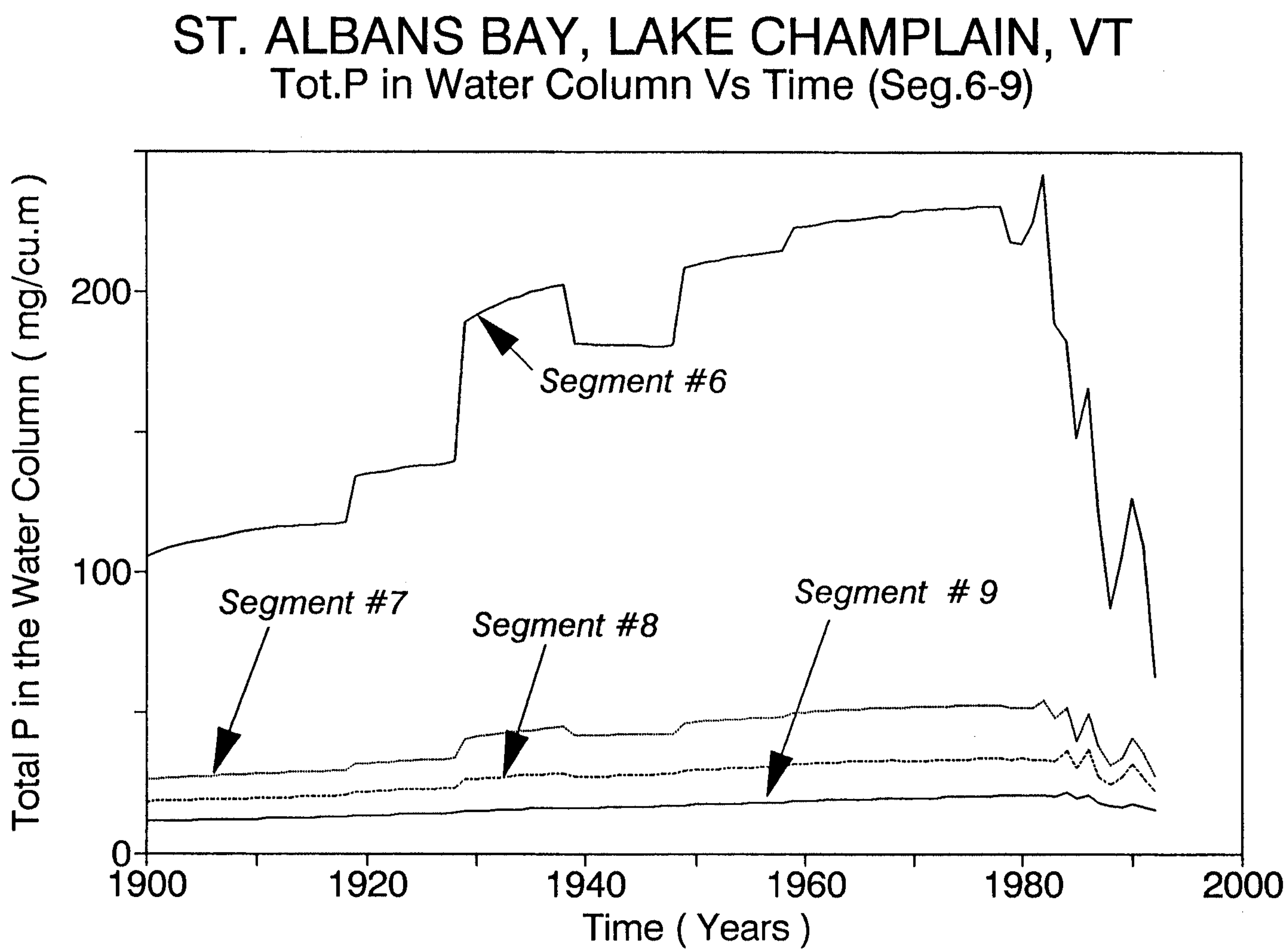

Figure 6-7. **Calibrated Model Simulation Results for Total Phosphorus in Water Column Segments of St. Albans Bay, 1900-1992.**

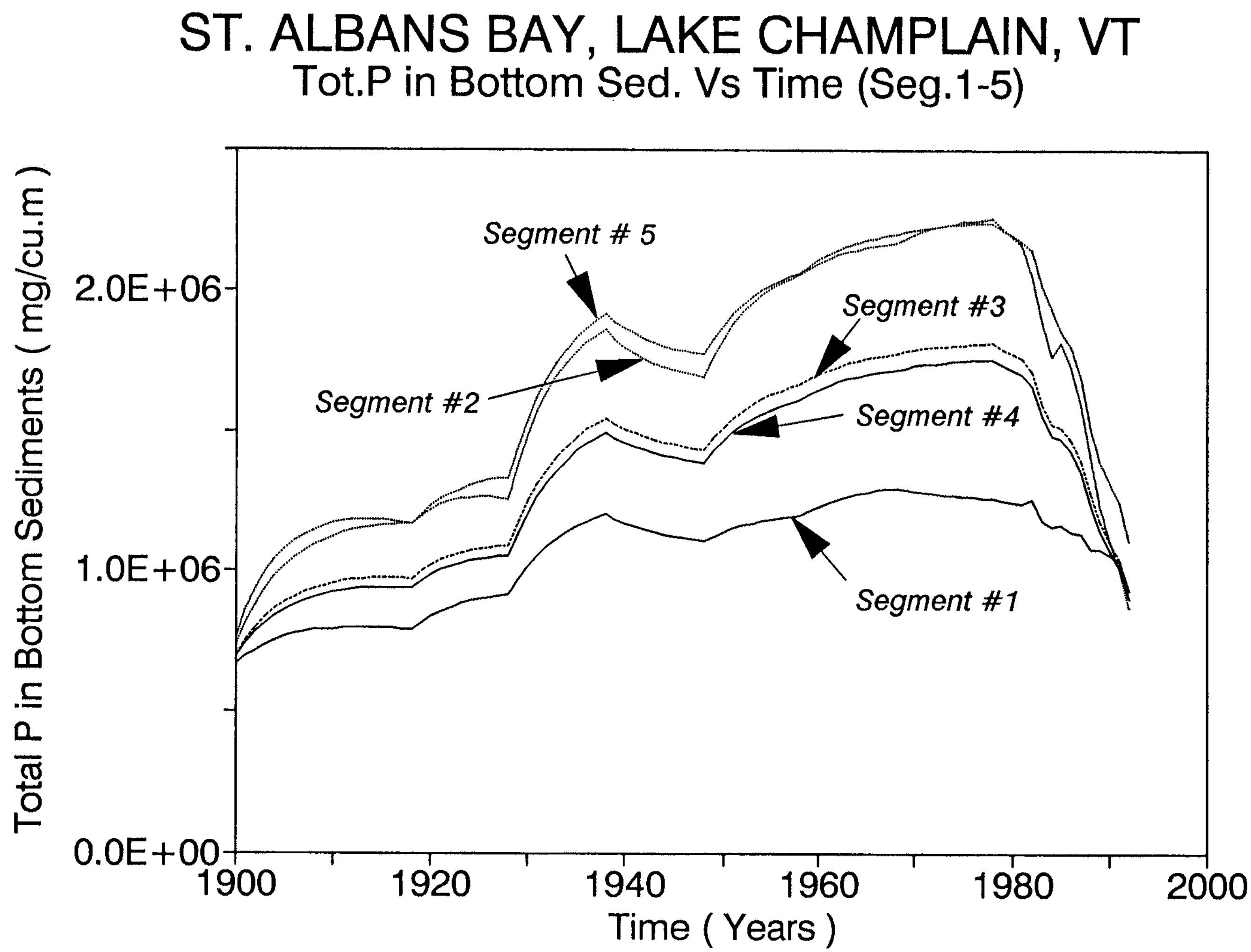

Figure 6-8. Calibrated Model Simulation Results for Total Phosphorus in Bottom Sediment Segments of Stevens Brook Wetland, 1900-1992.

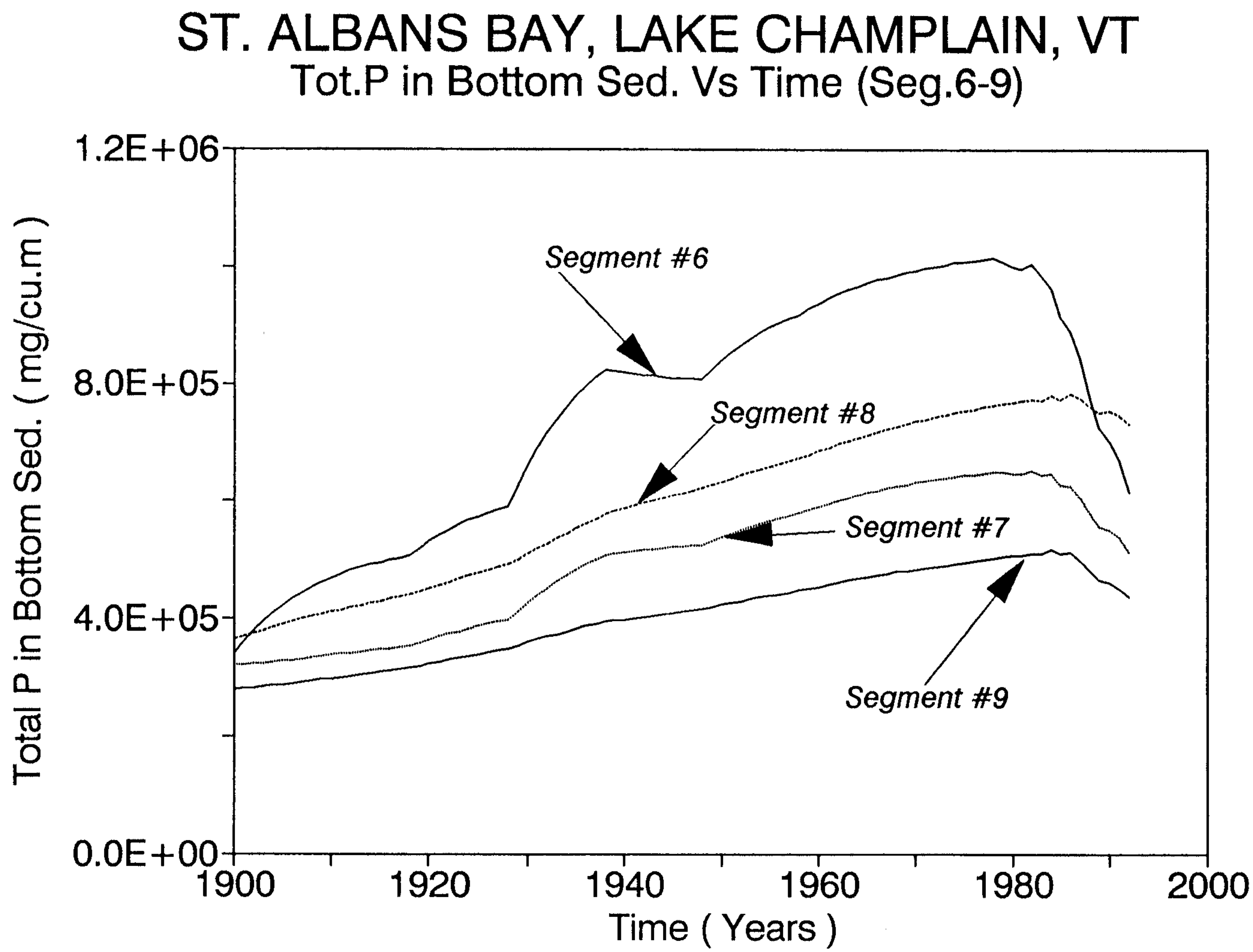

Figure 6-9. **Calibrated Model Simulation Results for Total Phosphorus in Bottom Sediment Segments of St. Albans Bay, 1900-1992.**

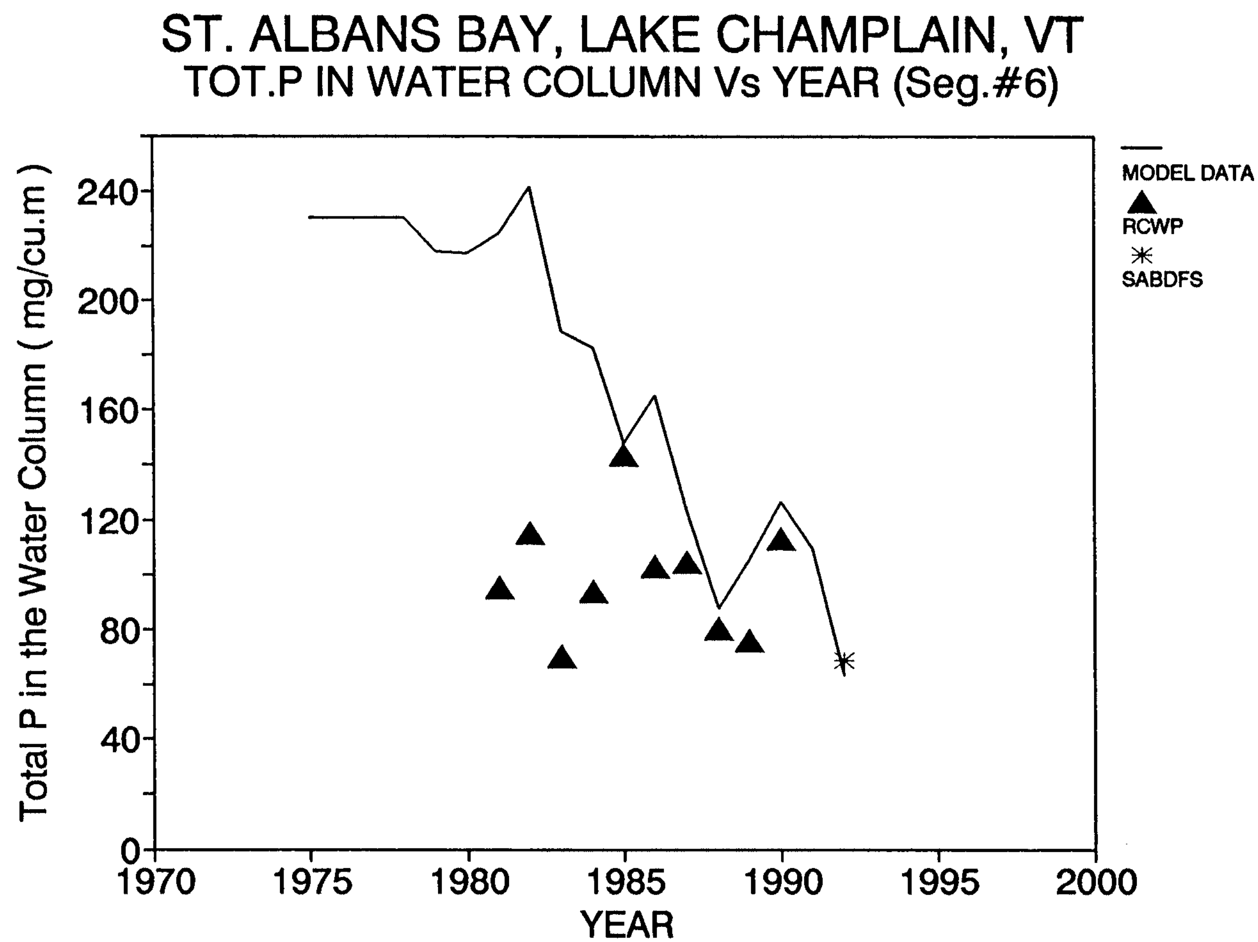

Figure 6-10. Comparison of Calibrated Model Simulation Results for Total Phosphorus with Mean Annual Measured Concentrations in the Water Column of Inner St. Albans Bay (Segment 6).

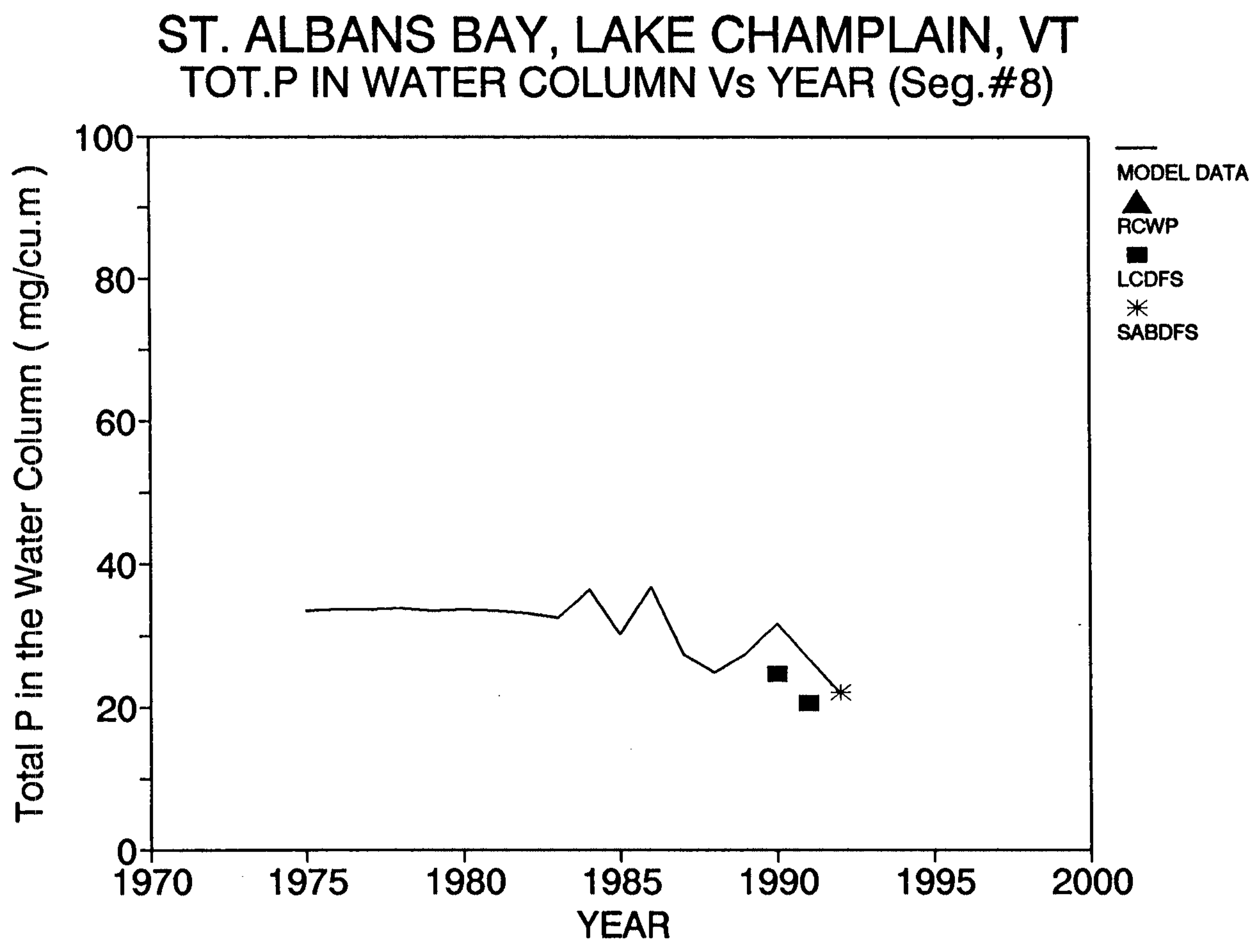

Figure 6-11. **Comparison of Calibrated Model Simulation Results for Total Phosphorus with Mean Annual Measured Concentrations in the Water Column of Middle St. Albans Bay (Segment 8).**

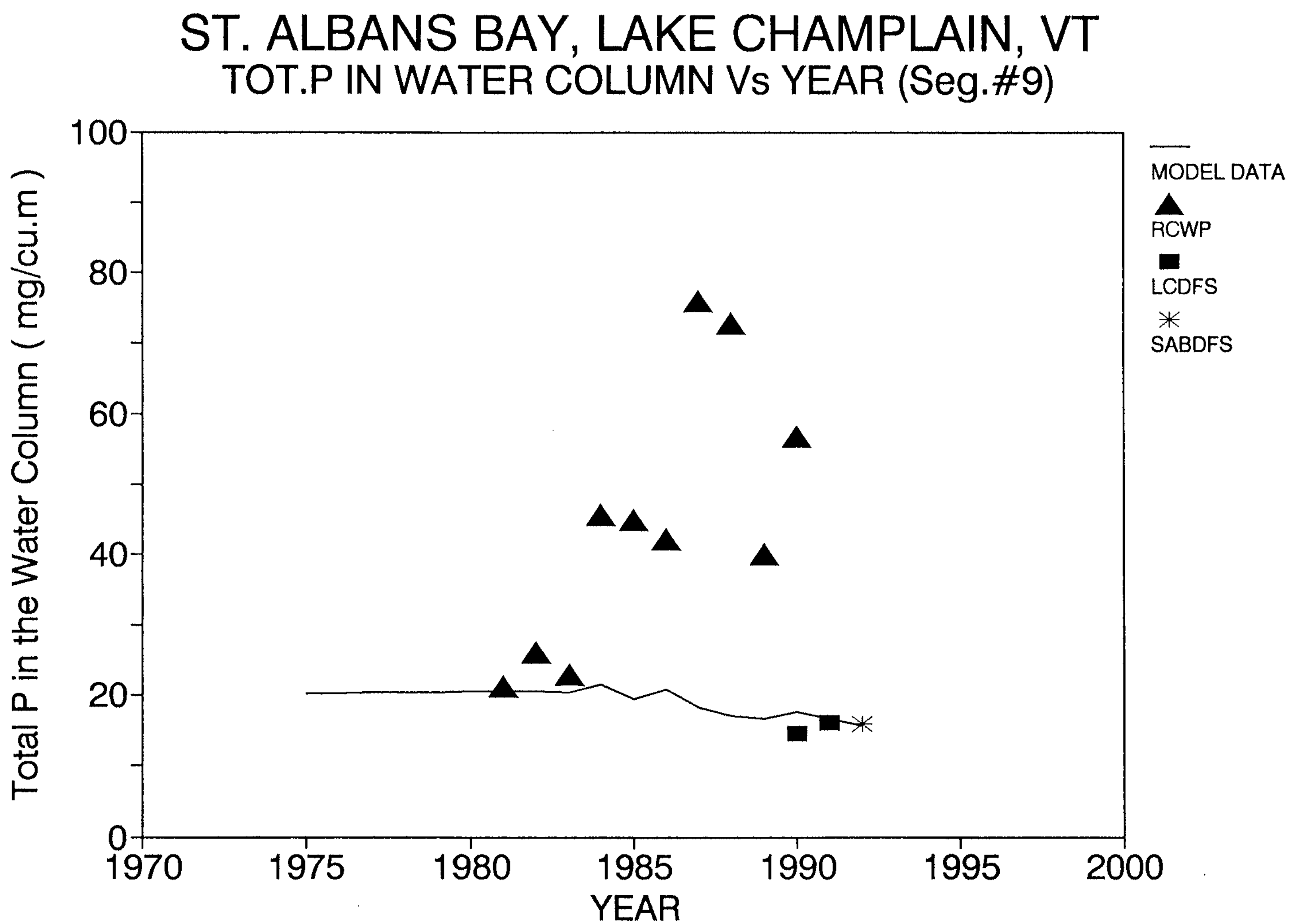

Figure 6-12. **Comparison of Calibrated Model Simulation Results for Total Phosphorus with Mean Annual Measured Concentrations in the Water Column of Outer St. Albans Bay (Segment 9).**

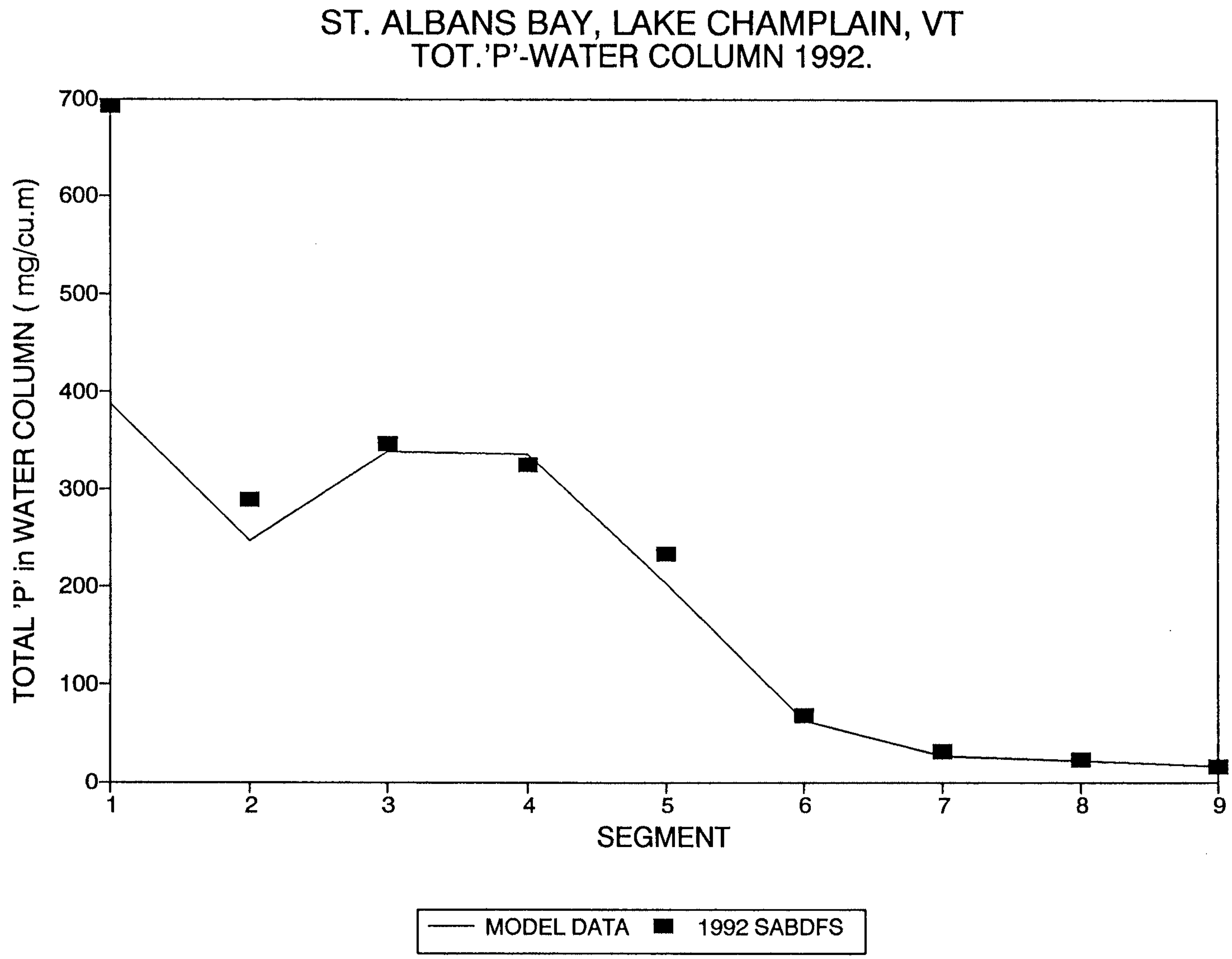

Figure 6-13. Comparison of Calibrated Model Predictions for Total Phosphorus and Average Measured Concentrations in All Water Column Segments (from 1992 SABDFS).

discontinued when the Brook ran dry, but sampling at Station 16 was not. Concentrations at Station 16 increased substantially when Jewett Brook flows approached zero. The calibration data reflects the influence of several samples collected during this period. Since the model simulates annual average conditions, it was not able to reproduce this seasonal phenomenon. However, the ability to accurately model downstream segments was not adversely affected. Profile plots comparing simulated and measured bottom sediment TP levels in all segments for 1982 and 1992 are presented in Figure 6-14. The predicted concentrations show close agreement with all 1992 data, and with the 1982 data in St. Albans Bay. Agreement is not as good with 1982 data for the Wetland. However, Ackerly (1983) only analyzed four sediment cores from the Wetland. The measured sediment TP values in Segments 1, 2, 4, and 5 appear highly variable since each solid triangle represents data from only one core.

Overall, the calibrated model simulates the phosphorus dynamics within the Bay/Wetland system with reasonable accuracy. The calibrated values of the kinetic coefficients are listed in Table 6-9.

Table 6-9. Calibrated Values of Kinetic Coefficients for Model of Total Phosphorus in St. Albans Bay and Stevens Brook Wetland.

Segment	Settling (m/d)	Resuspension (m/d)	Burial (m/d)
1	0.05	3.0×10^{-5}	2.0×10^{-5}
2	0.05	3.0×10^{-5}	2.5×10^{-5}
3	0.05	3.0×10^{-5}	2.0×10^{-5}
4	0.05	3.0×10^{-5}	2.0×10^{-5}
5	0.10	3.0×10^{-5}	2.5×10^{-5}
6	0.20	3.0×10^{-5}	1.5×10^{-5}
7	0.50	2.5×10^{-5}	1.5×10^{-5}
8	0.50	2.0×10^{-5}	1.0×10^{-6}
9	2.00	7.0×10^{-5}	1.0×10^{-5}

6.4.8 Effect of Reductions in WWTF Phosphorus Load

A review of previous studies on phosphorus loading to St. Albans Bay leads one to the conclusion that reductions in point source TP loading from the City of St. Albans WWTF

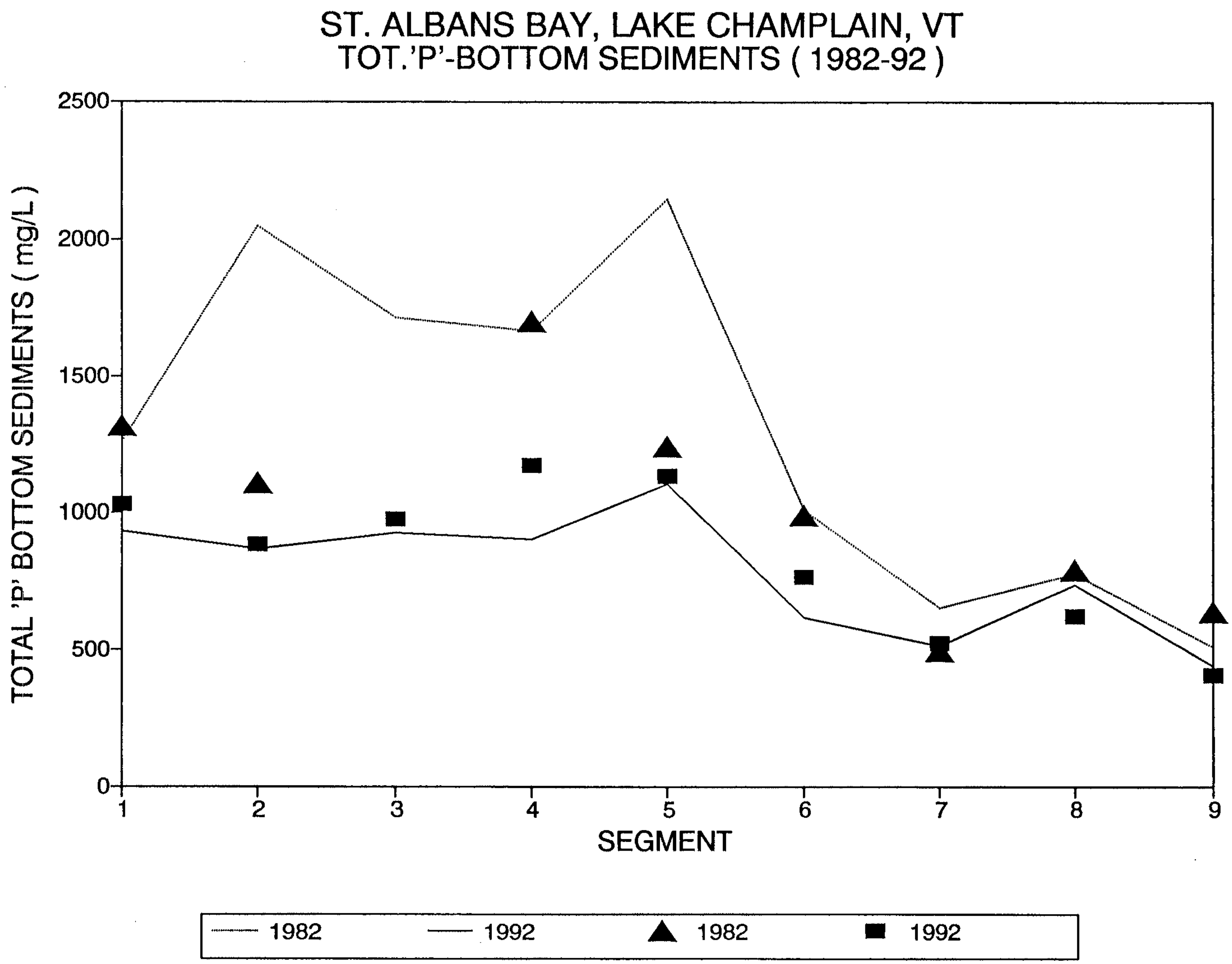

Figure 6-14. Comparison of Calibrated Model Predictions for Total Phosphorus in the Bottom Sediments of All Segments with Concentrations Measured by Ackerly (1983) for 1982 and This Study for 1992.

were almost entirely the result of improvements that went on-line in 1987. What is frequently overlooked is that a loading reduction of comparable magnitude occurred in 1983. This reduction is believed to be due largely to the closing of a Hood Dairy facility that discharged to the WWTF. To emphasize this point, the WWTF loading estimates for the years 1960-1989 (from Hyde et al. (1993) and the RCWP) are plotted in Figure 6-15. This indicates that the loading reduction occurred in two stages. The estimates show a loading reduction of about 34.8 kg/d (12,700 kg/yr) from the 1970 peak to 1983 levels. Most of this decline (73.2%, or 25.5 kg/d) occurred between 1982 and 1983, when the Hood Dairy closed. The WWTF upgrade resulted in a reduction of about 27.7 kg/d (10,100 kg/yr) from 1983-85 levels to 1988-89 loading rates. Overall, the WWTF loading decreased from a peak of about 68.3 kg/d (24,940 kg/yr) in 1970 to 3.9 kg/d (1430 kg/d) in 1988-89, a 94.3% reduction. When the eight-year RCWP means are used to estimate tributary loadings, this represents a 45.7% decrease in the total load to the Bay/Wetland system. Using the 1992 SABDFS tributary loading estimates, the point source reductions amount to a 76.1% decrease in total loading. This discussion serves to explain why the model predicts significant declines in water column and bottom sediment TP concentrations beginning in the early 1980's. It also points out that the system has now had at least 10 years to respond to the first stage of loading reductions.

6.4.9 Mass Balance Analysis of Calibrated Model

Using the calibrated model simulation, an analysis was performed of the individual terms in the mass balance equation for 1982 (pre-WWTF upgrade) and 1988 (post-upgrade) conditions. The results are presented in Tables 6-10 and 6-11, respectively. The mass balances for the Wetland segments are dominated by the advection term, while those for the Bay segments are dominated by dispersion. Although the absolute magnitudes of the settling and resuspension terms in the Bay are comparable to dispersion, the **net** exchange at the sediment-water interface is generally much less. However, the fact that dispersion dominates the mass balance for individual segments **does not** necessarily mean that it dominates on a whole-Bay basis, since the net gain or loss due to this process at internal segment boundaries is zero. To provide a better appreciation for the overall importance of sediment-water interactions, mass balances were developed for both the entire Bay and Wetland under 1982 and 1988 conditions. The results are summarized in Table 6-12.

To permit comparison with the simpler model of Chapra and Reckhow (1983) applied by Smeltzer et al. (1993) to the Bay and Wetland for 1992, apparent net settling rates (v_{net}) were also calculated for each of these conditions. This was accomplished by dividing the net settling loss (or gain) of TP by the total Bay surface area and the volume-weighted average TP concentration. The values obtained are listed at the bottom of Table 6-12. When viewed from a whole-system perspective, it is apparent that settling, not dispersion, was the major loss mechanism for TP in the Bay under 1982 conditions. The value of v_{net}, 0.1915 m/d (70 m/yr), was high compared to the range of 0.7-37.9 m/yr reported for 50 lakes by DePalma et al. (1979). Under 1988 conditions, the model indicates that the sediments became a net source of phosphorus, with v_{net} = -0.0322 m/d (-11.76 m/yr). In the Wetland, the sediments also changed from a net sink (loss) of TP in 1982 to a net source in 1988. However, even on a whole-system basis, advection far exceeded the net sediment-water exchange in both years.

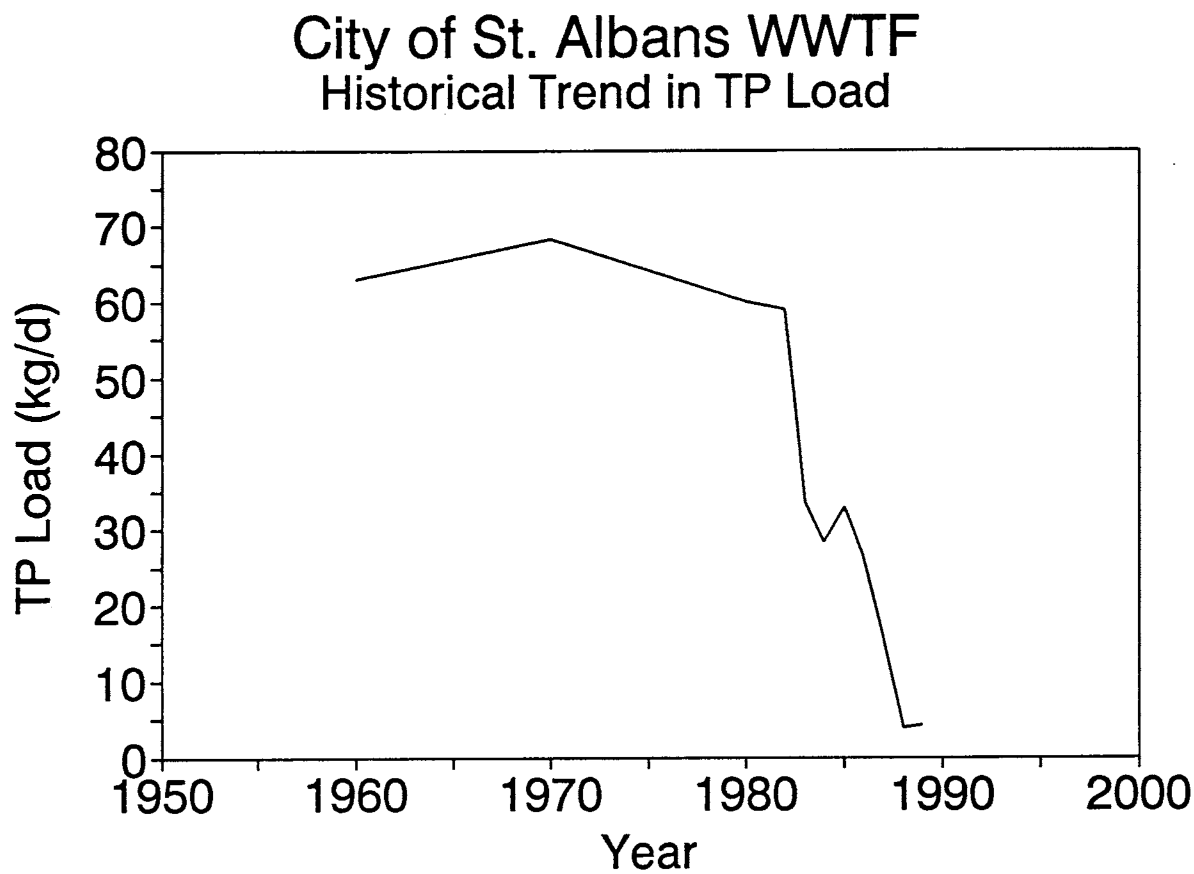

Figure 6-15. Historical Trends in Total Phosphorus Loading from the City of St. Albans Wastewater Treatment Facility, 1960-1989.

Table 6-10. Contribution of Individual Terms to the Mass Balance in Each Segment of St. Albans Bay and Stevens Brook Wetland, 1982 Conditions.

MASS BALANCE TERMS (kg/d) - 1982 CONDITIONS												
	External Loads		Upstream Flows		Downstr.	Upstream	Downstr.			Deep	Total Water	Total Bottom
Segment	#1	#2	#1	#2	Flow	Disp.	Disp.	Settling	Resusp.	Burial	Column	Sediments
1	29.31	0.00	0.00	0.00	-25.370	0.000	2.520	-4.462	2.861	-1.907	4.859	-0.307
2	20.01	58.97	0.00	0.00	-67.498	0.000	0.000	-0.907	0.768	-0.640	11.344	-0.501
3	0.00	0.00	25.37	67.50	-97.896	-2.520	-1.500	-3.858	2.747	-1.832	-10.159	-0.721
4	0.00	0.00	97.95	0.00	-96.880	1.500	-3.190	-6.664	4.653	-3.102	-2.633	-1.090
5	0.00	0.00	96.93	0.00	-75.268	3.190	-26.088	-3.400	1.967	-1.639	-2.667	-0.207
6	0.00	0.00	75.31	0.00	-16.354	26.088	-75.600	-30.996	19.376	-9.688	-2.179	1.932
7	0.00	0.00	16.36	0.00	-3.550	75.600	-55.440	-64.452	40.012	-24.007	8.533	0.433
8	25.26	0.00	3.55	0.00	-5.876	55.440	-81.454	-87.185	81.309	-4.065	-8.953	1.810
9	0.00	0.00	5.88	0.00	-3.648	81.454	-39.718	-337.512	292.568	-41.795	-0.981	3.149

Table 6-11. **Contribution of Individual Terms to the Mass Balance in Each Segment of St. Albans Bay and Stevens Brook Wetland, 1988 Conditions.**

MASS BALANCE TERMS (kg/d) - 1988 CONDITIONS												
Segment	External Loads #1	External Loads #2	Upstream Flows #1	Upstream Flows #2	Downstr. Flow	Upstream Disp.	Downstr. Disp.	Settling	Resusp.	Deep Burial	Total Water Column	Total Bottom Sediments
1	6.11	0.00	0.00	0.00	-4.400	0.000	-1.911	-3.140	2.417	-1.611	-0.925	-0.888
2	9.49	3.72	0.00	0.00	-11.846	0.000	0.000	-0.339	0.527	-0.439	1.552	-0.626
3	0.00	0.00	4.40	11.85	-17.569	1.911	-1.270	-1.732	2.039	-1.360	-0.375	-1.667
4	0.00	0.00	17.57	0.00	-17.225	1.270	-2.194	-2.963	3.456	-2.304	-0.087	-2.796
5	0.00	0.00	17.23	0.00	-11.282	2.194	-9.873	-1.274	1.388	-1.157	-1.622	-1.270
6	0.00	0.00	11.28	0.00	-2.367	9.873	-22.344	-11.221	14.880	-7.440	0.103	-11.100
7	0.00	0.00	2.37	0.00	-0.854	22.344	-19.066	-38.782	35.516	-21.310	1.526	-18.044
8	12.43	0.00	0.85	0.00	-1.801	19.066	-50.609	-65.513	80.131	-40.065	-5.442	-54.683
9	0.00	0.00	1.80	0.00	-1.236	50.609	-45.292	-280.440	276.209	-39.458	1.650	-35.227

Table 6-12. Whole-Bay and Whole-Wetland Mass Balances Predicted by Calibrated Total Phosphorus Model.

Mass Balance Term	1982 - kg/d		1988 - kg/d	
	Bay	Wetland	Bay	Wetland
External Load	25.26	108.29	12.43	19.32
Upstream Inflow	93.93	0.00	17.23	0.00
Outflow	-3.65	-96.88	-1.24	-17.23
Dispersion In	3.19	0.00	2.19	0.00
Dispersion Out	-39.72	-3.19	-45.29	-2.19
Settling	-520.14	-19.29	-395.96	-9.45
Resuspension	433.26	13.00	406.74	9.83
(Net Settling)	-86.88	-6.29	10.78	0.38
TOTAL	-4.86	1.93	-3.90	0.28
v_{net} (m/d)	0.1915	0.0181	-0.0322	-0.00222

6.5 Projection of Future Water Quality Trends

6.5.1 Modeling Approach

The calibrated model was applied to predict future trends in phosphorus concentrations within the Bay and Wetland to the year 2050 under the assumption that loadings would remain constant at present levels. Unfortunately, there is considerable uncertainty as to what the present loadings actually are. To account for this uncertainty, the model was run with two different future loading scenarios. In the first scenario (designated F1), loadings were considered to remain constant from 1992 to 2050 at the levels estimated by the 1992 SABDFS (Smeltzer, et al., 1993). In the second scenario (F2), nonpoint source loadings from the tributaries were set at the eight-year (1982-1989) average from the RCWP, and point source loading from the City of St. Albans WWTF was set at the average of values obtained by the RCWP for 1988 and 1989. Flows from all sources were assumed to equal nine-year (1982-90) RCWP averages. These inputs are summarized in Table 6-13. The boundary concentration of TP in Lake Champlain was assumed to remain at 13.5 mg/m^3 indefinitely. The model runs were started in 1980, with all input data for 1980-1991 identical to the calibration data set, in order to insure that the simulation results from the model calibration were reproduced for these years (they were!).

Table 6-13. Flows and Total Phosphorus Loads Used in Modeling Future Conditions in St. Albans Bay and Stevens Brook Wetland.

Quantity/Scenario	Jewett	Stevens	Mill	WWTF
TP Load (kg/d) - F1	6.70	2.00	8.40	3.30
TP Load (kg/d) - F2	17.93	16.36	38.27	3.91
Flow (m^3/d) - F1 & F2	16,643	25,518	116,042	8,425

6.5.2 Results of Model Simulations

The model predictions are summarized here by presenting the results for Segments 3, 6, and 9. These are considered representative of the Wetland, inner Bay, and outer Bay, respectively. Predicted trends in water column TP concentrations are shown in Figures 6-16 to 6-18, and those for the bottom sediments are shown in Figures 6-19 to 6-21. The predicted "steady-state" (year 2049) concentrations are summarized in Table 6-14. With the approach taken, future predictions take the form of total phosphorus concentration ranges that bracket the expected response of the system. Because the loading estimates from the two scenarios differ dramatically, the predicted concentration ranges are often quite wide.

Under future scenario F1 (1992 SABDFS loads), water column TP concentrations would continue to decrease, reaching levels well below those observed in 1992. 90% of the steady-state response would occur within 3-5 years in the Wetland, but would take somewhat longer (10-15 years) in the inner Bay, and considerably longer (20-25 years) in the outer Bay. In the Bay segments, these times are very close to the 90% response times of the bottom sediments. In the Wetland (Segment 3), the response of the bottom sediments is much slower than the water column, requiring 10-15 years. This is consistent with the conclusion drawn earlier that sediment interactions play a much less important role in the overall mass balance in the Wetland than they do in the Bay.

Under future scenario F2 (RCWP loads), the model results suggest that the TP concentrations observed during the 1992 SABDFS were anomalously low and not representative of annual average conditions. Furthermore, while bottom sediment TP levels would decline slightly over the next 5-10 years, water column concentrations would show essentially no change in the Wetland, and a further decrease of only about 2 mg/m^3 in the Bay.

6.5.3 Predicted Progress Toward Water Quality Goal

In May, 1991, the Vermont Water Resources Board adopted a set of water quality standards for total phosphorus in various areas of Lake Champlain based on recommenda-

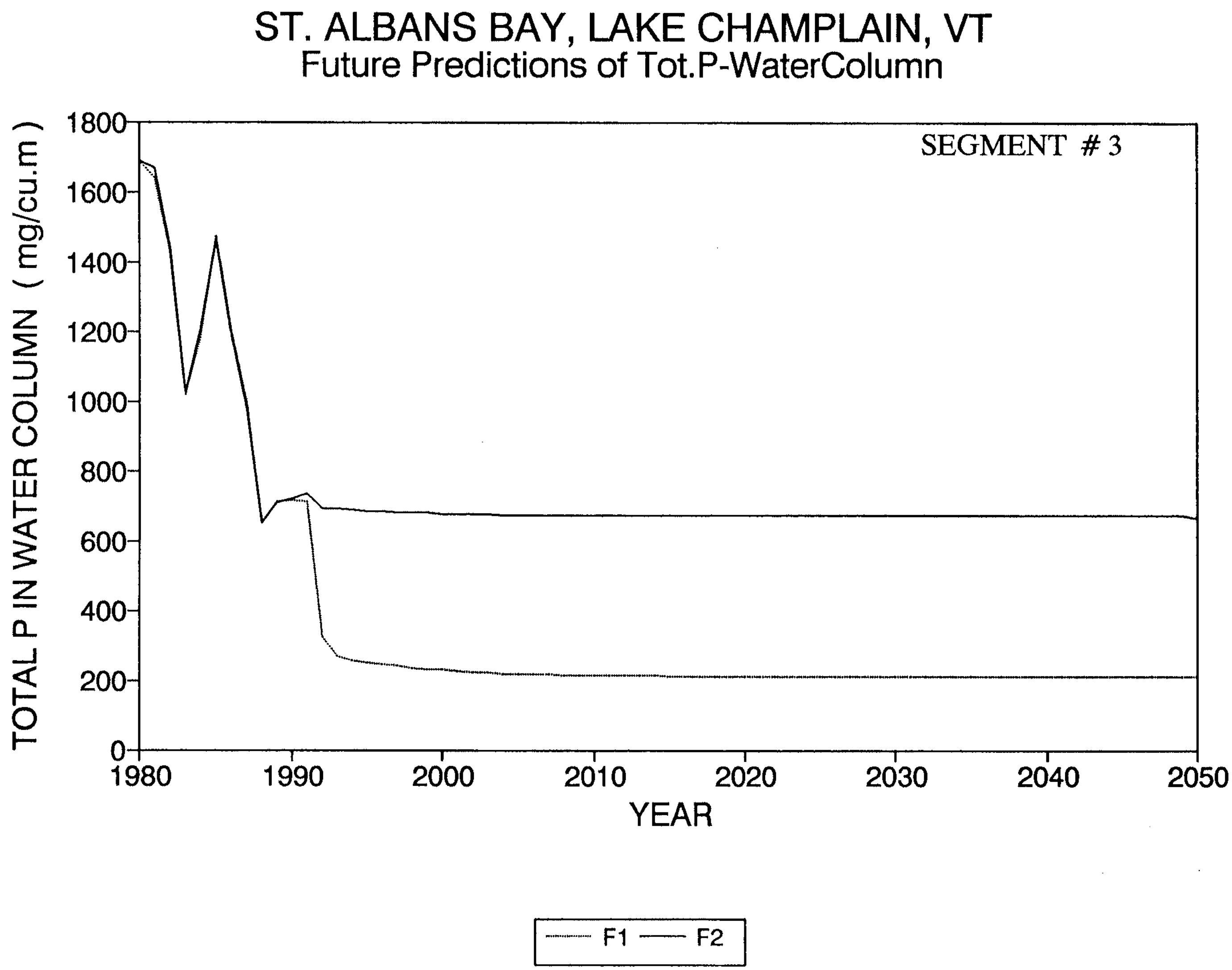

Figure 6-16. Model Predictions of Future Trends in Water Column Total Phosphorus Concentrations for Stevens Brook Wetland, Segment 3.

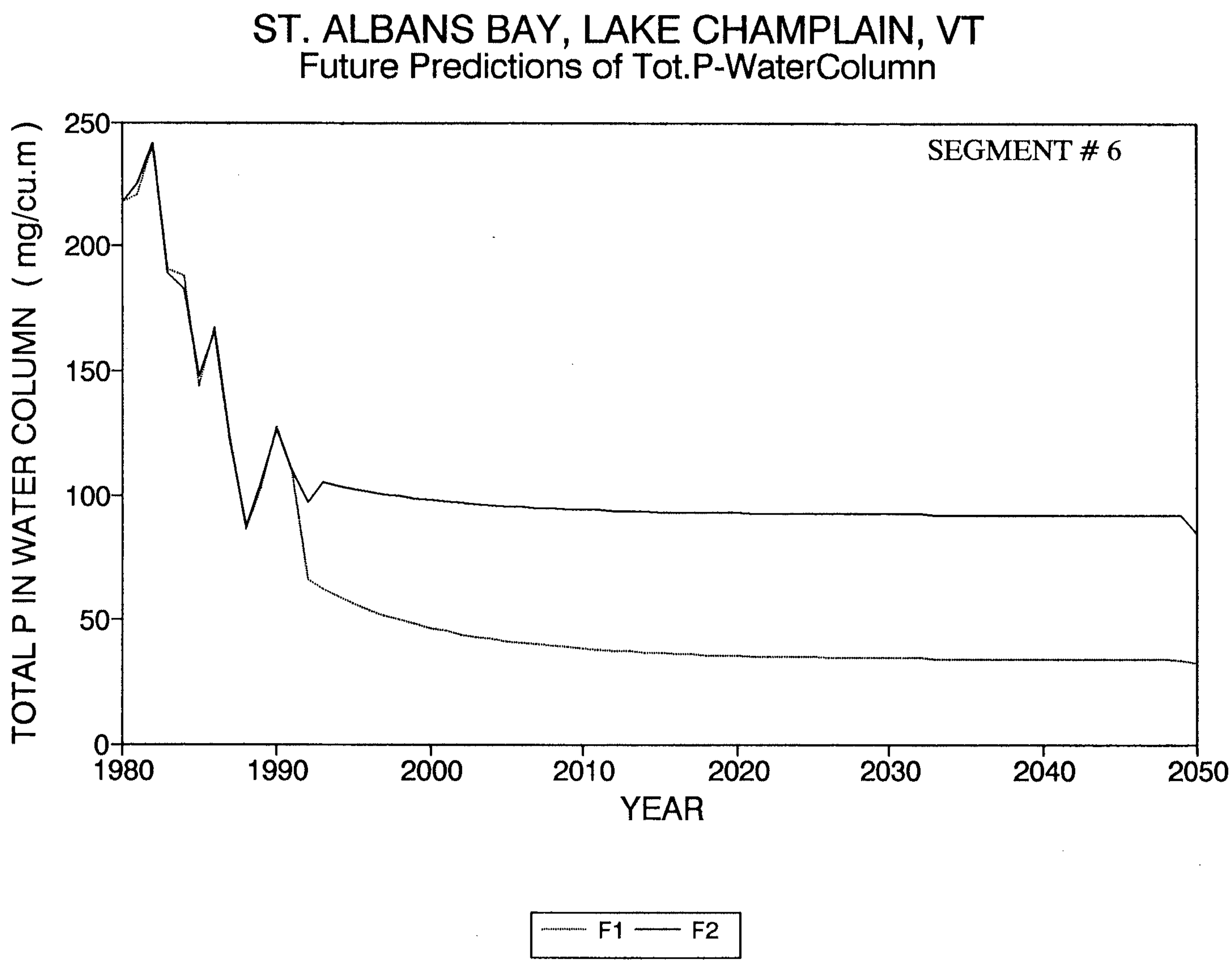

Figure 6-17. Model Predictions of Future Trends in Water Column Total Phosphorus Concentrations for Inner St. Albans Bay, Segment 6.

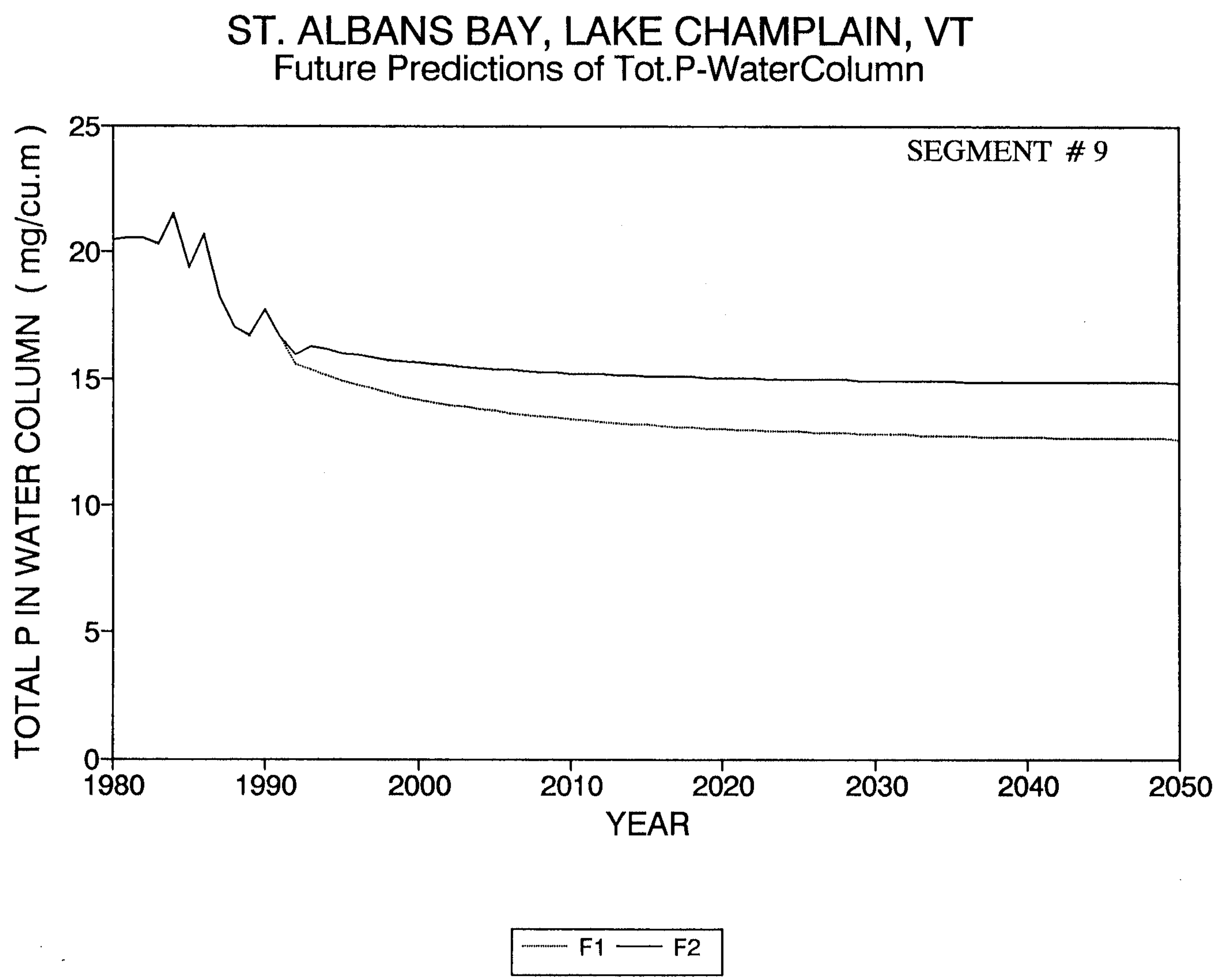

Figure 6-18. Model Predictions of Future Trends in Water Column Total Phosphorus Concentrations for Outer St. Albans Bay, Segment 9.

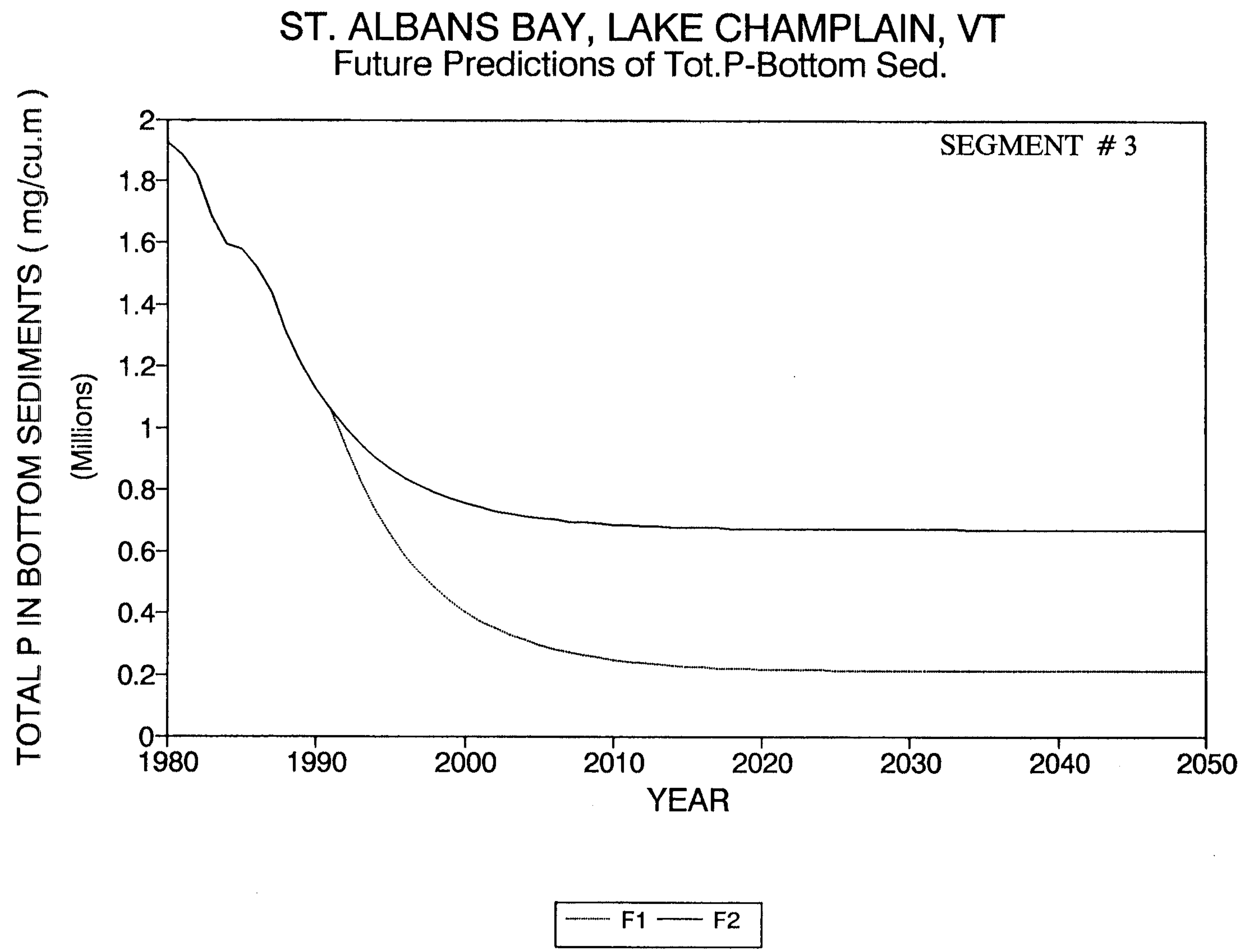

Figure 6-19. Model Predictions of Future Trends in Bottom Sediment Total Phosphorus Concentrations for Stevens Brook Wetland, Segment 3.

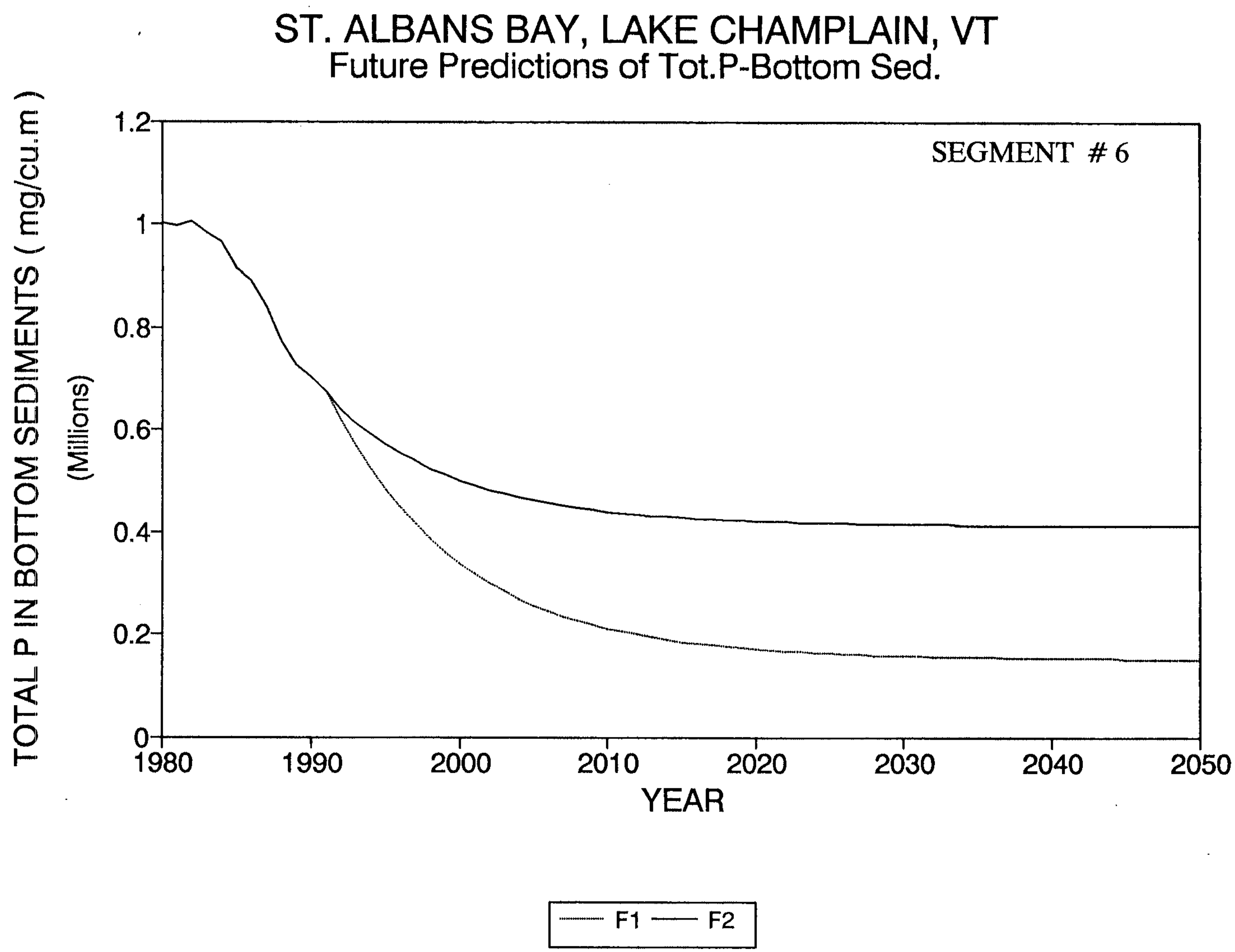

Figure 6-20. Model Predictions of Future Trends in Bottom Sediment Total Phosphorus Concentrations for Inner St. Albans Bay, Segment 6.

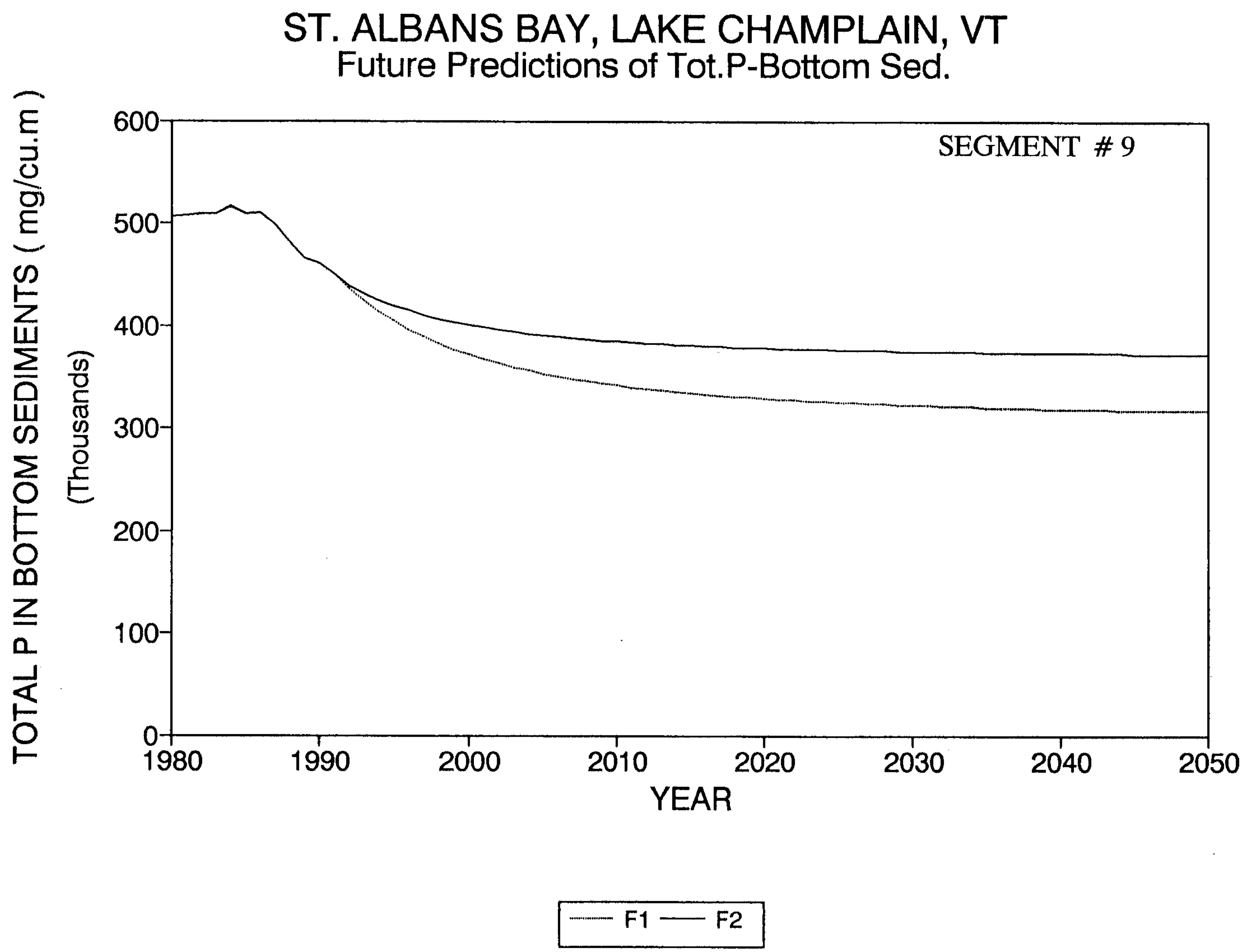

Figure 6-21. Model Predictions of Future Trends in Bottom Sediment Total Phosphorus Concentrations for Outer St. Albans Bay, Segment 9.

Table 6-14. Model Predictions of Steady-State (Year 2049) Total Phosphorus Concentrations in the Water Column and Bottom Sediments of All Segments in St. Albans Bay and Stevens Brook Wetland.

MODEL PREDICTIONS AT STEADY-STATE (Year 2049)						
SEGMENT	SCENARIO F1		SCENARIO F2		AVERAGE	
	TP-WC mg/cu.m	TP-BS mg/cu.m	TP-WC mg/cu.m	TP-BS mg/cu.m	TP-WC mg/cu.m	TP-BS mg/cu.m
1	312.80	3.13E+05	875.70	8.76E+05	594.25	5.94E+05
2	154.80	1.41E+05	592.20	5.39E+05	373.50	3.40E+05
3	210.00	2.10E+05	670.70	6.71E+05	440.35	4.40E+05
4	203.60	2.04E+05	650.00	6.50E+05	426.80	4.27E+05
5	145.10	2.64E+05	458.20	8.33E+05	301.65	5.49E+05
6	33.75	1.51E+05	92.35	4.11E+05	63.05	2.81E+05
7	14.87	1.89E+05	28.49	3.58E+05	21.68	2.73E+05
8	14.24	3.57E+05	23.03	5.57E+05	18.64	4.57E+05
9	12.64	3.17E+05	14.87	3.72E+05	13.76	3.44E+05

tions by the Vermont DEC (1990). The goal set for St. Albans Bay was 0.017 mg/L (17 mg/m^3). To evaluate likely future progress toward this goal, the model predictions were used to calculate volume-weighted average TP concentrations for the entire Bay and Wetland at several points in time. The results are presented in Table 6-15. If the average of the two scenarios is assumed to provide the best available estimate of future conditions, the model predicts that the water quality standard will be met by the year 2005 with no further loading reductions. In order to reduce the high level of uncertainty associated with this prediction, it would be necessary to initiate a new study of tributary loadings combining the temporal intensiveness of the RCWP study with a thorough evaluation of sampling and analytical protocols.

Table 6-15. Model Predictions of Volume-Weighted Average Total Phosphorus Concentration in St. Albans Bay and Stevens Brook Wetland for Selected Future Years.

Year	VOLUME-WEIGHTED AVERAGE TP CONCS. (mg/m^3)					
	Scenario F1		Scenario F2		Average	
	Bay	Wetland	Bay	Wetland	Bay	Wetland
1982	27.39	1312.1	27.39	1312.1	27.39	1312.1
1988	20.20	644.6	20.20	644.6	20.20	644.6
1993	17.76	277.6	20.28	693.0	19.02	485.3
1998	16.29	245.2	19.52	681.5	17.91	463.4
2005	15.09	227.8	18.92	675.3	17.01	451.6
2015	14.20	221.2	18.48	673.0	16.34	447.1
2025	13.74	219.9	18.20	672.6	15.97	446.3
2049	13.30	219.5	18.05	672.4	15.68	446.0

These results should be interpreted with caution. Whole-Bay annual average TP concentrations can be somewhat misleading. Even if the water quality standard is met, TP concentrations in the wetland and inner Bay may be high enough at times to cause significant algal growth. The combined inflows to the Wetland generally contain 100-200 mg/m^3 (or more) of **dissolved** phosphorus. During periods when tributary flows and dispersive exchanges are low (e.g. mid- to late-summer), this inflow would mix slowly with the more dilute waters of the outer bay, maintaining elevated concentrations capable of producing algal blooms in the inner Bay. Currently this problem is aggrevated by phosphorus recycle from the bottom sediments. As the rate of recycle decreases in the future, the severity, frequency, and spatial extent of algal blooms should decrease. Present and future phosphorus loadings from the bottom sediments were calculated based on the model predictions, and are discussed in the next two subsections.

6.5.4 Mass Balance Analysis for Future Conditions

The model predictions for the two future scenarios were used to investigate changes in the relative importance of the various terms in the water column mass balance equation (6-1). Such an analysis was presented in Table 6-12 for 1982 and 1988 conditions. Results for selected years in the period 1993-2050 are shown in Tables 6-16 through 6-19. The net apparent TP settling velocity was also calculated as described in subsection 6.4.9. This analysis shows that, regardless of the loading scenario assumed, the net movement of phosphorus across the sediment-water interface is projected to be a major component of the whole-Bay mass balance for the entire simulation period. Sediment-water interactions are predicted to be much less important, but nevertheless significant, in the Wetland. The model predicts a substantial increase in the net loss rate of phosphorus to the bottom sediments of St. Albans Bay during the time period of simulation. A similar trend is observed for the Wetland, although the quantities of phosphorus involved are much smaller. The apparent net settling velocities also increase with time and approach roughly the same steady-state value regardless of loading assumption in both the Bay (about 0.16 m/d) and the Wetland (about 0.023 m/d).

6.5.5 Rates of Phosphorus Recycle from Bottom Sediments

The role of the bottom sediments in retarding the recovery of a water body after a reduction in phosphorus loading is somewhat difficult to quantify, even when a detailed mass balance analysis is performed as in Tables 6-16 to 6-19. While resuspension, or recycling, of phosphorus from the bottom sediments may appear to be the major source of phosphorus to the water column, this process (actually several processes) is usually balanced by an even greater movement of phosphorus in the opposite direction via settling. Therefore, it is not possible to quantify the role of phosphorus recycle in slowing the recovery of St. Albans Bay simply by looking at the absolute magnitude of the resuspension term in the mass balance. However, it is **also** difficult to determine the impact of sediment-water interactions by considering the magnitude of the **net** flux rate (i.e. resuspension minus settling). Bottom sediments may slow a water body's recovery substantially even when they are acting as a net sink of phosphorus (i.e. when settling exceeds resuspension).

Table 6-16. Predicted Contributions to St. Albans Bay TP Mass Balance for Future Conditions Under Loading Scenario F1 (1992 SABDFS Loads).

Process	CONTRIBUTION TO WHOLE-BAY MASS BALANCE (kg/d) - SCENARIO F1					
	1993	1998	2005	2015	2025	2049
External Load	8.40	8.40	8.40	8.40	8.40	8.40
Upstream Inflow	13.61	11.76	10.76	10.40	10.32	10.30
Outflow	-2.57	-2.41	-2.29	-2.20	-2.15	-2.11
Dispersion In	0.66	0.61	0.58	0.58	0.58	0.59
Dispersion Out	-33.10	-16.72	-4.01	5.40	10.28	14.98
Settling	-350.28	-323.00	-300.89	-284.25	-275.64	-267.37
Resuspension	359.73	318.58	258.16	259.91	246.73	234.05
(Net Settling)	9.47	-4.42	-15.73	-24.34	-28.91	-33.32
TOTAL	-3.53	-2.79	-2.28	-1.76	-1.48	-1.16
v_{net} (m/d)	-.0322	.0164	.0629	.1035	.1270	.1509

Table 6-17. Predicted Contributions to Stevens Brook Wetland TP Mass Balance for Future Conditions Under Loading Scenario F1 (1992 SABDFS Loads).

Process	CONTRIBUTION TO WHOLE-WETLAND MASS BALANCE (kg/d) - SCENARIO F1					
	1993	1998	2005	2015	2025	2049
External Load	12.00	12.00	12.00	12.00	12.00	12.00
Upstream Inflow	0.00	0.00	0.00	0.00	0.00	0.00
Outflow	-13.61	-11.76	-10.76	-10.40	-10.32	-10.30
Dispersion In	0.00	0.00	0.00	0.00	0.00	0.00
Dispersion Out	-0.66	-0.61	-0.58	-0.58	-0.58	-0.59
Settling	-4.07	-3.60	-3.34	-3.25	-3.23	-3.22
Resuspension	6.60	3.95	2.55	2.03	1.93	1.90
(Net Settling)	2.53	-0.35	-0.79	-1.22	-1.30	-1.32
TOTAL	-0.26	-0.01	-0.14	-0.19	-0.20	-0.20
v_{net} (m/d)	-.03435	-.00538	.01307	.02078	.02228	.02266

Table 6-18. Predicted Contributions to St. Albans Bay TP Mass Balance for Future Conditions Under Loading Scenario F2 (Mean RCWP Loads).

Process	CONTRIBUTION TO WHOLE-BAY MASS BALANCE (kg/d) - SCENARIO F2				
	1993	1998	2005	2015	2049
External Load	38.27	38.27	38.27	38.27	38.27
Upstream Inflow	34.16	33.44	33.05	32.91	32.88
Outflow	-2.72	-2.63	-2.57	-2.52	-2.48
Dispersion In	1.94	1.92	1.91	1.91	1.92
Dispersion Out	-48.95	-39.89	-33.27	-28.57	-23.87
Settling	-393.18	-378.87	-367.70	-359.55	-351.34
Resuspension	366.86	344.54	327.19	314.69	302.06
(Net Settling)	-26.32	-34.33	-40.51	-44.86	-49.28
TOTAL	-3.62	-3.22	-3.11	-2.86	-2.55
v_{net} (m/d)	.0784	.1062	.1293	.1466	.1648

Table 6-19. Predicted Contributions to Stevens Brook Wetland TP Mass Balance for Future Conditions Under Loading Scenario F2 (Mean RCWP Loads).

Process	CONTRIBUTION TO WHOLE-WETLAND MASS BALANCE (kg/d) - SCENARIO F2				
	1993	1998	2005	2015	2049
External Load	38.20	38.20	38.20	38.20	38.20
Upstream Inflow	0.00	0.00	0.00	0.00	0.00
Outflow	-34.16	-33.44	-33.05	-32.91	-32.88
Dispersion In	0.00	0.00	0.00	0.00	0.00
Dispersion Out	-1.94	-1.92	-1.91	-1.91	-1.92
Settling	-10.17	-10.00	-9.91	-9.88	-9.87
Resuspension	7.62	6.60	6.06	5.87	5.82
(Net Settling)	-2.55	-3.40	-3.85	-4.01	-4.04
TOTAL	-0.45	-0.56	-0.61	-0.63	-0.64
v_{net} (m/d)	.01386	.01880	.02148	.02245	.02264

To shed some light on these confusing issues, a procedure was developed for calculating the "effective" phosphorus loading from the bottom sediments based on mass balance modeling results. The procedure is based on the assumption that any water body has a characteristic value of apparent net settling velocity ($v_{net,ss}$) when the system is at equilibrium with the external phosphorus load (i.e. at steady-state). Once this value is determined, it is possible to calculate a **theoretical** net settling rate of phosphorus (in kg/d) at any given time from the water column phosphorus concentration (using the product $v_{net,ss}AC$). If the **actual** net settling rate can also be estimated (e.g. by application of a mass balance model), then the **effective** phosphorus loading rate of the bottom sediments can be calculated as the difference between the theoretical and the actual values. This loading rate provides a realistic estimate of the importance of sediment-water interactions compared to other sources of phosphorus.

Taking the approach outlined above, effective phosphorus loading rates were calculated for St. Albans Bay and Stevens Brook Wetland bottom sediments under both future loading scenarios considered. The results are summarized in Table 6-20. In this Table, the effective loading from the bottom sediments is also given as a percentage of the total phosphorus load to the water column from all sources. Based on these calculations, it is estimated that sediment phosphorus recycle currently accounts for an effective loading of between 29 kg/d and 54 kg/d (or 28-70% of the total load) to the water column of St. Albans Bay. Under loading scenario F1, sediment recycle would remain an important source of phosphorus to the Bay (i.e >20% of the total) for the next 30 years. Under loading scenario F2, on the other hand, the calculations suggest that sediment phosphorus recycle has already decreased by over 50% from 1988 rates, and now accounts for less than 30% of the total load. This contribution would decline to 20% by 1998 and 10% by 2010. In the Wetland, the present effective sediment phosphorus recycle rate is estimated at between 1.6 kg/d and 4.2 kg/d (or 4-26% of the total loading). The contribution to the total load would already be less than 5% under loading scenario F2, and would drop below 10% by the year 2000 under scenario F1.

Assuming that the most likely response can be approximated by the average of the two scenarios considered, then the water column of St. Albans Bay currently receives an effective phosphorus load of about 42 kg/d from the bottom sediments, or 50% of the total load. This rate will decrease to about 28 kg/d (42% of total) by 1998, 17 kg/d (33% of total) by 2005, and 8 kg/d (22% of total) by 2015. It must be mentioned once again, however, that the actual future conditions could lie **anywhere** within the range of predictions for the two scenarios. If the RCWP estimates of nonpoint source loadings are, in fact, accurate, then the model predictions indicate that roughly 75% of the expected decrease in water column TP levels and 55% of the expected reduction in effective sediment phosphorus loading have already occurred. In this case, the St. Albans Bay water quality standard of 17 mg/m^3 could only be met by a reduction in nonpoint source loadings.

Table 6-20. Estimated Effective Phosphorus Loading from Bottom Sediments of St. Albans Bay and Stevens Brook Wetland for Selected Future Years.

Loading Scenario	Year	St. Albans Bay		Stevens Brook Wetland	
		Effective Sed TP Load (kg/d)	% of Total TP Load	Effective Sed TP Load (kg/d)	% of Total TP Load
F1	1988	61.4	65.8	4.26	17.0
	1993	54.0	70.4	4.20	25.9
	1998	36.4	63.7	1.82	13.2
	2005	22.1	52.8	0.58	4.6
	2015	11.2	36.6	0.11	0.9
	2025	5.5	22.2	0.02	0
	2049	0	0	0	0
F2	1988	65.9	67.4	4.25	10.0
	1993	29.1	28.1	1.61	4.0
	1998	19.0	20.5	0.69	1.8
	2005	11.2	13.2	0.21	0.5
	2015	5.6	7.1	0.03	0
	2049	0	0	0	0

SECTION 7

SUMMARY AND CONCLUSIONS

This study involved a detailed review of data from previous studies on St. Albans Bay, extensive sampling and analysis of phosphorus (P) levels and fractionation in St. Albans Bay bottom sediments, and development and application of a mass balance model for total phosphorus in St. Albans Bay and Stevens Brook Wetland. This work has produced a number of findings that enhance the understanding of internal phosphorus dynamics and expected future changes in water column and sediment phosphorus levels. These findings are summarized below:

1) The average total phosphorus content of all sediment core samples (N=43) analyzed is 1270 μg/g dry sediment. The averages vary significantly with location, as follows: Wetland (1817 μg/g) > Outer Bay (1255 μg/g) > Inner Bay (980 μg/g) > Middle Bay (919 μg/g).

2) Phosphorus fractionation analyses show that, on average, the sediments contain 456 μg/g (36.8% of total P) as biologically available inorganic P (BAIP), 530 μg/g (42.8% of total P) as HCl-extractable P, and 252 μg/g (20.4% of total P) as organic P.

3) BAIP accounts for 49.9% of total P in Wetland sediments, 25.2% in the Inner Bay, 23.6% in the Middle Bay, and 36.2% in the Outer Bay. Organic P accounts for a relative constant fraction (18.3-26.6%) of total sediment P. The amount of HCl-extractable P in the bottom sediments varies little (from 499 μg/g to 544 μg/g) with location in the Bay/Wetland system.

4) Phosphorus levels and fractionation do not vary significantly with depth in the bottom sediments of St. Albans Bay and Stevens Brook Wetland.

5) Changes in total sediment P and all extractable P fractions between 1982 and 1992 can be described by normal distributions. The differences in total P, BAIP, HCl-P, and Organic P concentrations are statistically significant at the $p<0.001$ level.

6) Total sediment P decreased by an average of 350 μg/g between 1982 and 1992. Of this, 106 μg/g (30%) came from the BAIP fraction, 69 μg/g (20%) from the HCl-P fraction, and 175 μg/g (50%) from the organic P fraction.

7) Between 1982 and 1992, organic matter in the bottom sediments of the Bay/Wetland system decomposed at a faster rate than it was deposited. This suggests that, on an annual average basis, primary productivity has declined as a result of phosphorus loading reductions.

8) The mean decreases in total sediment P, BAIP, and HCl-P between 1982 and 1992 all decrease with increasing depth in the bottom sediments, while the decrease in organic P shows no clear trend with depth.

9) The decrease in BAIP between 1982 and 1992 was statistically significant ($p<0.10$) in all zones except the Inner Bay; the decrease in HCl-P was significant in all zones except the Wetland; and the decrease in organic P was significant in all zones except the Outer Bay.

10) Total P is strongly correlated with BAIP ($N=120$, $r^2=0.925$, $p<0.001$) in Bay/Wetland bottom sediments; total P is the best surrogate parameter for estimating BAIP in this system.

11) It is estimated that the present (1992) pools of total sediment P stored in the top 8 cm of bottom sediments are: 16,170 kg in Stevens Brook Wetland; 110,600 kg in Inner St. Albans Bay; 231,300 kg in the Middle Bay, and 250,000 kg in the Outer Bay. The estimated pools of BAIP are: 7,790 kg in the Wetland; 29,940 kg in the Inner Bay; 60,650 kg in the Middle Bay; and 82,520 in the Outer Bay.

12) Based on a simple first-order model, "excess" total P (above "pristine" conditions) is being lost from the top 8 cm of Bay/Wetland sediments at a rate of 0.046 yr^{-1}.

13) Water column total phosphorus (TP) levels and nonpoint TP loading estimates obtained by the St. Albans Bay Rural Clean Water Program (RCWP) are much higher than those obtained by the Lake Champlain (LC) and St. Albans Bay (SAB) Diagnostic-Feasibility Studies (DFS). These discrepancies introduce considerable uncertainty into the simulation results of a total phosphorus model.

14) The reduction in point source TP loading to St. Albans Bay resulting from the 1982 closing of a Hood Dairy facility was comparable to that achieved by upgrading the City of St. Albans Wastewater Treatment Facility (WWTF). The Bay/Wetland system has had over 10 years to respond to these initial loading reductions.

15) The calibrated model for chloride in St. Albans Bay (4 spatial segments) and Stevens Brook Wetland (5 spatial segments) shows good agreement with the 1992 SABDFS data, indicating that hydrodynamic processes are accurately represented.

16) The calibrated TP model of Chapra and Canale (1991), applied for the period 1900-1992, provides a reasonable simulation of phosphorus dynamics in both the water column and bottom sediments of St. Albans Bay and Stevens Brook Wetland.

17) The TP mass balances for individual spatial segments were dominated by advection in Stevens Brook Wetland and by dispersion in St. Albans Bay. The **net** exchange of phosphours at the sediment-water interface was generally small compared to the mass of phosphorus transported by these processes.

18) Whole-system mass balances show that, under 1982 conditions, settling (v_{net} = 0.1915 m/d) was the most important loss mechanism for TP in St. Albans Bay. After the point source loading reductions (1988 conditions), the bottom sediments became a net source of phosphorus (v_{net} = -0.0322 m/d) to the water column. In Stevens Brook Wetland, the net sediment-water exchange was small compared to advection even on a whole-system basis.

19) Model predictions of future TP levels in the water column and bottom sediments of the Bay/Wetland system are highly sensitive to the assumption made for nonpoint source TP loading. If nonpoint loadings continue at levels measured by the RCWP (1982-89), little future improvement in water quality would be expected, and the goal of 0.017 mg/L set for the Bay would not be met without some reduction in nonpoint source TP loading. If nonpoint loadings continue at levels estimated by the SABDFS and LCDFS (1991-92), significant future decreases in TP levels would be expected, and the Bay-wide average TP goal of 0.017 mg/L would be met by 1995. If the average of model predictions for the two loading scenarios considered is taken as the best estimate of future conditions, the Bay-wide TP goal of 0.017 mg/L would be met by the year 2005 with no further loading reductions.

20) In order to reduce the level of uncertainty associated with model predictions of future conditions in St. Albans Bay, it would be necessary to conduct a study of current nonpoint source TP loadings combining intensive temporal coverage with a thorough evaluation of sampling and analytical protocols.

21) Based on long-term model simulations (to the year 2050), it is estimated that the apparent net TP settling rate will approach steady-state values of about 0.16 m/d in St. Albans Bay and 0.023 m/d in Stevens Brook Wetland.

22) Phosphorus levels in Stevens Brook Wetland and Inner St. Albans Bay are high enough to cause significant algal blooms during periods when tributary flows and dispersive exchange rates are low (e.g. mid- to late-summer). The frequency, severity, and spatial extent of this problem are expected to decrease in the future as the rate of phosphorus release from the bottom sediments declines.

23) It is estimated that the effective phosphorus loading from the bottom sediments to the water column of St. Albans Bay is currently between 29 kg/d and 54 kg/d (average = 42 kg/d), or 28-78% (average = 50%) of the TP load from all sources. This loading is expected to decline to: 19.0-36.4 kg/d (average = 27.7 kg/d), or 20.5-63.7% (average = 42.1%) of the total load, by 1998; 11.2-22.1 kg/d (average = 16.7 kg/d), or 13.2-52.8 (average = 33.0%) of the total load, by 2005; and 5.6-11.2 kg/d (average = 8.4 kg/d), or 7.1-36.6% (average = 21.9%) of the total load, by 2015.

24) The effective phosphorus loading from the bottom sediments in Stevens Brook Wetland is currently between 1.6 kg/d and 4.2 kg/d (average = 2.9 kg/d), or 4-26% (average = 15%) of the TP load from all sources. This contribution will drop to less than 10% of the total load by the year 2000.

SECTION 8

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APPENDIX A

RESULTS OF PREVIOUS RESEARCH

Table A-1. Estimates of Monthly Total Phosphorus Loadings (in kg) to St. Albans Bay, from St. Albans Bay Rural Clean Water Program (Meals, Personal Communication, 1992).

Year	Month	Jewett Brook	Stevens Brook	Mill River	St Albans WWTF	Total Load
81	12	0.00	161.97	34.29	0.00	196.26
82	1	241.05	554.75	199.15	823.06	1818.01
82	2	5.92	79.29	25.92	455.27	566.40
82	3	8694.94	3295.11	6845.40	1445.02	20280.48
82	4	1239.80	1255.10	1654.00	2309.44	6458.34
82	5	38.21	143.66	17.17	1972.55	2171.59
82	6	18.83	324.99	184.06	2425.19	2953.07
82	7	2.10	64.48	7.52	2335.19	2409.29
82	8	0.48	173.88	13.30	1231.65	1419.30
82	9	0.02	69.76	10.30	2177.43	2257.51
82	10	16.22	90.10	26.72	2699.51	2832.55
82	11	120.82	356.59	114.99	1574.48	2166.89
82	12	322.02	894.90	122.05	2073.92	3412.89
83	1	91.90	670.37	150.24	2604.47	3516.98
83	2	1628.40	1834.62	474.94	879.23	4817.18
83	3	939.20	979.40	902.04	1208.98	4029.61
83	4	923.56	1094.94	817.46	707.08	3543.04
83	5	1737.33	843.76	1560.20	1055.11	5196.39
83	6	108.57	183.18	41.66	981.84	1315.25
83	7	0.00	97.49	9.92	935.59	1043.00
83	8	10.78	147.58	43.51	936.86	1138.73
83	9	66.62	127.47	21.79	833.81	1049.70
83	10	7.36	69.27	94.72	712.07	883.43
83	11	1081.42	641.09	773.25	568.33	3064.09
83	12	2175.87	1304.99	1813.18	803.25	6097.29
84	1	19.67	140.06	45.07	1048.20	1252.99
84	2	3178.61	844.47	5637.79	953.05	10613.92
84	3	1111.96	859.88	1336.80	1040.85	4349.48
84	4	503.90	474.26	517.73	840.93	2336.82
84	5	698.60	1670.35	19734.34	922.11	23025.39
84	6	3788.14	1448.75	1086.67	974.98	7298.54
84	7	35.72	440.63	206.28	704.57	1387.20
84	8	28.94	928.03	368.13	848.85	2173.95
84	9	6.86	109.23	37.62	595.71	749.41
84	10	10.59	114.02	71.97	846.79	1043.37
84	11	184.81	138.27	148.83	809.65	1281.57
84	12	1080.56	729.90	580.92	741.71	3133.09

Table A-1. Continued.

Year	Month	Jewett Brook	Stevens Brook	Mill River	St Albans WWTF	Total Load
85	1	36.56	135.40	58.52	881.95	1112.43
85	2	1627.51	354.02	2579.72	776.45	5337.71
85	3	1312.80	727.22	937.50	847.70	3825.21
85	4	598.81	1252.40	1161.26	592.16	3604.62
85	5	82.15	77.67	85.83	1405.61	1651.26
85	6	25.91	77.67	142.11	1003.00	1248.69
85	7	15.67	41.32	28.75	1022.06	1107.80
85	8	0.00	32.87	5.88	1464.91	1503.66
85	9	1.44	54.34	20.43	859.33	935.53
85	10	41.79	59.38	128.24	1079.03	1308.44
85	11	190.91	104.82	276.50	887.00	1459.23
85	12	83.05	54.41	65.47	1191.32	1394.25
86	1	245.34	736.10	630.03	941.20	2552.66
86	2	96.69	137.51	193.82	1571.51	1999.52
86	3	1863.03	8011.80	34392.13	1175.06	45442.02
86	4	102.05	287.49	131.77	414.29	935.60
86	5	117.40	137.52	170.14	536.01	961.07
86	6	45.33	134.38	119.57	358.89	658.17
86	7	34.74	144.81	125.60	478.24	783.39
86	8	156.36	154.48	147.52	1177.23	1635.59
86	9	84.39	72.22	107.57	896.28	1160.46
86	10	313.74	99.40	141.58	726.85	1281.57
86	11	578.86	362.60	1302.78	589.40	2833.63
86	12	131.76	191.14	354.11	811.43	1488.44
87	1	74.09	109.21	144.72	916.93	1244.94
87	2	118.93	72.98	105.19	1048.66	1345.76
87	3	5103.85	2220.39	6072.54	1026.09	14422.87
87	4	520.86	229.07	377.49	860.80	1988.22
87	5	10.42	57.48	57.76	808.53	934.18
87	6	80.89	148.60	335.90	579.21	1144.60
87	7	9.52	43.38	105.10	97.80	255.79
87	8	0.73	30.54	25.63	86.32	143.23
87	9	5.83	92.04	51.31	124.00	273.19
87	10	27.30	190.24	335.03	47.08	599.65
87	11	127.40	114.20	355.69	78.65	675.94
87	12	336.73	166.92	340.85	80.83	925.33

Table A-1. Continued.

Year	Month	Jewett Brook	Stevens Brook	Mill River	St Albans WWTF	Total Load
====	=====	======	======	=====	======	=====
88	1	38.98	107.54	132.65	120.88	400.04
88	2	60.77	186.07	172.55	89.98	509.37
88	3	983.47	2087.19	3181.66	255.49	6507.82
88	4	239.86	263.34	348.40	160.32	1011.93
88	5	378.93	107.43	108.40	107.83	702.59
88	6	0.00	39.82	16.64	77.62	134.08
88	7	3.90	40.34	29.38	86.22	159.85
88	8	6.51	76.71	13.21	87.89	184.32
88	9	130.05	26.63	11.98	102.97	271.64
88	10	0.00	29.36	22.72	66.90	118.98
88	11	326.94	469.04	456.85	138.91	1391.73
88	12	60.10	30.30	41.95	63.43	195.78
89	1	181.65	297.13	299.77	63.29	841.85
89	2	288.73	545.03	931.87	94.13	1859.77
89	3	2654.62	1912.21	6544.27	181.80	11292.90
89	4	1389.55	588.36	1491.58	240.59	3710.08
89	5	172.58	49.41	129.33	165.10	516.42
89	6	19.67	68.96	132.59	114.89	336.11
89	7	0.00	23.94	6.49	125.72	156.14
89	8	0.00	23.60	3.33	80.06	106.98
89	9	16.09	144.29	8.45	123.20	292.03
89	10	698.37	262.21	115.26	108.18	1184.03
89	11	387.58	258.03	185.40	122.00	953.01
89	12	9.29	35.68	49.36	78.36	172.69
90	1	520.30	720.71	3223.23	108.25	4572.50
90	2	192.86	824.17	4283.53	130.90	5431.46
90	3	1385.17	564.35	2206.41	158.93	4314.86
90	4	1949.07	1626.00	1173.04	193.48	4941.59
90	5	157.29	196.94	441.25	131.55	927.03
90	6	5.72	49.29	95.22	125.55	275.78
90	7	73.67	144.40	1363.24	175.82	1757.14
90	8	404.78	217.48	1024.04	0.00	1646.30

Table A-2. Estimates of Historical Total Phosphorus Loadings to St. Albans Bay, from Hyde et al. (1993).

Year	Phosphorus Loading (kg/yr)				
	Jewett and Stevens Brooks			Mill River Nonpoint[1]	Total for Watershed
	Point	Nonpoint[1]	Total		
1850	69	7011	7080	7822	14902
1860	69	8639	8708	9638	18346
1870	138	8639	8777	9638	18415
1880	138	10016	10154	11174	21328
1890	8521	9766	18287	10895	29182
1900	8863	9766	18629	10895	29524
1910	9674	9140	18814	10197	29011
1920	11262	11268	22530	12571	35101
1930	19798	14148	33946	15784	49730
1940	16931	12019	28950	13409	42359
1950	22740	12520	35260	13968	49228
1960	22978	14023	37001	15644	52645
1970	24939[2]	12395	37334	13828	51162
1980	21900[3]	12520	34420	13968	48388
1990	788[4]	15274	16062	17041	33103

Notes:

1. Nonpoint source loads are estimates from Table 5, using the cattle index.
2. Measured point source load, 1975-1976, Vermont Agency of Environmental Conservation (1977).
3. Masured point source load, 1982, St. Albans Bay Rural Clean Water Program (1991).
4. Measured point source load, 1990-1991, Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation (1992).

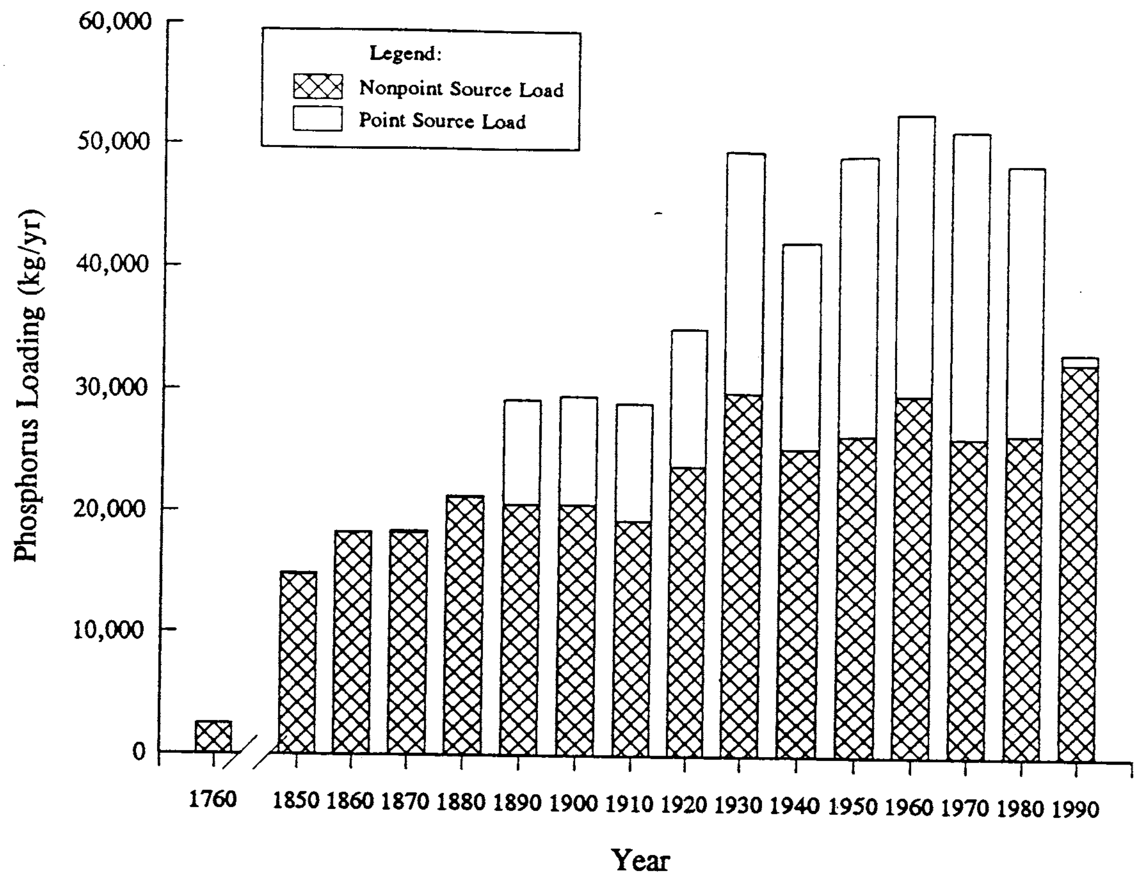

Figure A-1. **Estimates of Historical Total Phosphorus Loadings to St. Albans Bay, from Hyde et al. (1993).**

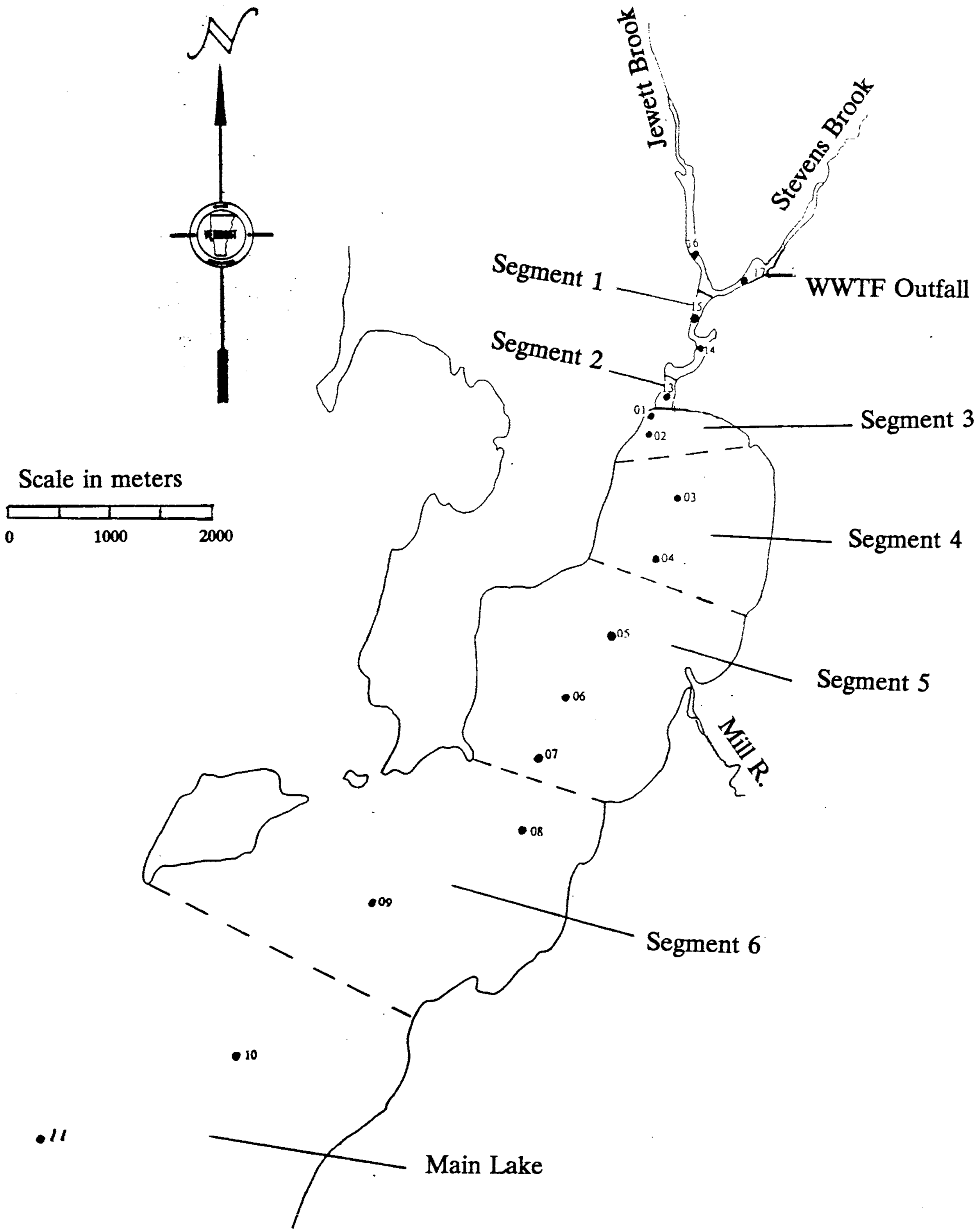

Figure A-2. **Location of Sampling Stations for the St. Albans Bay Diagnostic Feasibility Study, and Spatial Segmentation Used in a Mass Balance Modeling Study, from Smeltzer et al. (1993).**

Table A-3. Location of Sampling Stations for St. Albans Bay Diagnostic Feasibility Study, and Co-located Stations from Other Monitoring Studies, from Smeltzer et al. (1993).

Station	Latitude (deg min)	Longitude (deg min)	Total Depth (m)	Co-Located Stations[1]
Bay/Wetland				
01	44 48.60	73 09.15	1	RCWP-14
02	44 48.47	73 09.18	3	RCWP-12
03	44 48.12	73 08.97	4	
04	44 47.80	73 09.14	6	LCDFS-41
05	44 47.42	73 09.47	6	
06	44 47.12	73 09.73	7	LMP-17, LCDFS-40
07	44 46.78	73 09.98	7	
08	44 46.42	73 10.15	9	RCWP-11
09	44 45.97	73 11.20	20	LCDFS-37
10	44 45.13	73 12.13	22	
11	44 44.22	73 13.10	32	
13	44 48.71	73 09.08	1	
14	44 48.99	73 08.76	1	
15	44 49.18	73 08.80	1	
16	44 49.46	73 08.80	1	
17	44 49.27	73 08.50	1	
Tributaries				
STEV01	44 50.95	73 06.18		RCWP-22, LCDFS-STEV01
STEV02	44 49.33	73 08.28		
JEWE01	44 51.37	73 09.08		RCWP-21
JEWE02	44 50.18	73 09.00		
MILL01	44 46.78	73 08.67		RCWP-24, LCDFS-MILL01
WWTF				RCWP-25, LCDFS-SAM

1. RCWP = St. Albans Bay Rural Clean Water Program (1991)
LMP = Vermont Lay Monitoring Program (Picotte and Lohner, 1993)
LCDFS = Lake Champlain Diagnostic-Feasibility Study (Vermont DEC and New York State DEC, 1992)

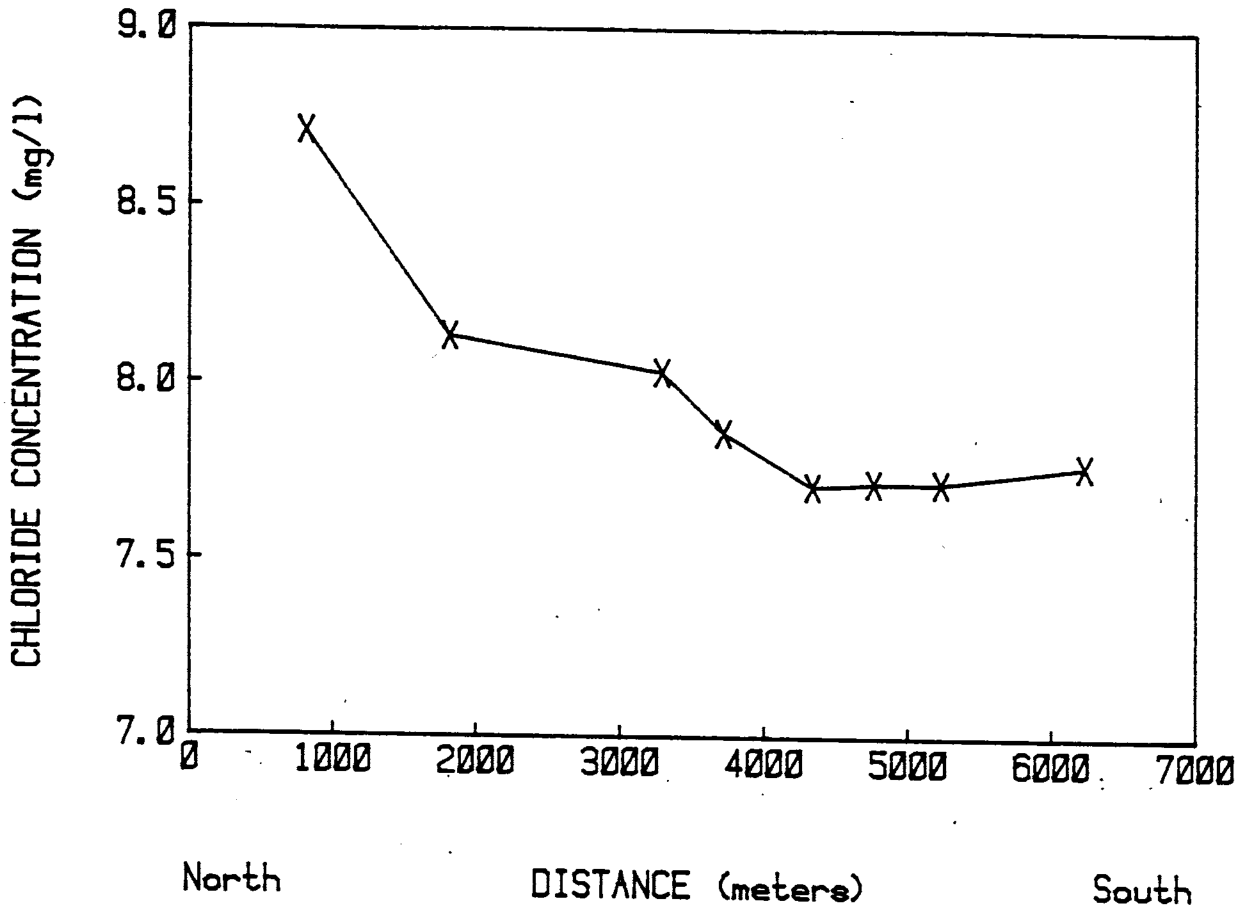

Figure A-3. **Mean Chloride Concentrations Measured at Ten Stations in St. Albans Bay During Summer of 1982, from Smeltzer (1983).**

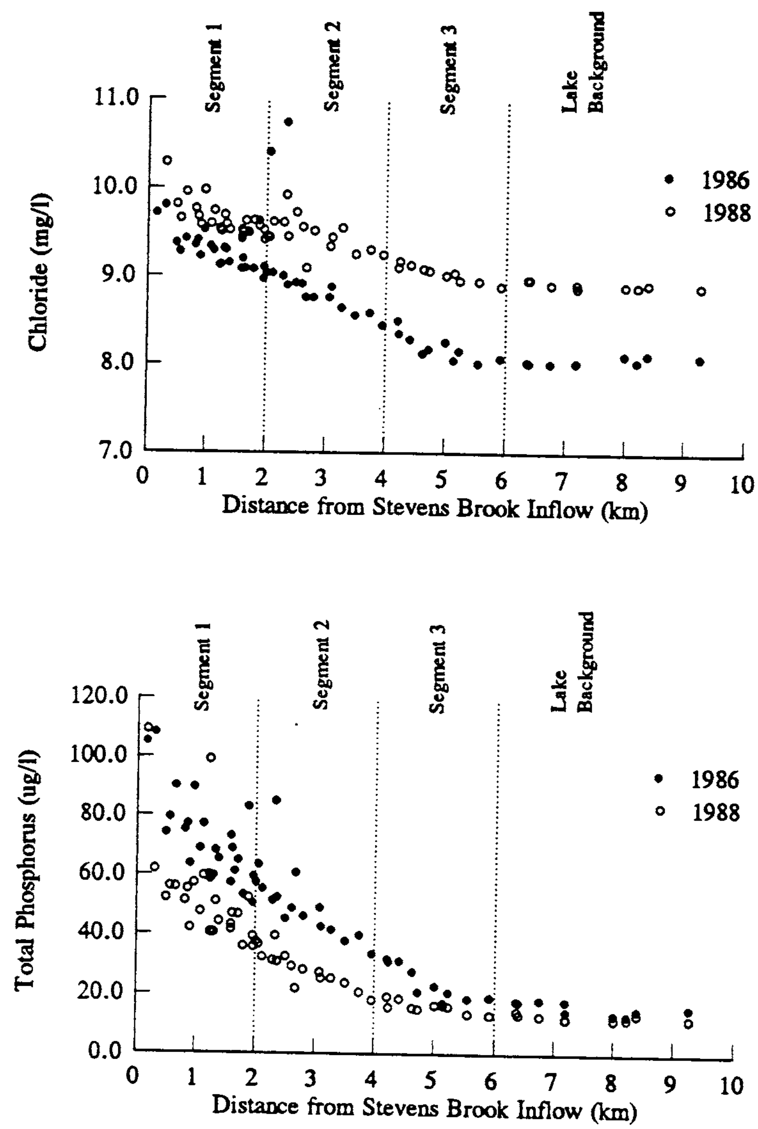

Figure A-4. **Mean Chloride and Total Phosphorus Concentrations Measured in St. Albans Bay During the Summers of 1986 and 1988, from Smeltzer (1991).**

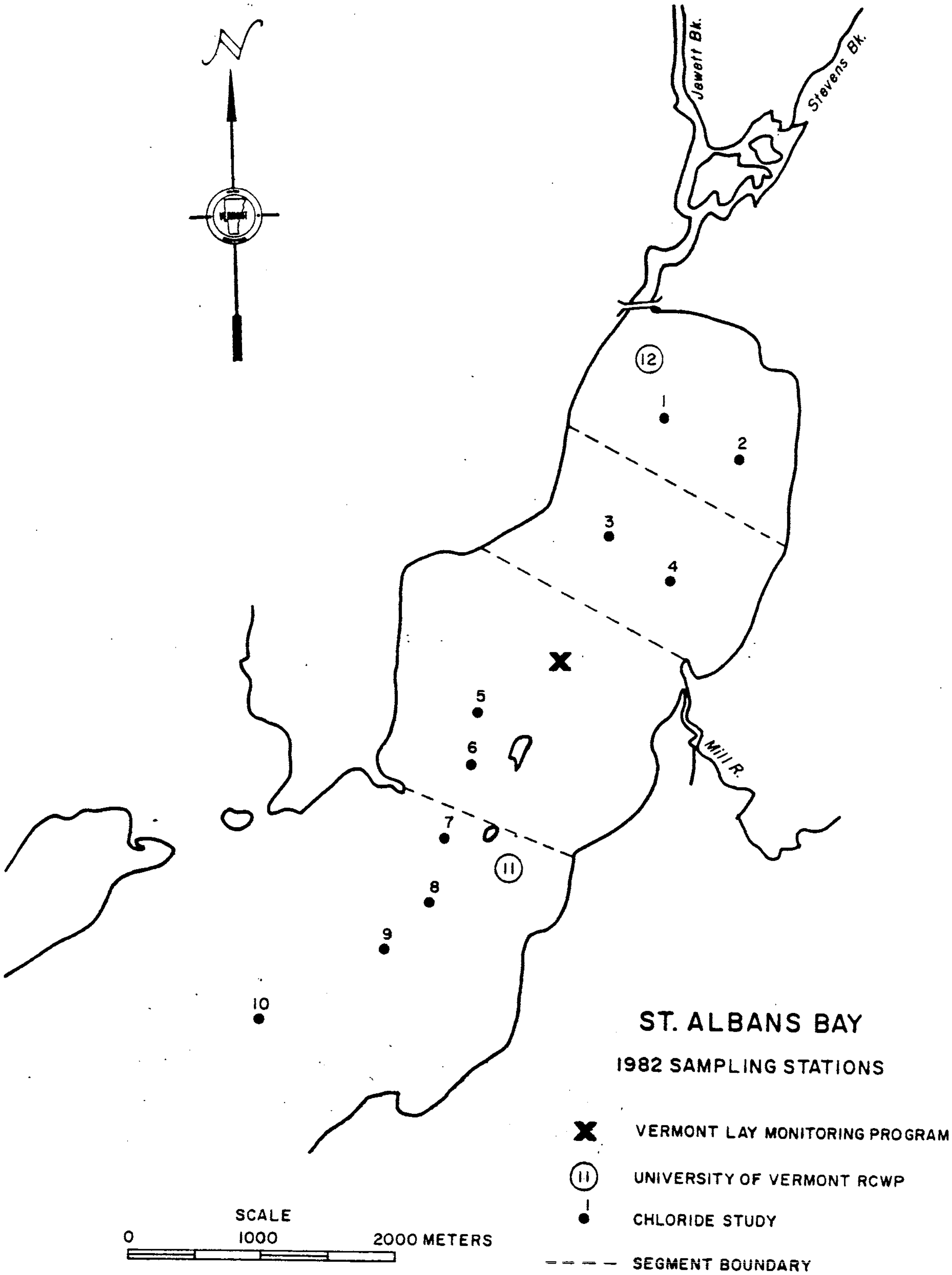

Figure A-5. **Spatial Segmentation Used by Smeltzer (1983) in a Mass Balance Modeling Study of St. Albans Bay.**

Table A-4. Monthly Mean Chloride Loadings and Dispersive Exchange Rates from a Calibrated Chloride Mass Balance Model for St. Albans Bay and Stevens Brook Wetland (from Smeltzer et al., 1993).

Segment	Month	Concentration (mg/l)	Tributary Inflow (m^3/day)	Tributary Loading (g/day)	Exchange Rate (m^3/day)
1	Apr	67.32	1.12 E5	7.56 E6	0
	May	66.78	1.81 E4	1.21 E6	0
	Jun	77.24	8.92 E3	6.89 E5	0
	Jul	82.13	7.55 E3	6.20 E5	0
	Aug	85.05	7.61 E3	6.47 E5	0
	Sep	91.35	7.78 E3	7.10 E5	0
	Oct	84.85	4.90 E4	4.15 E6	0
	Nov	57.57	1.07 E5	6.14 E6	0
2	Apr	58.40			2.36 E4
	May	49.40			9.61 E3
	Jun	48.00			7.64 E3
	Jul	43.53			9.47 E3
	Aug	48.12			8.46 E3
	Sep	55.83			6.86 E3
	Oct	56.20			5.44 E4
	Nov	39.03			1.18 E5
3	Apr	16.05			1.56 E6
	May	16.61			1.82 E5
	Jun	13.88			1.72 E5
	Jul	12.75			2.60 E5
	Aug	14.89			1.36 E5
	Sep	15.55			1.37 E5
	Oct	30.43			1.41 E5
	Nov	22.35			3.60 E5
4	Apr	12.35			6.99 E6
	May	11.63			1.23 E6
	Jun	10.60			1.11 E6
	Jul	10.74			1.11 E6
	Aug	10.95			9.45 E5
	Sep	11.23			6.23 E5
	Oct	11.54			2.31 E6
	Nov	11.93			6.41 E6
5	Apr	11.47	3.42 E4	1.23 E6	5.02 E6
	May	10.81	2.43 E4	8.93 E5	2.04 E6
	Jun	10.07	1.00 E4	3.80 E5	2.33 E6
	Jul	10.25	4.81 E3	1.85 E5	1.39 E6
	Aug	10.35	6.58 E3	2.50 E5	1.05 E6
	Sep	10.23	2.37 E4	8.50 E5	2.65 E6
	Oct	9.98	1.29 E5	4.28 E6	2.58 E7
	Nov	11.17	1.57 E5	5.19 E6	6.37 E6
6	Apr	10.05			7.32 E7
	May	10.00			4.80 E6
	Jun	9.69			1.48 E7
	Jul	9.76			4.97 E6
	Aug	9.64			4.68 E6
	Sep	9.77			6.54 E6
	Oct	9.73			2.68 E8
	Nov	9.85			2.91 E7
Lake	Apr	9.95			
	May	9.65			
	Jun	9.63			
	Jul	9.63			
	Aug	9.48			
	Sep	9.58			
	Oct	9.70			
	Nov	9.55			

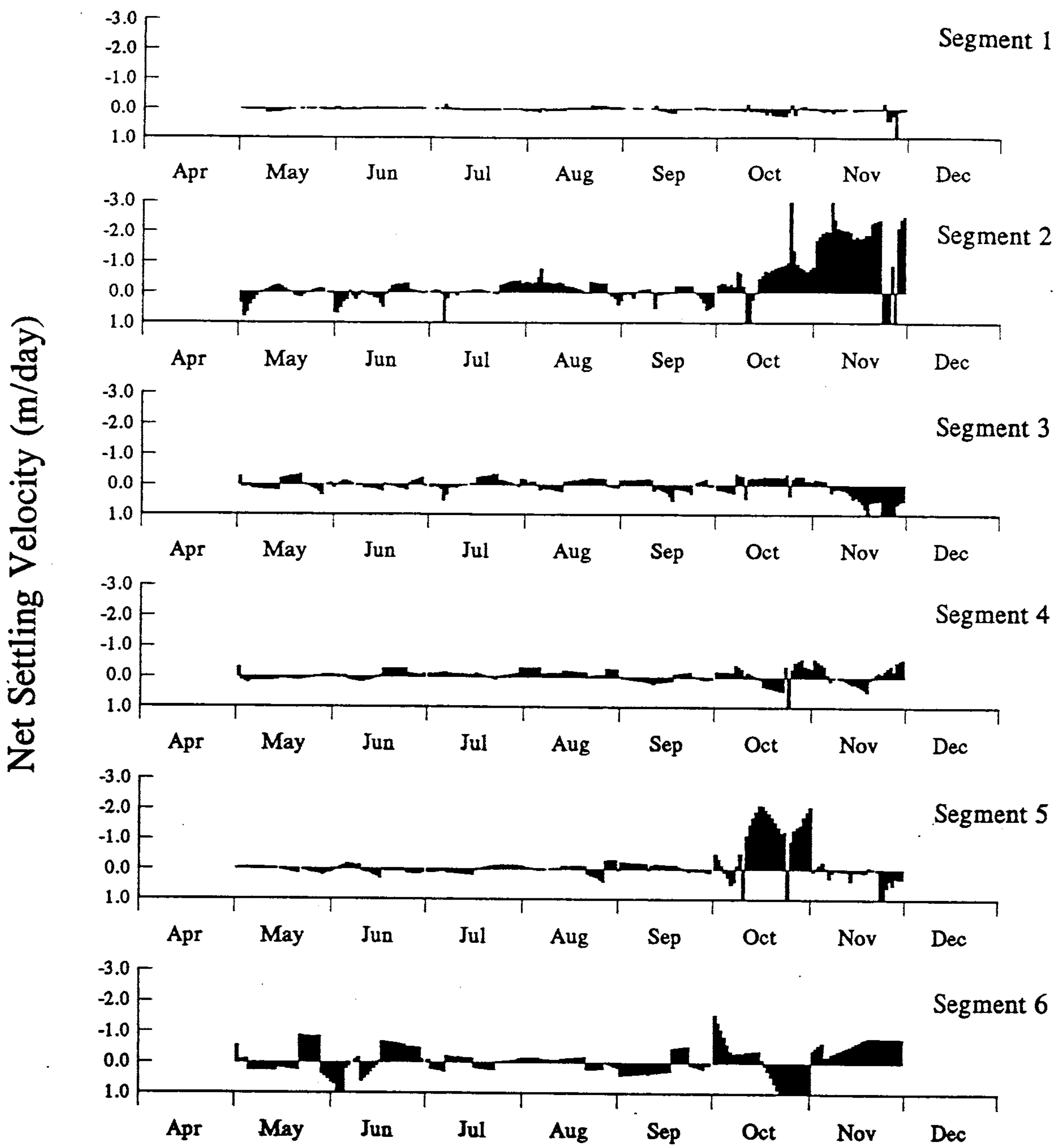

Figure A-6. **Net Phosphorus Settling Velocities Calculated for St. Albans Bay and Stevens Brook Wetland Using a Mass Balance Model, from Smeltzer <u>et al</u>. (1993).**

APPENDIX B

FIELD NOTES

TABLE B-1. FIELD NOTES ON SEDIMENT CORE SAMPLING

Sediment Core Sampling Dates

DATE: Mon, Aug. 17,1992

Sites/Cores

Inner Bay	:	2, 3, 4, 14, 15, 16, 21, 24, 25, 25DC, 35, 36, 37, 38, 39, 40
Middle Bay	:	11, 12, 12DC, 13, 41
Stevens Brook	:	20, 34

DATE: Tues., Aug. 18,1992

Sites/Cores:

Middle Bay	:	1, 5, 7, 8, 9, 10, 42, 43
Outer Bay	:	27, 44, 45

Decided to Omit 26
Unable to get core - 6

DATE: Thurs., Aug. 20,1992

Sites/Cores:

Stevens Brook Wetland	:	17, 18, 19, 22, 23, 28, 29, 30, 31, 32, 33, 33DC

COMMENTS ON FIELD SAMPLING

AUGUST 17, 1992

Core #21: Very sandy, core would not penetrate more than a few inches. Heavy algal population in inner bay.

Core #20: Extremely heavy algal growth in wetland. Took a couple of tries to get a good core at site #20.

Core #13: Heavy growth of Eurasian Milfoil; sandy soil difficult to penetrate core into sediments; because of this, duplicate was collected at site #12 rather than #13.

Sites #25 and #12: Duplicate cores collected.

Site #26: Access to Mill R. not possible; it was decided (Eric Smeltzer and myself) that this site did not contribute to the goals of this study; site was not sampled.

Site #11: Not possible to obtain a core at Lat/Long in table 3 of QA plan; bottom was rock; moved to slightly deeper water (Lat. 44°47.67'; Long. 73°9.83) and obtained core there.

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Site #9 : Heavy growth of Eurasian Milfoil; very sandy bottom could not sink corer into sediments; moved toward Lazy Lady Island and obtained core at Lat. 44°46.90'; Longitude 73°9.44'; Lots of freshwater mussel shells visible in shallow area east of Lazy Lady Island.

Site #5 : 5 or 6 tries yielded no acceptable core; tried moving boat position by 50-100' to no avail. Finally got core using pole system with lead weight attached to barrel and dropping from 5' above bottom.

Site #6 : Not possible to get a core; sand and rocks. Tried moving boat, gave up after 4 or 5 tries.
-Localized growth of algal colonies floating on surface in middle and outer bay.
-Used steel cable with lead weight on corer to get samples at sites #45,44 and 27. Used pole system at all other sites.

AUGUST 20,1992

Stevens Brook Wetland:
-Samples # 22, 23, and 29 taken in region with noticeable current; all others in flooded areas.
-Entire :flooded: region surrounded by thick growth of cattails.

TABLE B-2. DESCRIPTIONS OF SEDIMENT CORES

August 17, 1992

Core 2	Water depth = 4.9 m (16.1'); Core depth = 33cm; generally homogeneous at any given depth, with exception of about 12 cm (some undecomposed plant material); sediments became thicker -more clay with depth and very slightly lighter in color(but mostly pretty black)
Core 3	Water depth = 3.0 m (9.8'); Core depth = 23 cm. Plant material (leaves) at top; less water at 1 cm depth than #2 (more coarse grained) gritty texture.
Core 4	Water depth = 4.3 m (14.1); Core depth =32cm, Watery and flocculent in top 3-4 cm; very fine (smooth) texture; some partially decomposed plant material throughout.
Core 14	Water depth = 5.1 m (16.7'); Core depth = 31 cm; Watery and flocculent in top 2-4 cm; very fine (smooth) texture, bottom (4-12 cm) very cohesive(with clay) and much dryer than top 4 cm dark color.
Core 15	Water depth = 4.6 m (15.1'); Core depth = 35 cm; top 2 cm watery, very fine grained dark color.
Core 16	Water depth = 2.4 m (77.9'); Core depth = 28 cm; top 2 cm watery; some plant material at 3-4 cm ; slightly gritty texture, black color; fairly dry at >4 cm
Core 21	Water depth = 0.9 m (3.0'); Core depth = 6 cm; very sandy, Distinct green color at surface and throughout fair amount of plant material; Entire core very dry, but water drained out bottom due to sandy, shallow core;unable to get slices at 7-8 cm and 11-12 cm.
Core 24	Water depth = 5.0 m (16.4'); Core depth = 31 cm; black muck very similar to other deep cores (e.g.#2); not as watery at surface as some others(e.g.14-16); fine grained with quite a bit of clay.
Core 25	Water depth = 4.6 m (15.1'); Core depth = 36 cm; some silt in core (slightly gritty texture); black in to 4 cm, grey streaks (clay) deeper in core; some plant matter.
Core 25 DC	Water depth = 4.6 m (15.1'); Core depth = 37 cm; top 1 cm more cohesive than most; dry, friable sediment at >2 cm. Otherswise similar to #25.

Core 35 Water depth = 4.0 m (13.1'); Core depth =32 cm; very watery core; very fine grained and "mushy"; small amount of plant matter.

Core 36 Water depth = 4.0 m(13.1'); Core depth = 27 cm; very dry sediment ; mussel shell at 3 cm; silty clay at top; mostly clay (fine grained sediment) at >4 cm; fair amount of plant material.

Core 37 Water depth = 3.0 m(9.8'); Core depth = 17 cm; Watery sediment; organic odor with fair amount of plant matter; silty; changed to a more dense silty clay at about 6 cm.

Core 38 Water depth = 4.9 m (16.1); Core depth = 40 cm; fairly watery; organic odor; silty with plant matter in advanced stage of decay

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Core 39 Water depth = 5.0 m (16.4'); Core depth = 28 cm; slightly watery mixture of organic matter and clay (light and dark "patches"), small amount of silt, slightly gritty.

Core 40 Water depth = 4.6 m (15.1') core depth = 28 cm; slightly watery at surface, but very firm at > 3 cm; fairly smooth texture clay (mostly) with some silt-more gritty at >4cm.

Core 20 Water depth = 1.8 m (5.9'); Core depth = 26 cm; silty (gritty texture); noticeably higher in organic matter (plant material)than bay sites; fairly watery, even at 8-12 cm.

Core 34 Water depth = 0.9 m (3.0'); Core depth = 18 cm; interface at 1-2 cm between brown flocculent organic matter in early stages of demoposition and black sediment. Top 2 cm very watery silty-gritty texture.

Core 41 Water depth = 2.7 m (8.9); Core depth = 28 cm; watery, very fine grained (smooth texture) throughout; lots of organic matter (well decomposed); some plant material (quite a bit at >6 cm)

Core 11 Water depth = 3.9m(12.8'); Core depth = 16 cm; dense clay plug at bottom of core (light grey); above this, dense, well packed sand(very coarse grained); field duplicate at 11-12 cm.

Core 12	Water depth = 5.7 m (18.7'); Core depth= 33 cm; top 1-2 cm watery and black in color; at >4 cm, more clay (lighter color) and a little bit of silt (smooth, slightly gritty texture)
Core 12 DC	Water depth = 5.8 m (18.7'); Core depth = 38 cm; light brown layer at very top (0-0.5 cm); black organic matter (decomposed) at 0.5-2.0 cm depth, gradually mixing with lighter (brown and grey) sediment at >2 cm. Mostly smooth (clay) texture, very slight grittiness (silt)
Core 13	Water depth = 1.4 m (4.6'); Core depth = 6 cm; very sandy and dry; lots of roots and plant matter. Field duplicate taken at 1-2 cm; not enough core to get 7-8 cm and 11-12 cm slices.
Core 1 [FD at 1-2 cm]	Water depth = 6.2 cm (20.3'); Core depth = 34 cm; light brown at top (0-0.5 cm), then darker below (possibly boundary between oxidized and reduced layers); mostly clay-cohesive structure at >4 cm
Core 5	Water depth = 6.0 m (19.7'); Core depth = 7 cm; sandy throughout, mussel at 1-4 cm limited amount of sediment obtained. Shell fragments throughout; 3-4 cm sample spooned from top of eggshell"plug".
Core 7	Water depth = 5.0 m (16.4'); Core depth = 14 cm; top 2 cm mostly plant material and roots (including live Eurasian Milfoil);2-4 cm very coarse sand, gravel; 4-14 cm very dense grey clay.
Core 8	Water depth = 5.7 m (18.7'); Core depth = 34 cm; light colored (brown) flocculent material at surface, alongwith parts of some aquatic plants; very "mushy" (watery) core; smooth texture with very small amount of silt. Field duplicate taken at 3-4 cm.
Core 9	Water depth = 2.5 m (8.2'); core depth = 31 cm; reddish-brown flocculent sediment at surface (>1 cm). Quite a bit of plant material in top 4 cm; fairly coarse texture (silt-sand) in top 4 cm; silt only in 4-8 cm; silty clay at 8-12 cm; fine roots down to 12 cm; field duplicate taken at 7-8 cm
Core 10	Water depth = 5.6 m (18.4'); Core depth = 47 cm; fairly uniform composition with depth; mostly clay mixed with organic matter; medium water content.

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Core 27 Water depth = 11.5 m (37.7'); Core depth = 38 cm; watery core; dark color- high in decomposed organic material Smooth texture- fine grain size; field duplicate taken at 7-8 cm

Core 42 Water depth = 6.4 m (21.0'); Core depth = 37 cm; fairly firm core medium water content; smooth texture-fine grained sediment; less organic matter that #27.

Core 43 Water depth = 4.8 m (15.7'); Core depth = 37 cm; distinct patches of black organic matter and light brown sediment; clay with small amount of silt at >4 cm; small amount of plant material. Field duplicate taken at 11-12 cm.

Core 44 Water depth = 9.0 m (29.5'); Core depth = 16 cm; fairly uniform color and texture with depth; medium water content; dark color-lots of organic matter (well decomposed); fairly smooth texture with small amount of grit.

Core 45 Water depth = 10.3 m (33.8'); Core depth = 17 cm; very watery core; silty clay with lots of decomposed organic matter.

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Core 17 Water depth = 0.6 m (2.0'); Core depth = 17 cm; fairly watery in top 1 cm; black organic matter with small amount of silt down to 10 cm. Some plant material below 10 cm, mostly undecomposed wood fiber.

Core 18 Water depth = 0.3 m (1.0'); Core depth = 27 cm; fairly dry, firm core with quite a bit of undecomposed plant material (especially at >4 cm); silty texture at top; brownish-red wood fiber "plug" at bottom; field duplicate taken at 1-2 cm.

Core 19 Water depth = 0.2 m (0.66'); Core depth = 19 cm; flocculent light brown layer at top (0.2 cm), gritty texture-quite a bit of silt and plant material; took extra slices at 2-3, 4-5,
5-6, and 6-7 cm. Lighter color than most brown silt mixed with black organic matter.

Core 22 Water depth = 0.3 m (1.0'); Core depth = 18 cm; dry, sandy core with thin layer of finer (silty) material at surface; took field duplicate at 0-1 cm.

Core 23 Water depth = 0.4 m (1.3'); Core depth = 13 cm; thin layer (0.2-0.4 cm) of flocculent light grown material at top otherwise, sandy, dry core. Field duplicate taken at 3-4 cm.

Core 28 Water depth = 0.2 m (0.66'); Core depth = 37 cm; medium water content in core; organic matter with some silt and plant material more silt and lighter color deeper in core, brownish-red wood fiber at bottom of core.

Core 29 Water depth = 0.7 m (2.3'); Core depth = 16 cm; sand mixed with organic matter; patches of light and dark color; fairly dry core; very sandy with little organic matter at >11 cm.

Core 30 Water depth = 0.9 m (3.0'); Core depth = 31 cm; mixture of silt and organic matter with fair amount of plant material. Also saved 2-3 cm and 4-7 slices.

Core 31 Water depth = 0.2 m (0.66'); Core depth = 21 cm; mixture of silt and organic matter; medium water content. Smooth (just slightly gritty) texture; small amount of sand at 12 cm. Took 2-3 cm and 4-7 cm slices (saved) also.

Core 32 Water depth = 0.3 m (1.0'); Core depth = 25 cm; very watery core, high in organic matter; smooth texture, very little silt; also saved 4-7 cm slice.

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Core 33D Water depth = 0.6 m (2.0'); Core depth = 11 cm; Watery, light colored (brown) flocculent material at surface (top 0.5 cm); lots of sticks and plant material throughout; gritty texture; 11-12 cm slice not precisely measured, but taken from "plug" at base of core(inside eggshell). Forgot to take duplicate at site 19; will analyze # 33 and 33D for extractable P for QA.

Core 33 Water depth = 0.6 m (2.0'); Core depth = 30 cm; watery at surface (flocculent material); mixture of silt and organic matter; much less plant material than #33FD (infact, very little in #33); medium water content at >2 cm.

APPENDIX C

QUALITY ASSURANCE RESULTS

In the Quality Assurance Project Plan (QAPP) for this study, data quality objectives were established in four primary areas - precision, accuracy, completeness, and representativeness. A brief overview of the quality assurance work is presented here. A more detailed evaluation is presented in a separate report.

Precision is indicated by the reproducibility of replicate analyses. In this study, analyses were performed on laboratory duplicates (samples designated LD), field duplicates (FD), and duplicate (collocated) cores (DC). Results obtained for these samples are compared with those for primary samples (PS) in Table C-1 through C-6. In general, precision was excellent, and met the goals set in the QAPP. However, in some cases where concentrations of an analyte were low (particularly for NH_4Cl-P and % Organic Matter), the relative differences between replicates were fairly high.

Accuracy is a measure of the degree to which analytical measurements reflect the true level of analyte in the sample. This was evaluated through the analysis of sediment samples spiked with known amounts of orthophosphate, and analysis of a standard reference material (Buffalo River sediment). The recovery of orthophosphate spikes by the sediment phosphorus extraction sequence is summarized in Table C-7. While the recovery exceeded 90% for several samples, less than 75% was recovered for a few samples. Similar problems were experienced by Ackerly (1983). It is possible that a portion of the phosphorus becomes bound in a form not removed by the extraction reagents.

Completeness refers to the amount of valid data obtained relative to the statistical requirements of the study objectives. The goal of this study was to obtain valid 1992 observations of NH_4Cl-P, NaOH-P, HCl-P, and total P for comparison with at least 95% of the 1982 measurements. This goal was not met, in the strictest sense, since it was not possible to obtain a core at site #6 visited by Ackerly (1983). However, the data base proved more than adequate to meet the statistical requirements of the study objectives.

Representativeness is defined as the degree to which data derived from a survey describe a characteristic of a population or an environmental condition. This is important in selecting the number and spatial distribution of sampling sites, and was considered in designing the sampling program for this study.

Table C-1. Comparison of Sediment Phosphorus Fractionation Results for Primary Samples and Laboratory Duplicates.

CORE NUMBER	DEPTH	NH4Cl			NaOH			NH4Cl+NaOH			HCl			EXTRACTABLE INORGANIC 'P'		
	cm	LD ug/g	PS ug/g	Difference %	LD ug/g	PS ug/g	Difference %	LD ug/g	PS ug/g	Difference %	LD ug/g	PS ug/g	Difference %	LD ug/g	PS ug/g	Difference %
3	1	2.00	2.10	4.9	139.9	143.3	2.4	141.9	145.4	2.4	758	724	4.8	900	869	3.6
3	4	0.95	1.12	14.9	87.6	104.1	15.9	88.6	105.3	15.8	757	753	0.6	846	858	1.5
3	8	1.32	1.50	11.9	105.9	106.0	0.1	107.2	107.5	0.2	766	763	0.4	873	870	0.3
3	12	0.67	0.95	29.9	46.8	57.0	17.9	47.5	58.0	18.1	721	705	2.4	769	763	0.8
25	1	0.49	0.34	43.8	212.5	229.2	7.3	213.0	229.5	7.2	597	599	0.4	810	829	2.3
25	2	0.67	1.04	35.2	210.9	220.3	4.3	211.6	221.3	4.4	594	587	1.2	806	808	0.3
25	4	0.63	0.48	31.4	284.5	278.1	2.3	285.1	278.6	2.3	615	619	0.7	900	898	0.3
25	8	1.42	1.26	12.0	483.1	489.8	1.4	484.5	491.1	1.3	886	611	45.1	1371	1102	24.4
25	12	0.39	0.30	30.4	154.4	160.4	3.7	154.8	160.7	3.7	733	751	2.4	888	912	2.7
27	1	2.31	2.50	7.5	1054.5	1057.2	0.3	1056.8	1059.7	0.3	523	533	1.8	1580	1593	0.8
27	2	1.50	1.60	6.0	693.7	699.0	0.8	695.2	700.6	0.8	449	454	1.1	1144	1155	0.9
27	4	0.30	0.35	13.2	316.4	309.3	2.3	316.7	309.7	2.3	479	474	1.1	796	784	1.6
27	8	0.16	0.21	22.0	251.5	248.3	1.3	251.6	248.5	1.2	492	502	2.0	744	751	0.9
27	12	0.16	0.16	0.1	103.2	106.2	2.8	103.4	106.4	2.8	524	533	1.7	628	640	1.9
BRS		1.52	1.47	3.1	277.3	286.7	3.3	278.8	288.1	3.2	344	348	1.3	622	636	2.2
	MEAN	0.97	1.03	17.7	294.8	299.7	4.4	295.8	300.7	4.4	616	597	4.5	912	898	3.0

Table C-2. Comparison of Total Phosphorus and Organic Matter Results for Primary Samples and Laboratory Duplicates.

CORE NUMBER	DEPTH cm	TOTAL PHOSPHORUS			ORGANIC MATTER		
		LD ug/g	PS ug/g	Difference %	LD %	PS %	Difference %
1	1	1115	1090	2.3	9.2	7.0	32.1
3	2	748	948	21.1	2.5	1.8	40.6
5	4	369	382	3.4	0.5	0.5	4.1
7	4	796	784	1.5	1.6	1.0	52.6
11	8	474	479	1.1	1.1	0.4	155.6
16	12	1059	1119	5.3	3.2	2.4	33.3
19	1	1730	1838	5.9	10.2	6.2	65.1
21	4	646	606	6.6	1.0	0.5	97.0
22	1	1220	1292	5.6	4.7	3.7	25.1
25	2	1031	1058	2.5	6.5	5.1	26.8
29	4	1454	1633	11.0	5.3	4.9	8.6
33	8	2090	2099	0.4	9.9	10.1	1.8
34	12	2256	2366	4.6	8.4	8.4	0.2
36	1	993	905	9.8	3.3	3.3	0.6
37	2	979	878	11.5	7.7	7.7	0.8
37	8	853	792	7.7	7.1	7.1	0.7
38	4	1378	1201	14.7	7.9	7.7	2.7
44	12	809	835	3.1	3.5	3.1	11.7
	MEAN	1111	1128	6.6	5.2	4.5	31.1

Table C-3. **Comparison of Sediment Phosphorus Fractionation Results for Primary Samples and Field Duplicates.**

CORE NUMBER	DEPTH	NH4Cl			NaOH			NH4Cl+NaOH			HCl			EXTRACTABLE INORGANIC 'P'		
	cm	FD ug/g	PS ug/g	Difference %	FD ug/g	PS ug/g	Difference %	FD ug/g	PS ug/g	Difference %	FD ug/g	PS ug/g	Difference %	FD ug/g	PS ug/g	Difference %
1	2	0.99	0.45	121.6	528.4	453.8	16.4	529.4	454.3	16.5	473	494	4.3	1002	867	15.6
8	4	0.53	1.01	47.4	177.5	245.3	27.6	178	246.3	27.7	523	474	10.5	701	886	20.9
9	8	0.16	0.15	8.6	57.4	37.9	51.5	57.56	38.04	51.3	480	473	1.4	537	803	33.1
10	8	0.16	0.14	13.4	289.0	218.2	32.4	289.2	218.4	32.4	486	552	11.9	775	701	10.6
11	12	0.52	6.49	91.9	38.8	41.4	6.2	39.31	47.85	17.8	555	606	8.4	594	702	15.4
13	2	1.92	2.11	9.0	63.4	45.2	40.1	65.31	47.35	37.9	653	599	9.0	718	829	13.3
18	2	13.06	16.10	18.9	554.3	539.7	2.7	567.3	555.8	2.1	560	587	4.6	1128	808	39.5
22	1	10.83	11.66	7.1	375.1	388.4	3.4	385.9	400	3.5	573	619	7.5	959	898	6.8
23	4	5.20	5.36	3.0	475.5	477.1	0.3	480.7	482.4	0.3	589	611	3.6	1069	1102	3.0
27	8	0.26	0.21	21.1	234.7	248.3	5.5	235	248.5	5.4	509	751	32.2	744	912	18.4
	MEAN	3.36	4.37	34.2	279.4	269.5	18.6	282.8	273.9	19.5	540	576.5	9.3	823	851	17.6

Table C-4. **Comparison of Total Phosphorus, Total Iron and Organic Matter Results for Primary Samples and Field Duplicates.**

CORE NUMBER	DEPTH	TOTAL PHOSPHORUS			TOTAL IRON			ORGANIC MATTER		
		FD	PS	Difference	FD	PS	Difference	FD	PS	Difference
	cm	ug/g	ug/g	%	ug/g	ug/g	%	%	%	%
1	2	1427	1077	32.4	34805	35986	3.3	5.17	7.63	32.2
8	4	1042	914	14.1	27367	26988	1.4	7.27	6.01	21.0
9	8	737	571	29.1	23486	17528	34.0	5.66	7.30	22.6
10	8	981	958	2.4	33340	34518	3.4	3.85	4.85	20.6
11	12	685	552	24.2	27190	16706	62.8	0.86	7.08	87.9
13	2	819	624	31.1	17349	16516	5.0	1.59	5.70	72.1
18	2	1337	1318	1.5	17530	16422	6.7	2.90	5.09	43.1
22	1	1236	1292	4.3	22926	24835	7.7	3.61	3.47	4.0
23	4	1126	1257	10.4	25801	25319	1.9	1.23	5.01	75.4
27	8	891	1023	12.9	30831	34287	10.1	4.57	1.96	133.0
	MEAN	1028	959	16.2	26062	24911	13.6	3.67	5.41	51.2

Table C-5. Comparison of Sediment Phosphorus Fractionation Results for Primary Samples and Duplicate Cores.

CORE NUMBER	DEPTH	NH4Cl			NaOH			NH4Cl+NaOH			HCl			EXTRACTABLE INORG. PHOSPHORUS		
	(cm)	D.C ug/g	P.S ug/g	Difference %	D.C ug/g	P.S ug/g	Difference %	D.C ug/g	P.S ug/g	Difference %	D.C ug/g	P.S ug/g	Difference %	D.C ug/g	P.S ug/g	Difference %
12	1	0.44	1.50	70.5	350.6	371.4	5.6	351.0	372.9	5.9	461	494	6.7	812	867	6.4
12	2	0.85	1.35	37.2	415.4	411.3	1.0	416.3	412.7	0.9	465	474	1.7	882	886	0.5
12	4	0.89	1.62	45.1	377.3	328.5	14.9	378.2	330.1	14.6	469	473	0.9	847	803	5.5
12	8	0.39	0.79	50.8	163.5	148.4	10.1	163.9	149.2	9.8	565	552	2.4	729	701	4.0
12	12	0.29	1.21	76.3	91.3	95.0	3.9	91.6	96.2	4.8	602	606	0.7	693	702	1.2
25	1	0.33	0.34	3.7	218.0	229.2	4.9	218.3	229.5	4.9	579	599	3.4	797	829	3.8
25	2	1.08	1.04	4.4	234.4	220.3	6.4	235.5	221.3	6.4	596	587	1.5	832	808	2.9
25	4	0.57	0.48	19.3	292.0	278.1	5.0	292.6	278.6	5.0	620	619	0.1	912	898	1.6
25	8	1.22	1.26	3.7	471.4	489.9	3.8	472.6	491.1	3.8	610	611	0.1	1083	1102	1.7
25	12	0.21	0.30	30.6	144.3	160.4	10.1	144.5	160.7	10.1	742	751	1.2	887	912	2.8
	MEAN	0.63	0.99	34.1	275.8	273.2	6.6	276.4	274.2	6.6	571	576	1.9	847	851	3.0

Table C-6. **Comparison of Total Phosphorus, Total Iron and Organic Matter Results for Primary Samples and Duplicate Cores.**

CORE NUMBER	DEPTH (cm)	TOTAL PHOSPHORUS			ORGANIC MATTER			TOTAL IRON		
		D.C ug/g	P.S ug/g	Difference %	D.C %	P.S %	Difference %	D.C ug/g	P.S ug/g	Difference %
12	1	1090	1176	7.3	7.17	7.63	5.9	33520	34846	3.8
12	2	1170	1174	0.4	6.22	6.01	3.6	33191	44262	25.0
12	4	1121	1057	6.1	4.00	7.30	45.2	31732	31968	0.7
12	8	912	877	4.1	3.68	4.85	24.0	25124	27215	7.7
12	12	832	823	1.1	3.32	7.08	53.1	20737	23723	12.6
25	1	1104	1083	2.0	5.26	5.70	7.7	22757	26181	13.1
25	2	1112	1058	5.1	4.16	5.09	18.4	24085	24680	2.4
25	4	1197	1116	7.2	5.62	3.47	62.1	23368	23340	0.1
25	8	1152	1238	6.9	5.24	5.01	4.5	22258	24255	8.2
25	12	923	845	9.2	1.88	1.96	4.0	11832	14236	16.9
33	1	2030	2119	4.2	14.19	9.8	44.8			
33	2	2119	2274	6.8	15	10.48	43.1			
33	4	2150	1983	8.4	14.36	9.36	53.4			
33	8	1625	2099	22.6	21.07	10.09	108.8			
33	12	1230	2358	47.8	25.16	11.18	125.0			
	MEAN	1318	1419	9.3	9.09	7.00	40.2	24860	27471	9.1

Table C-7. **Recovery of Orthophosphate Spikes in the Sediment Phosphorus Extraction Sequence.**

CORE NUMBER	DEPTH (cm)	SPIKE ug PO4-P	SPIKE ug/g	NH4Cl ug/g	NaOH ug/g	HCl ug/g	TOTAL EXTR INORG P ug/g	PERCENT RECOVERY
8	8	0	0.00	0.53	78.46	632.78	711.77	
8	8	500	972.42	57.34	734.56	636.26	1428.16	73.67
10	12	0	0.00	0.16	125.52	511.09	636.78	
10	12	500	980.03	23.03	884.33	534.36	1441.71	82.13
11	2	0	0.00	1.08	44.07	469.63	514.79	
11	2	500	970.75	623.11	281.57	467.85	1372.52	88.36
13	1	0	0.00	2.10	69.98	610.11	682.19	
13	1	500	976.22	700.39	221.95	610.23	1532.57	87.11
16	4	0	0.00	3.12	190.94	522.82	716.88	
16	4	500	976.03	437.50	675.13	548.33	1660.96	96.73
17	8	0	0.00	23.68	1072.89	475.34	1571.91	
17	8	500	983.26	49.11	1685.79	483.45	2218.35	65.74
18	12	0	0.00	15.15	795.39	226.88	1037.41	
18	12	100	199.76	35.31	893.42	230.42	1159.15	60.94
20	4	0	0.00	9.10	829.85	571.30	1410.24	
20	4	100	194.95	20.97	967.40	571.33	1559.70	76.67
25	1	0	0.00	0.34	229.18	599.12	828.64	
25	1	100	197.02	7.70	373.55	606.17	987.42	80.59
25	1	500	974.21	155.55	962.11	602.33	1719.99	91.49
25	2	0	0.00	1.04	220.27	587.08	808.39	
25	2	100	194.51	8.38	373.55	604.14	986.07	91.35
25	2	500	977.82	193.81	922.57	608.37	1724.75	93.71
25	4	0	0.00	0.48	278.12	618.99	897.58	
25	4	100	195.12	8.92	450.23	645.94	1105.09	106.35
25	4	500	983.42	194.92	1022.26	653.03	1870.21	98.90
25	12	0	0.00		160.42	751.31	911.72	
25	12	100	194.66		323.31	740.15	1063.47	77.95
							Mean =	84.78

APPENDIX D

ADDITIONAL DATA AND ANALYSIS ON 1992 CORE SAMPLES

Table D-1. Complete Listing of All Analytical Results for 1992 Study of St. Albans Bay and Stevens Brook Wetland Bottom Sediments.

Core Number	Depth (cm)	QA Code	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Porosity %	Total Iron ug/g
1	1		0.65	421.2	421.8	422	844	1090	7.00	85.78	35856
1	2		0.45	453.8	454.3	358	812	1077	7.18	90.58	35986
1	4		0.63	539.7	540.4	458	998	1115	6.74	83.34	35961
1	8		1.51	618.1	619.6	518	1138	1183	4.84	82.51	35081
1	12		0.20	226.0	226.2	528	755	800	2.79	77.75	31924
2	1		0.63	251.8	252.4	520	773	943	6.03	88.78	28051
2	2		1.05	219.2	220.3	266	486	877	5.33	88.77	25326
2	4		1.01	245.3	246.3	556	803	913	5.58	86.44	25922
2	8		1.00	179.7	180.7	550	731	800	4.69	83.96	25770
2	12		0.52	17.9	18.4	628	646	683	1.81	73.96	18705
3	1		2.10	143.3	145.4	724	869	994	0.85	71.50	12376
3	2		1.87	138.0	139.9	754	894	948	1.76	68.94	11674
3	4		1.12	104.1	105.3	753	858	868	1.73	64.87	9794
3	8		1.50	106.0	107.5	763	870	669	1.62	59.53	9612
3	12		0.95	57.0	58.0	705	763	773	1.94	57.47	10252
4	1		0.80	404.9	405.7	480	886	1158	4.02	90.05	33430
4	2		0.67	309.3	310.0	482	792	1002	6.57	89.26	35140
4	4		0.85	399.1	400.0	495	895	1087	7.51	89.15	33968
4	8		1.22	233.1	234.3	488	722	954	7.22	86.10	30542
4	12		0.83	149.3	150.1	488	638	838	5.26	78.84	29710
5	1		1.78	84.0	85.8	375	460	495	1.78	73.98	8632
5	2		2.05	64.6	66.6	405	472	397	1.42	64.81	6983
5	4		1.70	30.2	31.9	540	572	382	0.50	45.20	4626
7	1		8.61	152.9	161.5	690	851	954	2.33	71.56	14928
7	2		2.95	50.3	53.2	694	747	797	2.75	57.03	11347
7	4		0.48	88.3	88.8	671	760	783	1.04	48.74	39457
7	8		0.76	126.9	127.6	654	782	824	0.92	54.48	44328
7	12		0.63	141.7	142.3	650	793	843	0.90	54.90	47422
8	1		1.14	519.2	520.3	506	1026	1517	9.49	94.01	30702
8	2		0.86	250.5	251.4	488	740	1115	8.05	92.30	27349
8	4		0.63	130.9	131.5	513	645	915	6.04	88.25	26988
8	8		0.53	78.5	79.0	633	712	955	3.42	76.08	20886
8	12		0.81	55.7	56.5	656	713	809	2.12	71.31	18145
9	1		2.00	26.7	28.7	522	550	618	2.02	68.40	6710
9	2		2.05	21.6	23.7	520	544	606	1.67	64.45	6139
9	4		0.16	23.7	23.9	453	476	541	1.12	52.26	6663
9	8		0.15	37.9	38.0	396	434	571	4.88	71.84	17528
9	12		0.16	45.7	45.9	499	545	729	8.00	79.44	24678
10	1		0.16	484.0	484.1	412	896	1283	8.71	88.88	37331
10	2		0.16	532.0	532.2	415	947	1320	8.32	88.44	37671
10	4		0.43	593.6	594.0	447	1041	1315	6.93	87.69	37301
10	8		0.14	218.2	218.4	462	681	958	4.59	80.04	34518
10	12		0.16	125.5	125.7	511	637	876	4.51	75.31	30620
11	1		0.30	51.7	52.0	438	490	588	1.91	60.98	13056
11	2		1.08	44.1	45.2	470	515	603	1.77	50.86	14629
11	4		2.27	36.4	38.7	510	548	566	1.10	41.02	15029
11	8		3.64	27.0	30.6	433	464	479	0.42	39.91	14287
11	12		6.49	41.4	47.9	543	591	552	0.65	37.77	16706

Table D-1. Continued.

Core Number	Depth (cm)	QA Code	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
12	1		1.50	371.4	372.9	494	867	1176	7.63	91.57	34845
12	2		1.35	411.3	412.7	474	886	1174	6.01	90.54	44264
12	4		1.62	328.5	330.1	473	803	1056	7.30	88.74	31969
12	8		0.79	148.4	149.2	552	701	876	4.85	80.89	27214
12	12		1.21	95.0	96.2	606	702	823	7.08	72.67	23723
13	1		2.10	70.0	72.1	610	682	701	0.93	47.73	14223
13	2		2.11	45.2	47.4	531	579	624	1.02	43.31	16516
13	4		1.85	35.4	37.3	560	598	594	0.88	36.15	18117
14	1		2.16	322.8	325.0	483	808	1151	1.45	90.42	34519
14	2		2.65	481.0	483.7	516	1000	1250	5.62	89.45	34009
14	4		2.53	45.5	48.0	488	536	1244	7.12	88.86	33309
14	8		1.63	197.6	199.2	507	706	952	5.69	83.76	29560
14	12		1.22	111.9	113.1	537	650	759	4.26	75.29	28780
15	1		1.67	299.9	301.5	524	825	1132	5.98	89.69	32220
15	2		1.95	362.5	364.5	523	887	1227	7.25	88.02	32998
15	4		2.13	409.9	412.0	520	932	1255	6.83	85.99	32219
15	8		2.11	376.7	378.8	524	903	1156	5.87	85.73	31200
15	12		1.53	135.3	136.8	504	641	884	3.74	78.64	31626
16	1		8.36	472.8	481.1	497	978	1210	5.67	82.92	17771
16	2		7.62	462.3	469.9	518	988	1186	5.04	75.99	16233
16	4		3.12	190.9	194.1	523	717	789	2.80	66.50	11454
16	8		2.18	142.7	144.8	443	588	695	1.86	61.97	10047
16	12		10.47	347.7	358.2	639	997	1119	2.42	62.64	14891
17	1		27.88	1228.1	1256.0	439	1695	2135	8.42	87.92	30578
17	2		24.38	1204.1	1228.5	453	1681	2108	8.72	86.53	28241
17	4		28.54	1187.7	1216.2	436	1652	2067	8.30	85.66	27908
17	8		23.68	1072.9	1096.6	475	1572	1941	6.40	82.44	26490
17	12		30.04	1549.7	1579.7	268	1847	2706	31.90	91.91	16561
18	1		28.63	641.5	670.1	501	1171	1609	4.95	76.49	19256
18	2		16.10	539.7	555.8	501	1057	1317	3.84	71.54	16422
18	4		13.10	507.5	520.6	468	988	1213	4.23	67.82	15708
18	8		15.17	785.8	801.0	278	1079	1708	16.04	85.31	20079
18	12		15.15	795.4	810.5	227	1037	1844	21.70	89.18	25685
19	1		27.39	976.4	1003.8	538	1542	1838	6.18	85.81	24040
19	2		24.63	932.3	956.9	522	1479	1809	8.37	83.63	22391
19	3		21.80	855.6	877.4	552	1429	1825	8.32	83.44	22577
19	4		21.08	939.4	960.4	524	1484	1760	8.59	83.26	22392
19	5		20.13	863.1	883.2	518	1401	1825	8.41	82.44	22272
19	6		21.55	919.3	940.9	520	1461	1830	8.55	82.54	21976
19	7		21.51	895.4	917.0	530	1447	1821	6.85	82.62	22784
19	8		16.27	937.0	953.3	524	1477	1834	8.70	82.03	22986
19	12		16.73	935.0	951.7	565	1517	1768	5.95	77.64	22339
20	1		13.19	933.6	946.8	471	1418	1914	10.00	91.14	30204
20	2		8.61	926.2	934.8	443	1378	1893	9.47	89.14	29889
20	4		9.10	829.8	838.9	571	1410	1757	7.97	87.61	27339
20	8		7.76	565.1	572.9	600	1173	1336	3.18	74.72	18947
20	12		10.42	587.0	597.4	565	1163	1320	5.13	75.91	10875
21	1		10.08	186.7	196.8	575	771	779	1.89	54.28	9238
21	2		10.56	291.6	302.1	585	887	890	3.58	63.65	10556
21	4		6.21	75.9	82.2	550	632	605	0.53	47.48	5809

Table D-1. Continued.

Core Number	Depth (cm)	QA Code	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
22	1		11.66	388.4	400.0	765	1165	1292	3.72	58.47	24835
22	2		10.96	407.6	418.6	760	1178	1296	3.42	57.61	24945
22	4		11.06	451.4	462.5	743	1205	1261	2.83	57.49	22825
22	8		9.82	400.9	410.8	778	1189	1963	3.45	49.61	22604
22	12		8.97	503.6	512.6	723	1235	1742	4.18	58.85	27660
23	1		11.22	1113.1	1124.3	675	1799	2254	2.80	48.25	22295
23	2		8.23	984.2	992.4	672	1665	990	1.68	42.78	22200
23	4		5.36	477.1	482.4	614	1096	1256	1.81	39.14	25319
23	8		5.73	1008.8	1014.5	723	1737	1866	2.44	42.04	40801
23	12		5.43	793.2	798.6	623	1422	1516	1.21	39.74	38810
24	1		0.72	226.8	227.5	477	705	1040	6.25	88.05	29798
24	2		0.58	270.5	271.1	490	762	1070	6.18	87.79	28478
24	4		0.76	300.5	301.2	485	786	1063	5.15	85.05	26939
24	8		0.44	181.1	181.5	538	719	977	2.91	76.63	23774
24	12		0.25	104.3	104.6	577	681	871	4.02	69.84	21449
25	1		0.34	229.2	229.5	599	829	1082	5.70	86.47	26181
25	2		1.04	220.3	221.3	587	808	1057	5.09	85.03	24679
25	4		0.48	278.1	278.6	619	898	1116	3.47	83.65	23340
25	8		1.26	489.8	491.1	611	1102	1237	5.01	81.83	24255
25	12		0.30	160.4	160.7	751	912	845	1.96	62.36	14235
27	1		2.50	1057.2	1059.7	533	1593	2080	9.72	94.15	42759
27	2		1.60	699.0	700.6	454	1155	1586	7.97	91.81	37675
27	4		0.35	309.3	309.7	474	784	1145	6.05	85.77	34553
27	8		0.21	248.3	248.5	502	751	1022	4.79	80.89	34287
27	12		0.16	106.2	106.4	533	640	868	4.02	79.29	28829
28	1							1509	11.19	85.48	26180
28	2							1507	11.47	85.09	26858
28	4							1468	11.91	85.10	25346
28	8							1415	11.44	83.67	25936
28	12							1087	11.39	80.30	24721
29	1							1722	4.20	64.18	23031
29	2							1752	4.18	61.53	23031
29	4							1633	4.89	69.12	26316
29	8							1461	4.66	64.41	24480
29	12							1392	5.29	43.05	29275
30	1							1587	4.48	73.68	21032
30	2							1557	4.71	70.37	20333
30	3							1473	4.67	69.57	21833
30	4							1450	4.74	69.14	20955
30	8							1489	4.90	68.16	21955
30	12							1558	4.65	65.81	22490
31	1							1824	6.25	74.76	22890
31	2							1745	6.02	74.80	21893
31	3							1938	6.83	75.96	24299
31	4							1847	6.58	76.97	24073
31	8							1942	5.42	72.38	23063
31	12							1918	4.91	70.23	21116
32	1							2398	17.69	91.16	29243
32	2							2360	18.72	90.42	30462
32	4							2407	18.58	90.14	30655
32	8							2301	18.86	89.00	30130
32	12							2377	18.12	87.59	29549

Table D-1. Continued.

Core Number	Depth (cm)	QA Code	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
33	1							2119	9.80	85.72	24825
33	2							2274	10.48	84.87	26109
33	3							1887	9.11	80.79	23929
33	4							1983	9.36	83.32	24370
33	8							2099	10.09	82.74	24518
33	12							2358	11.18	82.75	23730
34	1		29.23	1262.7	1291.9	477	1769	2278	10.13	89.34	30641
34	2		23.70	1327.6	1351.3	475	1826	2301	10.07	87.93	30752
34	4		18.83	1379.5	1398.3	447	1845	2280	9.83	86.68	30514
34	8		22.08	1331.5	1353.6	523	1877	2289		82.87	27578
34	12		31.15	1394.3	1425.4	506	1932	2366	8.36	79.85	25174
35	1							1168	7.75	88.33	28469
35	2							1111	9.27	86.63	27586
35	4							1450	8.01	87.50	29012
35	8							1379	6.99	84.59	25450
35	12							842	5.95	77.73	23058
36	1							905	3.28	66.63	13627
36	2							931	3.65	69.16	14622
36	4							896	3.03	66.01	13460
36	8							881	2.12	56.46	14355
36	12							853	1.91	54.92	14652
37	1							691	7.55	89.50	26702
37	2							878	7.69	87.46	26268
37	4							825	6.99	87.68	25015
37	8							792	7.08	86.64	25703
37	12							739	2.47	60.63	17544
38	1							1061	7.85	88.81	28594
38	2							1136	7.72	88.45	31156
38	4							1201	7.66	87.93	32066
38	8							1059	6.86	85.19	29528
38	12							771	5.67	79.53	23210
39	1							875	7.70	88.20	31754
39	2							927	7.79	87.37	31961
39	4							1131	7.62	87.16	32468
39	8							1015	5.76	80.55	28612
39	12							895	4.23	71.42	21452
40	1							825	3.96	83.12	16876
40	2							849	3.75	78.39	17385
40	4							888	3.61	71.86	17494
40	8							854	1.94	50.94	16240
40	12							765	2.29	61.05	24020
41	1							1367	8.66	86.76	38454
41	2							1083	8.46	90.36	32261
41	4							1022	8.25	89.61	30667
41	8							952	8.05	87.31	29478
41	12							927	7.65	85.52	29333
42	1							1143	8.39	91.71	29702
42	2							1364	8.20	86.87	36917
42	4							1178	6.86	83.88	34833
42	8							956	6.17	78.94	30942
42	12							870	5.41	75.58	29551

Table D-1. Continued.

Core Number	Depth (cm)	QA Code	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
43	1							970	7.82	85.18	30681
43	2							944	7.11	84.60	30110
43	4							787	4.75	74.79	24745
43	8							763	2.97	65.91	18786
43	12							715	4.63	76.29	25285
44	1							1611	7.48	88.49	31883
44	2							1262	5.30	83.82	30504
44	4							952	3.76	75.94	26838
44	8							816	3.20	74.16	25933
44	12							835	3.10	73.15	23822
45	1							1761	9.25	94.20	37540
45	2							1434	8.95	93.98	35732
45	4							1554	7.80	92.63	34331
45	8							1012	4.98	82.93	29842
45	12							883	4.39	80.13	32543
12	1	DC	0.44	350.6	351.0	460.6	811.6	1089	7.17	88.33	33298
12	2	DC	0.85	415.4	416.3	465.5	881.7	1170	6.22	87.69	32918
12	4	DC	0.89	377.3	378.2	468.6	846.8	1121	4.00	86.00	31517
12	8	DC	0.39	163.5	163.9	565.1	728.9	912	3.68	74.78	25085
12	12	DC	0.29	91.3	91.6	601.8	693.4	832	3.32	71.42	20749
25	1	DC	0.33	218.0	218.3	578.7	797.0	1104	5.26	84.45	22761
25	2	DC	1.08	234.4	235.5	596.1	831.6	1112	4.16	84.84	23966
25	4	DC	0.57	292.0	292.6	619.6	912.2	1197	5.62	82.57	23363
25	8	DC	1.22	471.4	472.6	610.4	1083.0	1152	5.24	79.38	22266
25	12	DC	0.21	144.3	144.5	742.1	886.6	923	1.88	57.82	11900
33	1	DC						2030	14.19	88.18	28844
33	2	DC						2119	15.00	86.68	30026
33	4	DC						2150	14.36	86.10	30137
33	8	DC						1625	21.07	84.23	26300
33	12	DC						1230	25.16	89.08	27216
1	2	FD	0.99	528.4	529.4	472.6	1002.0	1426	5.17	90.50	34652
8	4	FD	0.53	177.5	178.0	523.3	701.4	1042	7.27	88.88	27088
9	8	FD	0.16	57.4	57.6	479.5	537.1	737	5.66	74.72	23365
10	8	FD	0.16	289.0	289.2	486.0	775.1	980	3.85	79.18	33247
11	12	FD	0.52	38.8	39.3	554.7	594.0	685	0.86	33.16	27249
13	2	FD	1.92	63.4	65.3	653.1	718.4	818	1.59	45.92	17368
18	2	FD	13.06	554.3	567.3	560.3	1127.6	1337	2.90	69.63	17532
22	1	FD	10.83	375.1	385.9	572.7	958.6	1236	3.61	58.46	22979
23	4	FD	5.20	475.5	480.7	588.6	1069.3	1126	1.23	37.18	25855
27	8	FD	0.26	234.7	235.0	509.3	744.2	891	4.57	79.78	30905
43	12	FD						723	4.75	76.41	25139
3	1	LD	2.00	139.9	141.9	758	900				
3	2	LD	1.79	133.0	134.8	758	893				
3	4	LD	0.95	87.6	88.6	757	846				
3	8	LD	1.32	105.9	107.2	766	873				
3	12	LD	0.67	46.8	47.5	721	769				
25	1	LD	0.49	212.5	213.0	597	810				
25	2	LD	0.67	210.9	211.6	594	806				
25	4	LD	0.63	284.5	285.1	615	900				
25	8	LD	1.42	483.1	484.5	886	1371				
25	12	LD	0.39	154.4	154.8	733	888				

Table D-1. Continued.

Core Number	Depth (cm)	QA Code	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
27	1	LD	2.31	1054.5	1056.8	523	1580				
27	2	LD	1.50	693.7	695.2	449	1144				
27	4	LD	0.30	316.4	316.7	479	796				
27	8	LD	0.16	251.5	251.6	492	744				
27	12	LD	0.16	103.2	103.4	524	628				
BRS		LD	1.52	277.3	278.8	344	622				
BRS		LD	1.47	286.7	288.1	348	636				
1	1	LD						1115	9.25		
3	2	LD						748	2.48		
5	4	LD						369	0.52		
7	4	LD						796	1.59		
11	8	LD						474	1.07		
16	12	LD						1059	3.23		
19	1	LD						1730	10.20		
21	4	LD						646	1.04		
22	1	LD						1220	4.65		
25	2	LD						1031	6.45		
29	4	LD						1454	5.31		
33	8	LD						2090	9.91		
34	12	LD						2256	8.38		
36	1	LD						993	3.26		
37	2	LD						979	7.75		
37	8	LD						853	7.13		
38	4	LD						1378	7.87		
44	12	LD						809	3.46		
BRS-1hr		LD						764	3.23		
BRS-1hr		LD						755	3.11		
BRS-1.5h		LD						687	2.72		
BRS-2hr		LD						761	3.83		
BRS-2hr		LD						750	3.53		

Table D-2. Statistical Summary of Measured Parameters for Primary Sediment Core Samples from St. Albans Bay and Stevens Brook Wetland, Sorted by Sediment Depth. All Measurements on Primary Samples Included.

	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
All Data:									
Mean	6.56	433.1	439.6	534.5	974.1	1246.6	6.01	76.39	25143
Std Dev	8.54	381.8	388.7	104.3	379.8	497.7	3.99	13.90	8106
Number	128	128	128	128	128	216	215	216	216
Depth = 0-1 cm:									
Mean	7.57	473.8	481.4	528.7	1010.1	1322.1	6.25	80.99	25720
Std Dev	9.67	375.7	382.6	95.4	384.1	499.2	3.35	12.53	8689
Number	26	26	26	26	26	43	43	43	43
Depth = 1-2 cm:									
Mean	6.13	448.0	454.2	513.7	967.9	1247.3	6.32	78.94	25481
Std Dev	7.65	357.0	362.8	109.9	367.6	460.3	3.31	13.68	8932
Number	26	26	26	26	26	43	43	43	43
Depth = 3-4 cm:									
Mean	5.21	382.2	387.4	534.3	921.7	1200.5	5.73	75.39	25071
Std Dev	7.32	354.2	360.1	84.0	344.8	459.4	3.44	16.09	8678
Number	26	26	26	26	26	43	43	43	43
Depth = 7-8 cm:									
Mean	5.20	413.6	418.8	542.4	961.2	1210.8	5.52	74.48	25433
Std Dev	7.06	366.7	372.8	113.6	386.5	483.6	3.65	13.00	7250
Number	23	23	23	23	23	40	39	40	40
Depth = 11-12 cm:									
Mean	6.25	368.7	374.9	557.9	932.8	1153.0	5.93	71.16	24354
Std Dev	9.00	431.5	440.0	120.6	395.3	553.1	5.88	12.57	7220
Number	23	23	23	23	23	40	40	40	40

Primary Samples Only - QA Samples Excluded

Table D-3. Statistical Summary of Measured Parameters for Primary Sediment Core Samples from St. Albans Bay and Stevens Brook Wetland, Sorted by Sediment Depth. All Primary Samples Included Unless TEIP > Total P.

	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
All Data:									
Mean	6.76	449.4	456.2	530.3	986.5	1270.3	6.20	77.43	25637
Std Dev	8.76	380.8	388.0	102.3	377.9	490.5	3.94	12.94	7761
Number	120	120	120	120	120	208	207	208	208
Depth = 0-1 cm:									
Mean	7.57	473.8	481.4	528.7	1010.1	1322.1	6.25	80.99	25720
Std Dev	9.67	375.7	382.6	95.4	384.1	499.2	3.35	12.53	8689
Number	26	26	26	26	26	43	43	43	43
Depth = 1-2 cm:									
Mean	6.21	441.7	447.9	511.6	959.5	1274.4	6.55	80.17	26012
Std Dev	7.91	346.3	352.5	107.4	340.3	449.7	3.22	12.57	8647
Number	24	24	24	24	24	41	41	41	41
Depth = 3-4 cm:									
Mean	5.46	425.9	431.4	532.2	963.5	1251.0	6.11	77.82	26238
Std Dev	7.71	353.8	360.2	89.0	345.1	435.4	3.26	13.85	7659
Number	23	23	23	23	23	40	40	40	40
Depth = 7-8 cm:									
Mean	5.37	427.5	432.9	532.4	965.3	1224.7	5.62	74.86	25839
Std Dev	7.17	368.9	375.0	105.7	394.7	481.8	3.64	12.94	6879
Number	22	22	22	22	22	39	38	39	39
Depth = 11-12 cm:									
Mean	6.52	394.2	400.7	549.4	950.1	1177.0	6.17	72.27	24821
Std Dev	9.32	442.8	451.8	118.6	406.5	556.3	5.94	11.57	7101
Number	21	21	21	21	21	38	38	38	38

Primary Samples Only - QA Samples Excluded
Samples with Total Extr. P > Total P Eliminated

Table D-4. Statistical Summary of Measured Parameters for Primary Sediment Core Samples from St. Albans Bay and Stevens Brook Wetland, Sorted by Location. All Measurements on Primary Samples Included.

	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
All Data:									
Mean	6.56	433.1	439.6	534.5	974.1	1246.6	6.01	76.39	25143
Std Dev	8.54	381.8	388.7	104.3	379.8	497.7	3.99	13.90	8106
Number	128	128	128	128	128	216	215	216	216
Stevens Brook Wetland:									
Mean	17.34	893.1	910.5	538.2	1448.7	1805.1	8.21	75.55	24771
Std Dev	7.77	307.2	312.2	127.5	267.2	368.1	5.29	13.79	4621
Number	39	39	39	39	39	72	71	72	72
Inner St. Albans Bay:									
Mean	2.34	240.3	242.6	554.4	797.1	969.1	4.84	78.02	23400
Std Dev	2.79	124.2	125.0	96.3	131.3	178.6	2.20	11.65	7942
Number	43	43	43	43	43	73	73	73	73
Middle St. Albans Bay:									
Mean	1.42	191.4	192.8	514.4	707.2	887.9	4.73	73.12	25930
Std Dev	1.64	187.9	187.5	87.7	176.4	266.4	2.90	16.61	10877
Number	41	41	41	41	41	56	56	56	56
Outer St. Albans Bay:									
Mean	0.96	484.0	485.0	499.2	984.2	1254.8	6.05	84.76	32471
Std Dev	0.93	347.4	348.4	31.6	350.1	380.3	2.21	7.23	4858
Number	5	5	5	5	5	15	15	15	15

Primary Samples Only - QA Samples Excluded

Table D-5. Statistical Summary of Measured Parameters for Primary Sediment Core Samples from St. Albans Bay and Stevens Brook Wetland, Sorted by Location. All Primary Samples Included Unless TEIP > Total P.

	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
All Data:									
Mean	6.76	449.4	456.2	530.3	986.5	1270.3	6.20	77.43	25637
Std Dev	8.76	380.8	388.0	102.3	377.9	490.5	3.94	12.94	7761
Number	120	120	120	120	120	208	207	208	208
Stevens Brook Wetland:									
Mean	17.58	890.7	908.3	534.7	1443.0	1816.6	8.30	76.01	24807
Std Dev	7.73	310.8	316.0	127.2	268.4	357.7	5.27	13.32	4643
Number	38	38	38	38	38	71	70	71	71
Inner St. Albans Bay:									
Mean	2.31	249.8	252.1	544.4	796.5	980.4	4.99	78.94	23979
Std Dev	2.80	123.4	124.2	88.4	131.9	172.4	2.12	10.91	7557
Number	40	40	40	40	40	70	70	70	70
Middle St. Albans Bay:									
Mean	1.25	207.5	208.7	514.6	723.3	919.2	5.03	75.21	27032
Std Dev	1.49	190.9	190.7	90.0	177.6	249.0	2.79	15.04	10381
Number	37	37	37	37	37	52	52	52	52
Outer St. Albans Bay:									
Mean	0.96	484.0	485.0	499.2	984.2	1254.8	6.05	84.76	32471
Std Dev	0.93	347.4	348.4	31.6	350.1	380.3	2.21	7.23	4858
Number	5	5	5	5	5	15	15	15	15

Primary Samples Only - QA Samples Excluded
Samples with Total Extr. P > Total P Removed

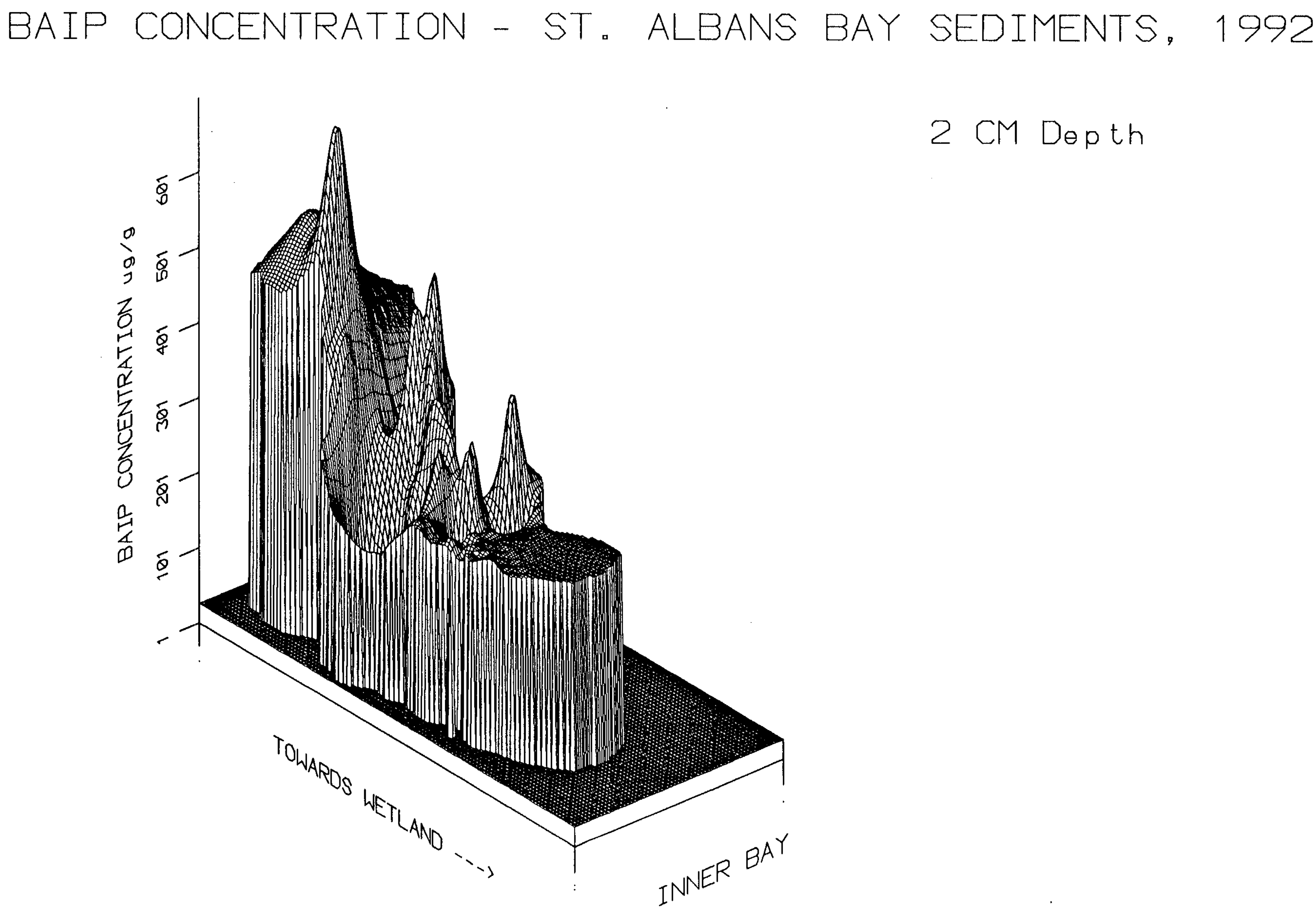

Figure D-1. Three-Dimensional Surface Plot of BAIP ($\mu g/g$) at 1-2 cm Depth in St. Albans Bay Bottom Sediments.

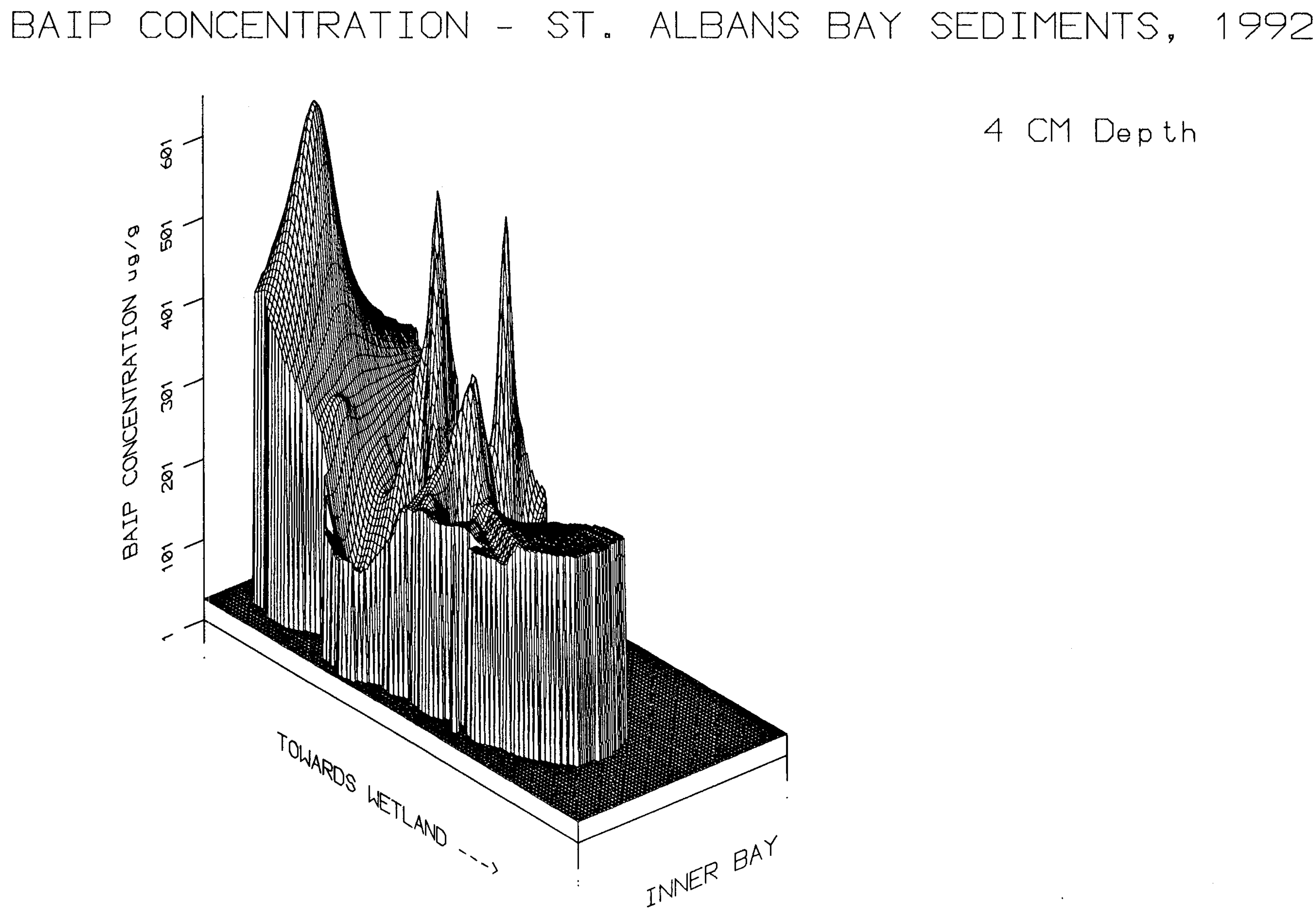

Figure D-2. **Three-Dimensional Surface Plot of BAIP ($\mu g/g$) at 3-4 cm Depth in St. Albans Bay Bottom Sediments.**

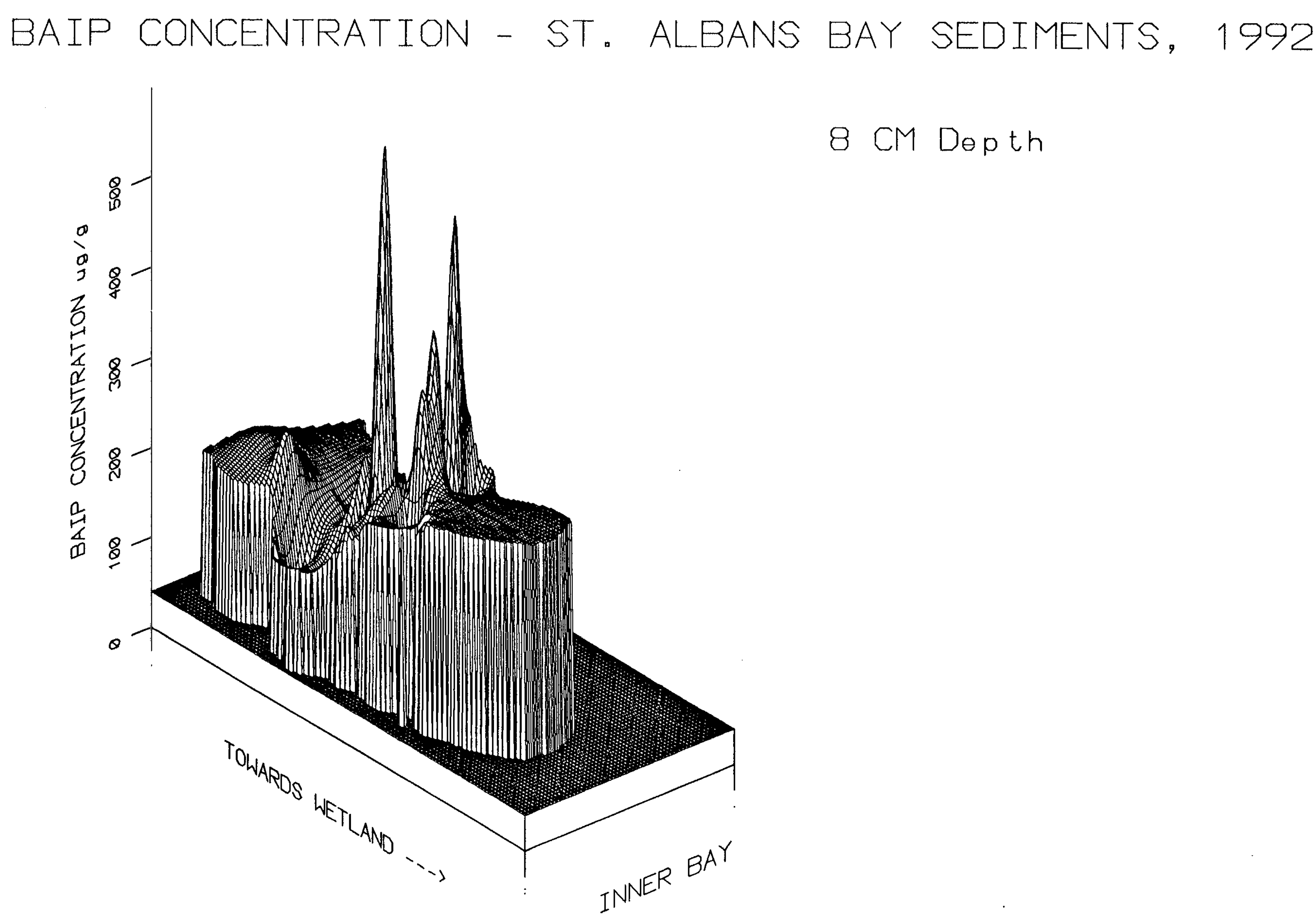

Figure D-3. **Three-Dimensional Surface Plot of BAIP (μg/g) at 7-8 cm Depth in St. Albans Bay Bottom Sediments.**

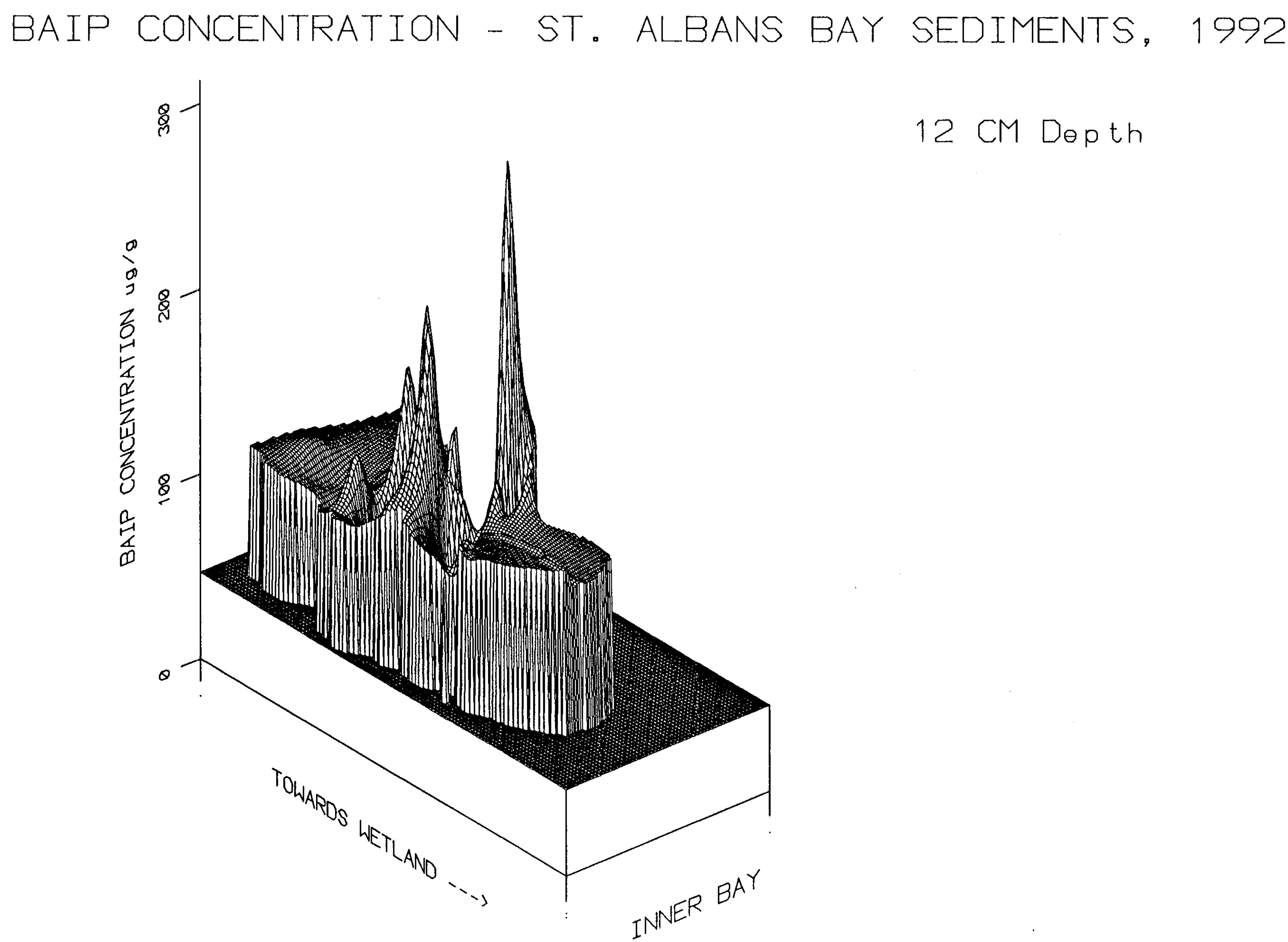

Figure D-4. Three-Dimensional Surface Plot of BAIP (μg/g) at 11-12 cm Depth in St. Albans Bay Bottom Sediments.

TOTAL PHOSPHORUS – ST. ALBANS BAY SEDIMENTS, 1992

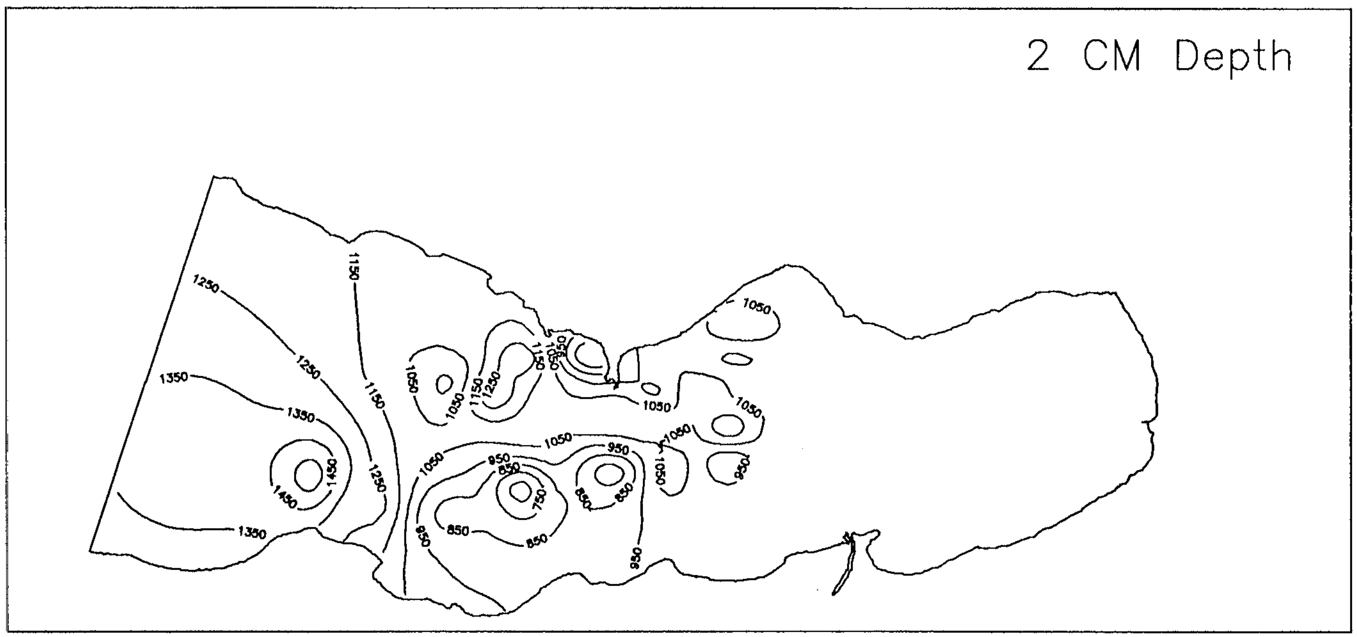

Figure D-5. Contour Map of Total P ($\mu g/g$) at 1-2 cm Depth in St. Albans Bay Bottom Sediments.

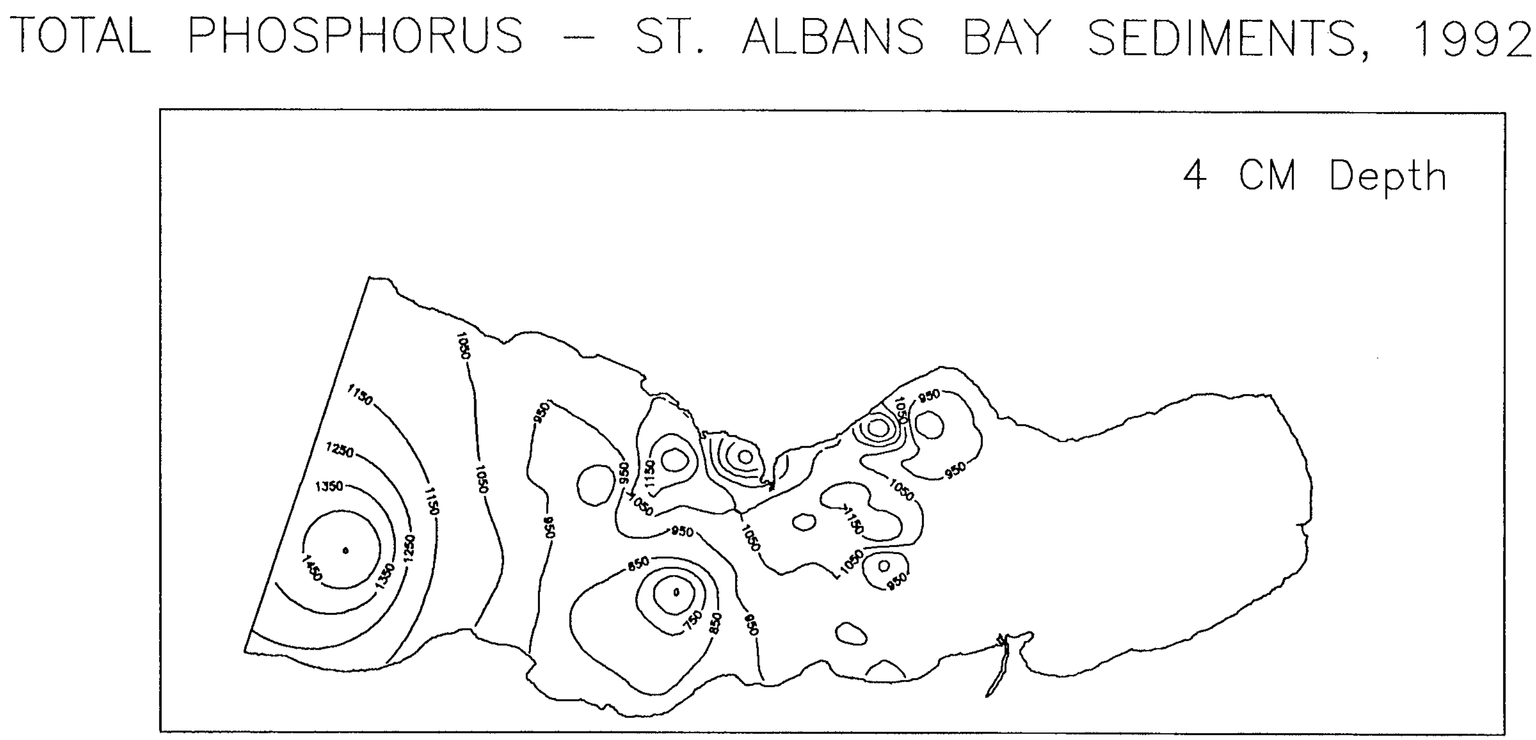

Figure D-6. Contour Map of Total P (μg/g) at 3-4 cm Depth in St. Albans Bay Bottom Sediments.

TOTAL PHOSPHORUS – ST. ALBANS BAY SEDIMENTS, 1992

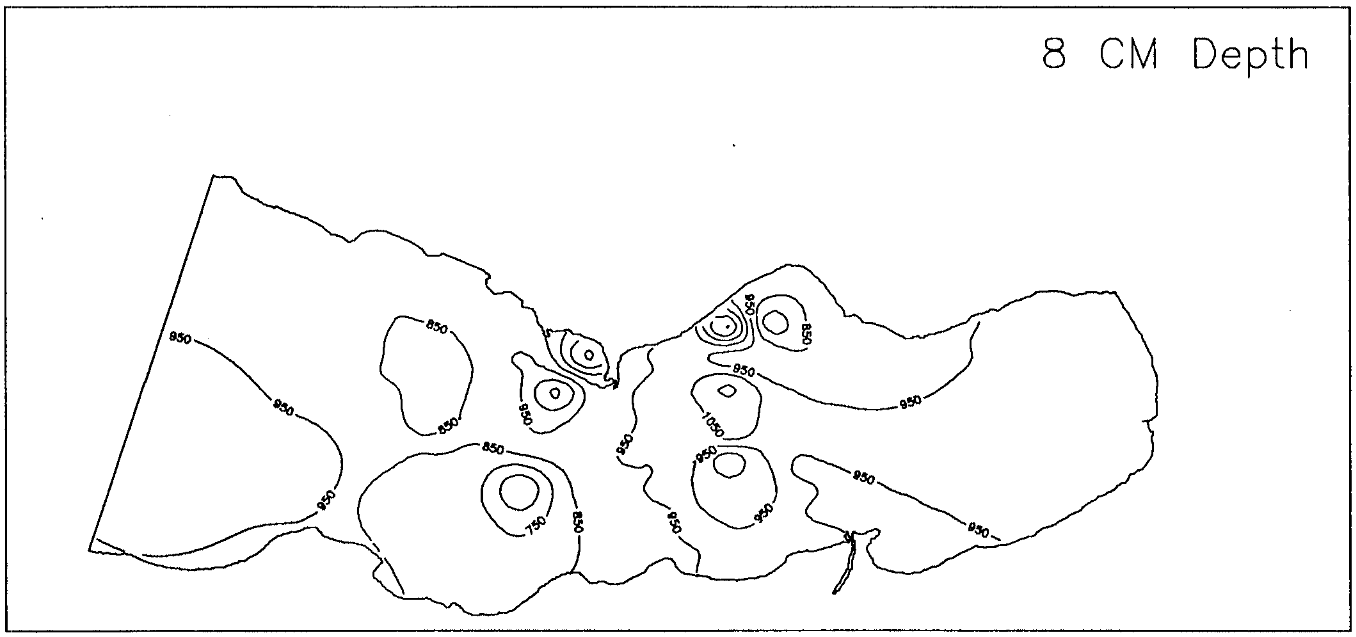

Figure D-7. Contour Map of Total P ($\mu g/g$) at 7-8 cm Depth in St. Albans Bay Bottom Sediments.

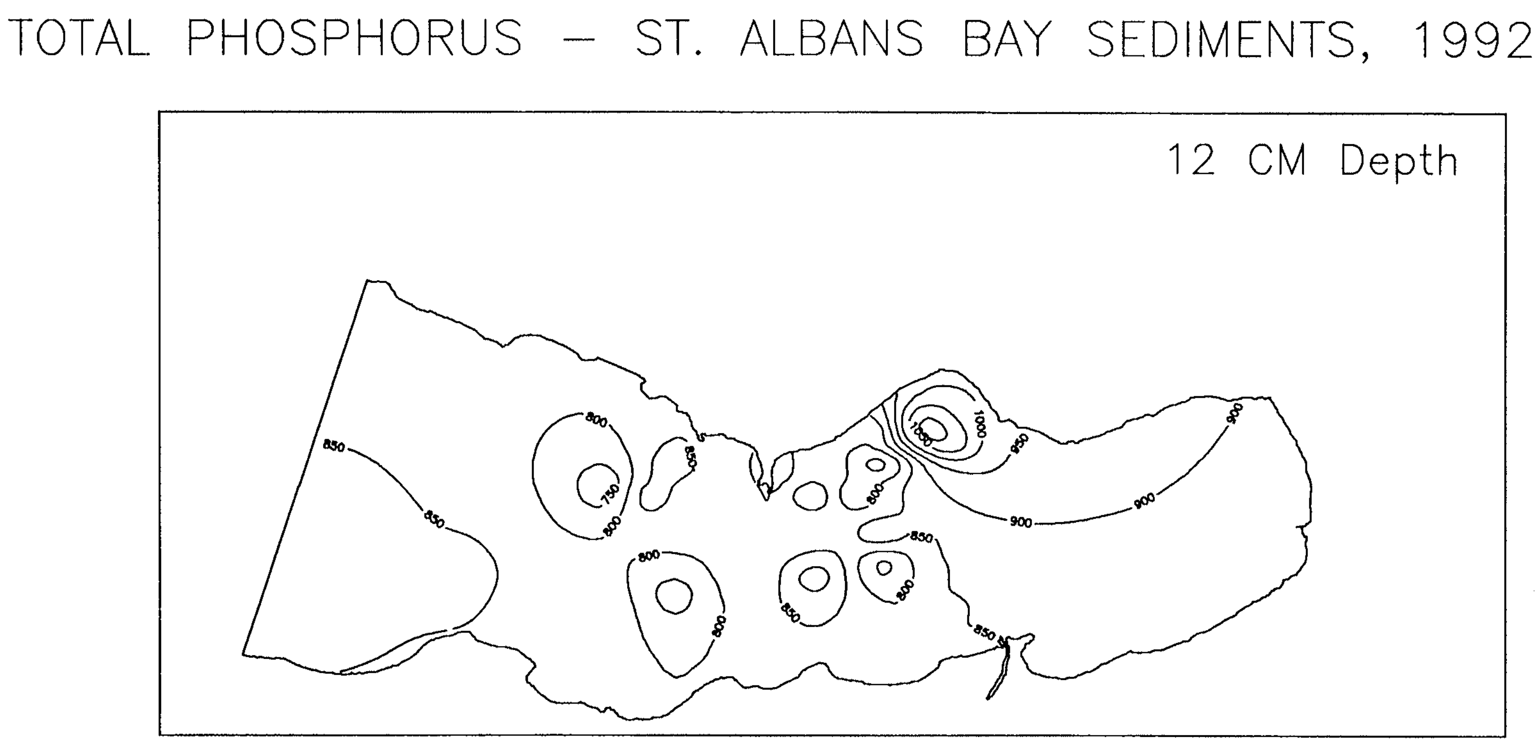

Figure D-8. Contour Map of Total P (μg/g) at 11-12 cm Depth in St. Albans Bay Bottom Sediments.

TOTAL 'P' – STEVENS BROOK WETLAND SEDIMENTS, 1992

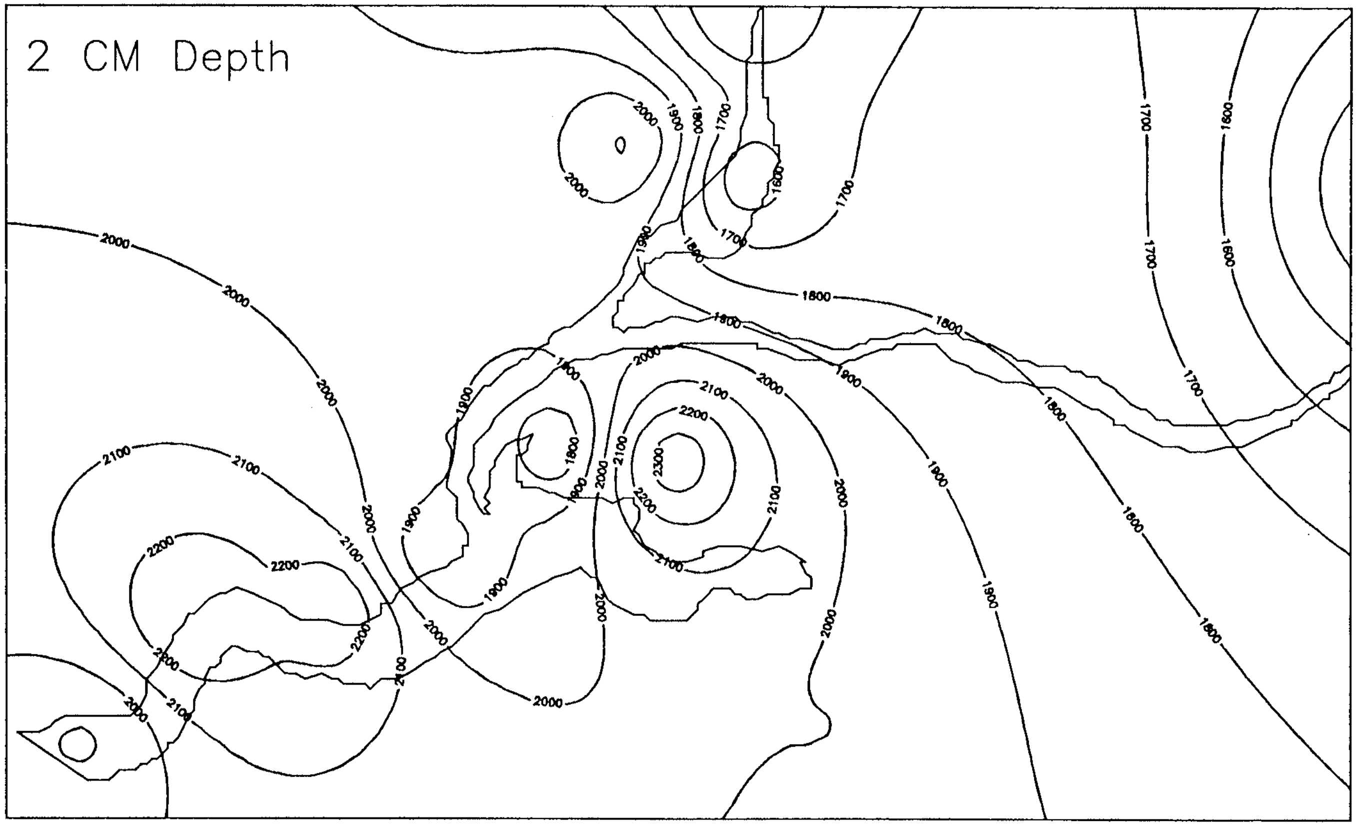

Figure D-9. Contour Map of Total P ($\mu g/g$) at 1-2 cm Depth in Stevens Brook Wetland Bottom Sediments.

TOTAL 'P' – STEVENS BROOK WETLAND SEDIMENTS, 1992

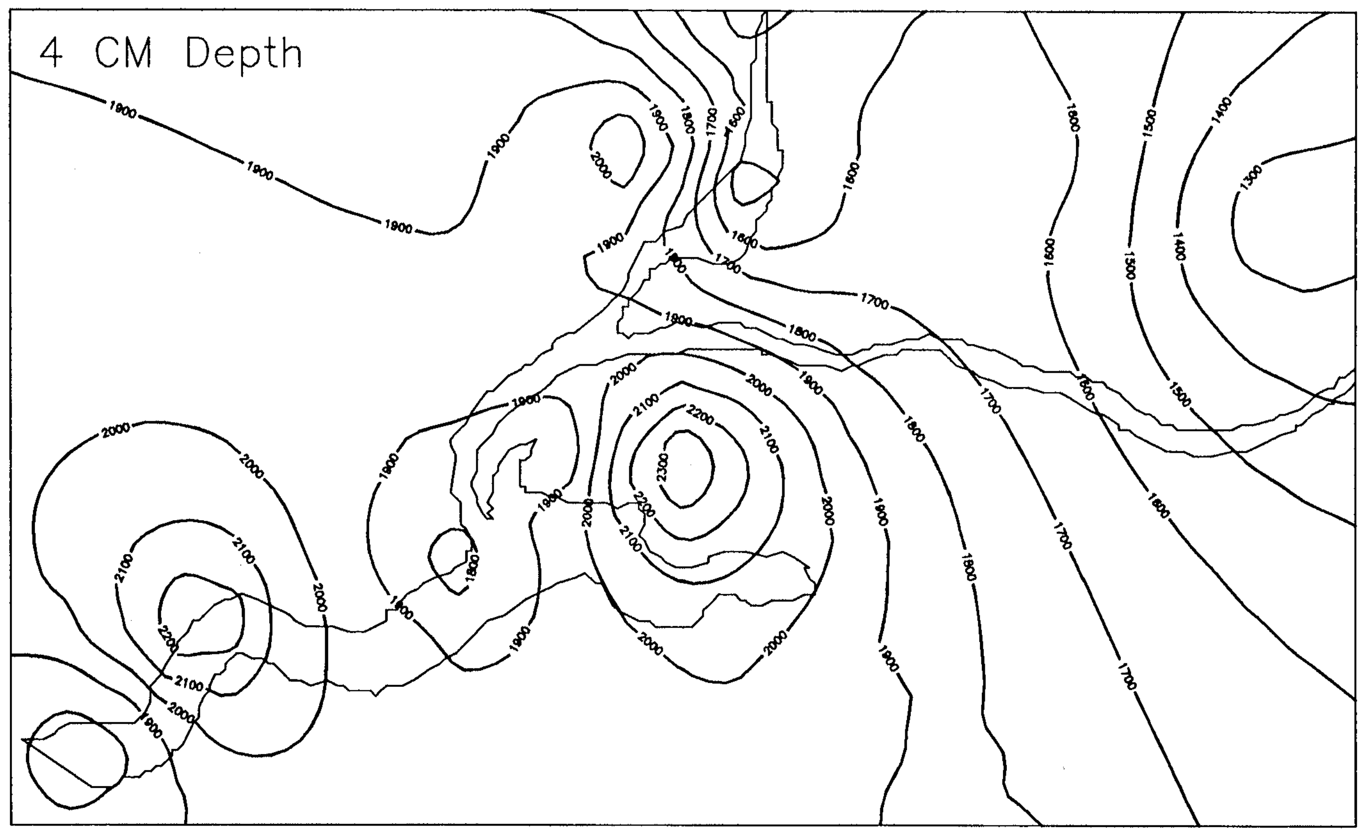

Figure D-10. Contour Map of Total P (μg/g) at 3-4 cm Depth in Stevens Brook Wetland Bottom Sediments.

TOTAL 'P' – STEVENS BROOK WETLAND SEDIMENTS, 1992

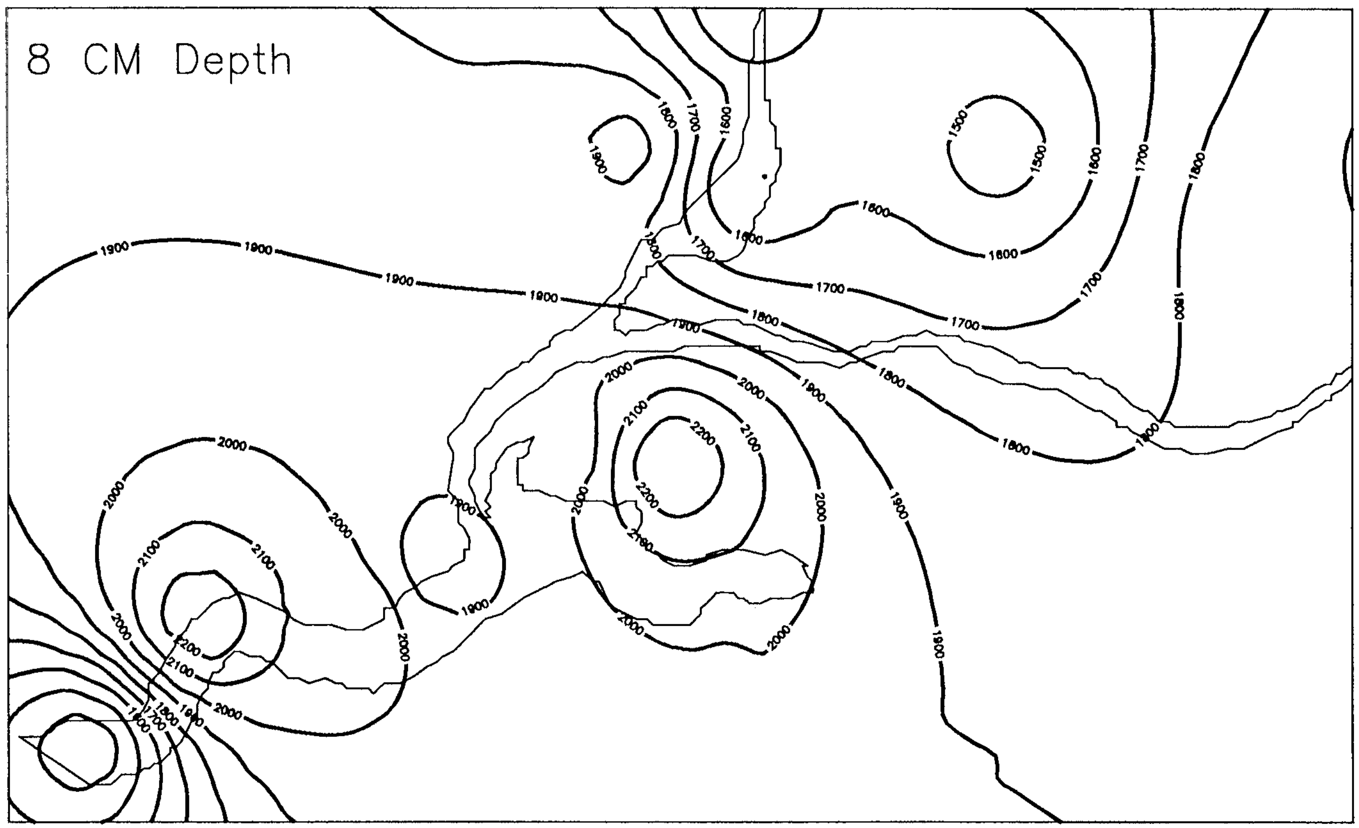

Figure D-11. Contour Map of Total P ($\mu g/g$) at 7-8 cm Depth in Stevens Brook Wetland Bottom Sediments.

TOTAL 'P' – STEVENS BROOK WETLAND SEDIMENTS, 1992

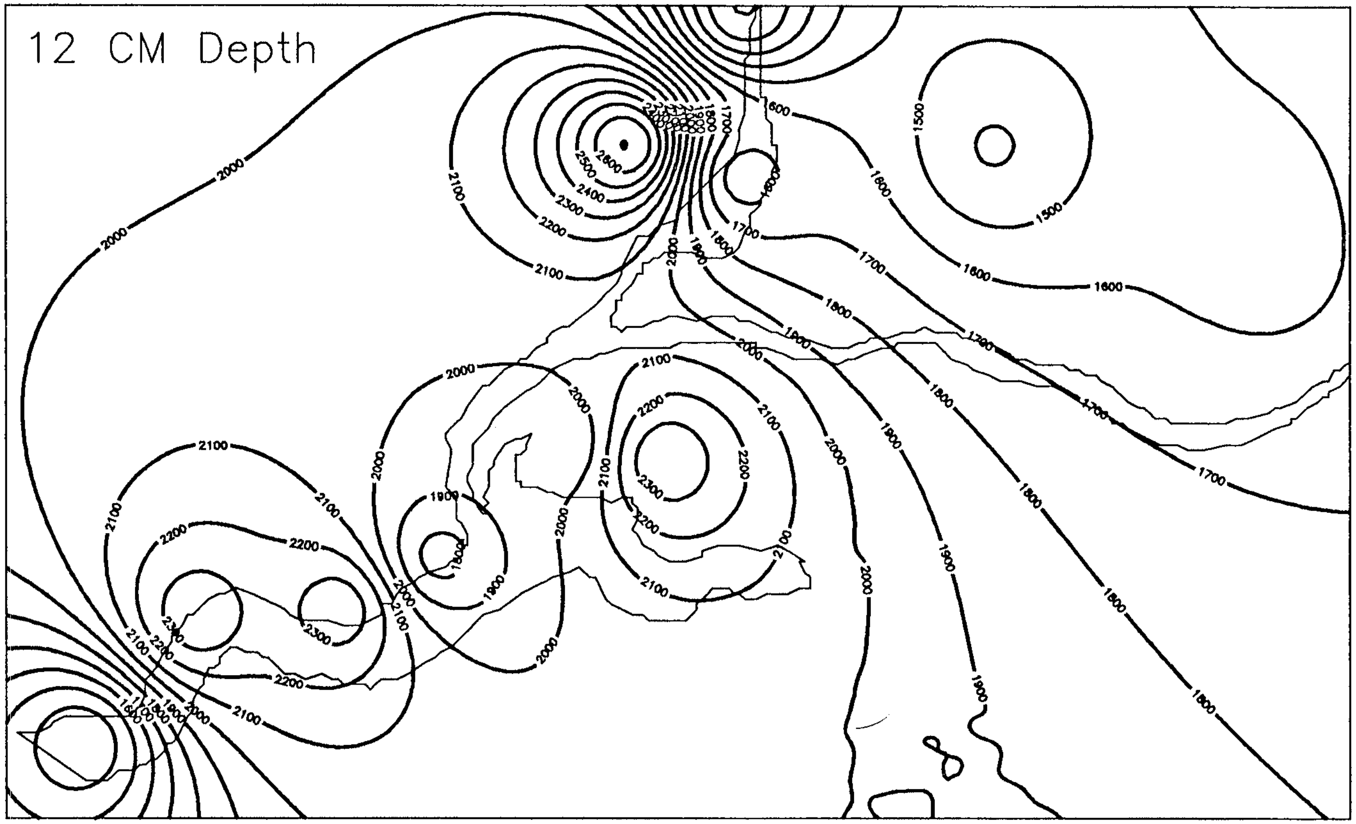

Figure D-12. Contour Map of Total P ($\mu g/g$) at 11-12 cm Depth in Stevens Brook Wetland Bottom Sediments.

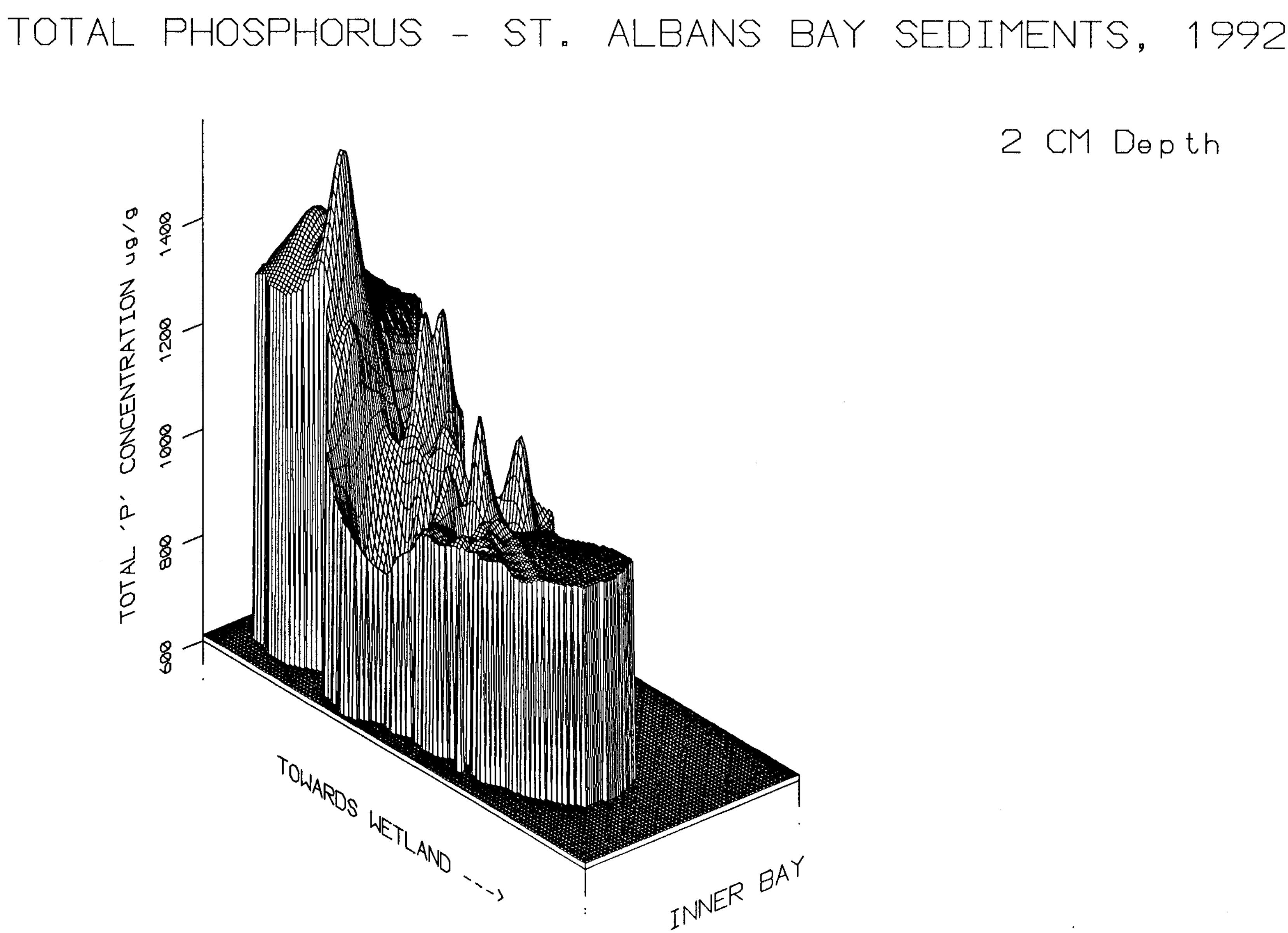

Figure D-13. Three-Dimensional Surface Plot of Total P ($\mu g/g$) at 1-2 cm Depth in St. Albans Bay Bottom Sediments.

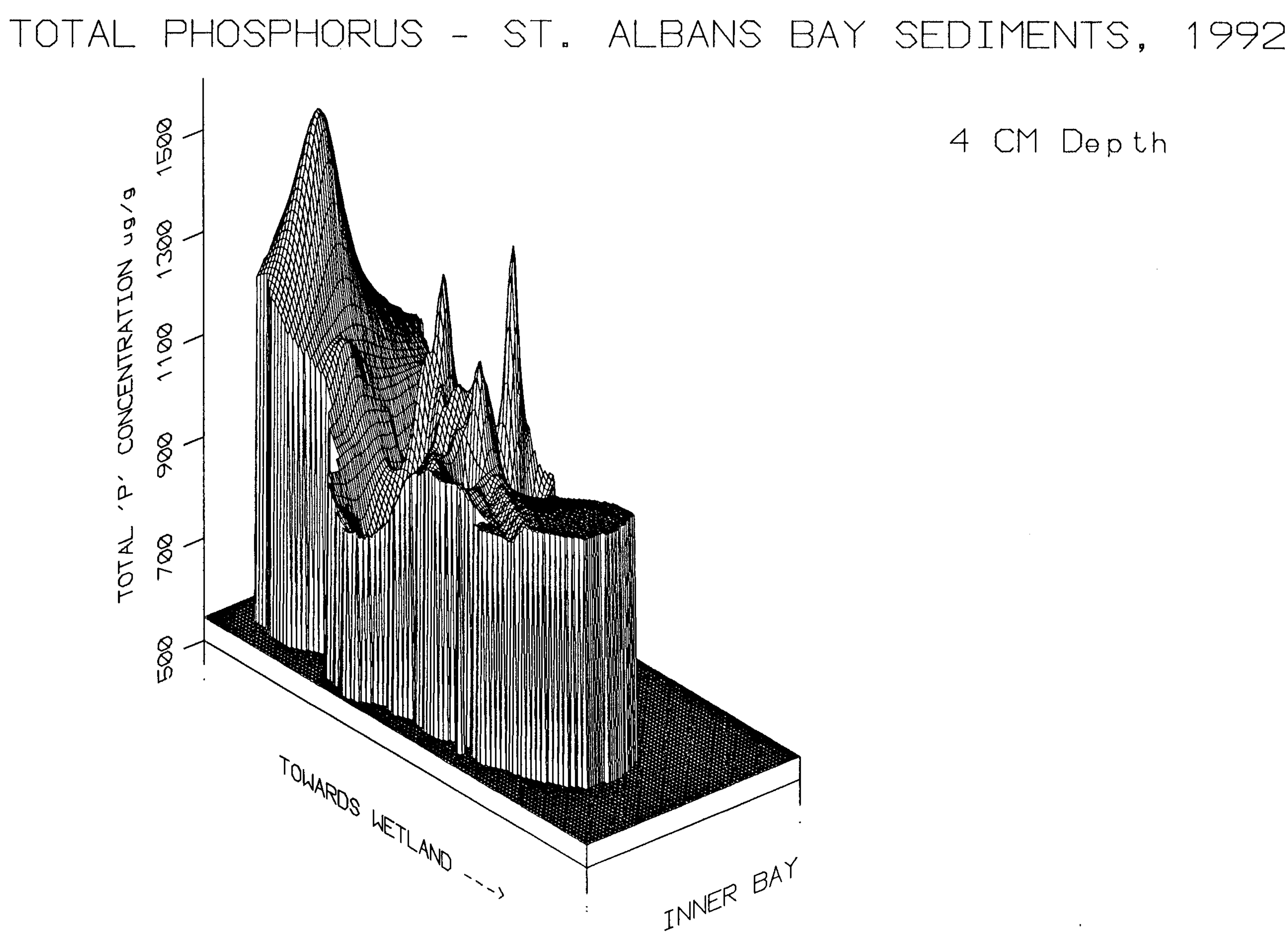

Figure D-14. Three-Dimensional Surface Plot of Total P ($\mu g/g$) at 3-4 cm Depth in St. Albans Bay Bottom Sediments.

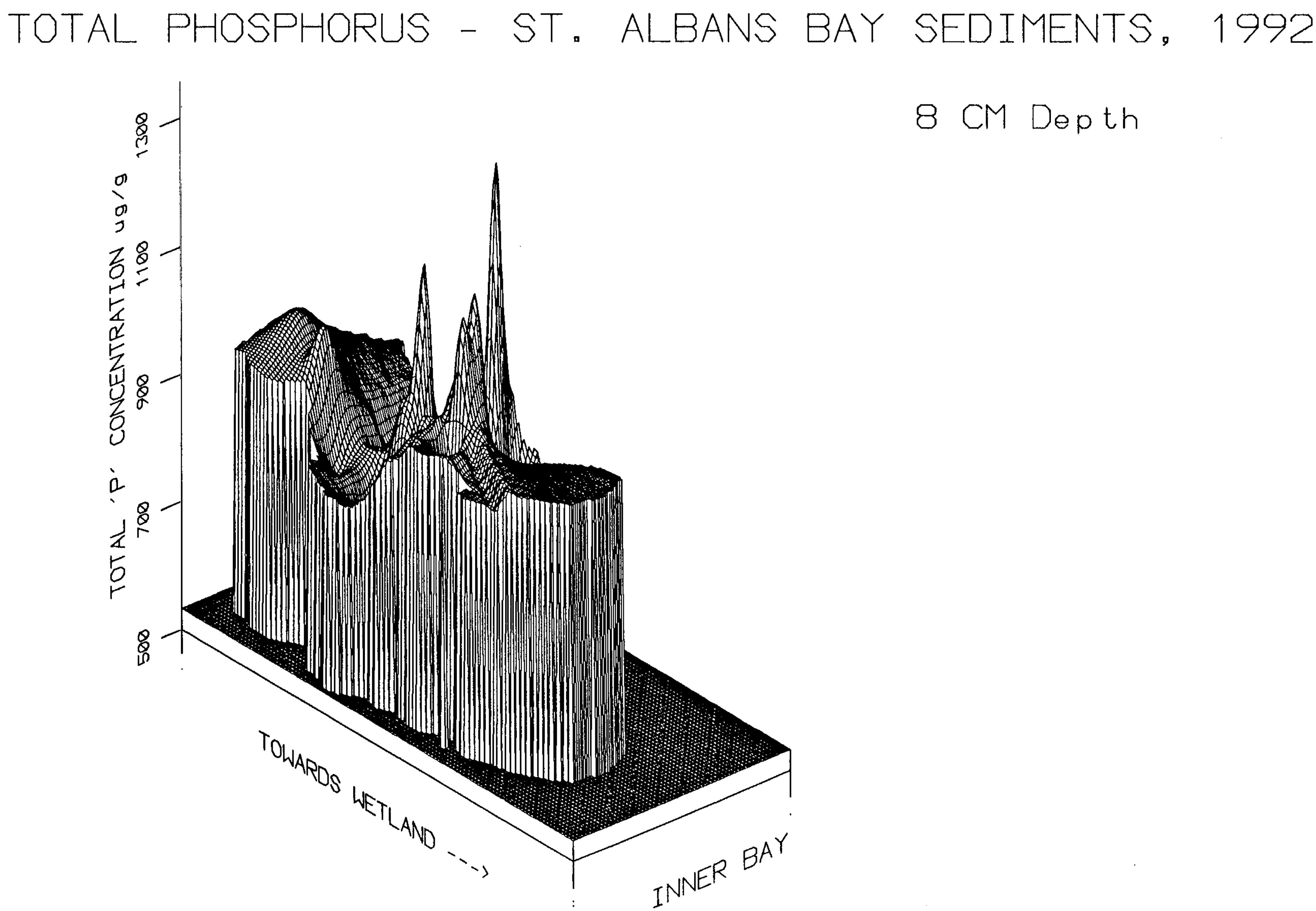

Figure D-15. Three-Dimensional Surface Plot of Total P (μg/g) at 7-8 cm Depth in St. Albans Bay Bottom Sediments.

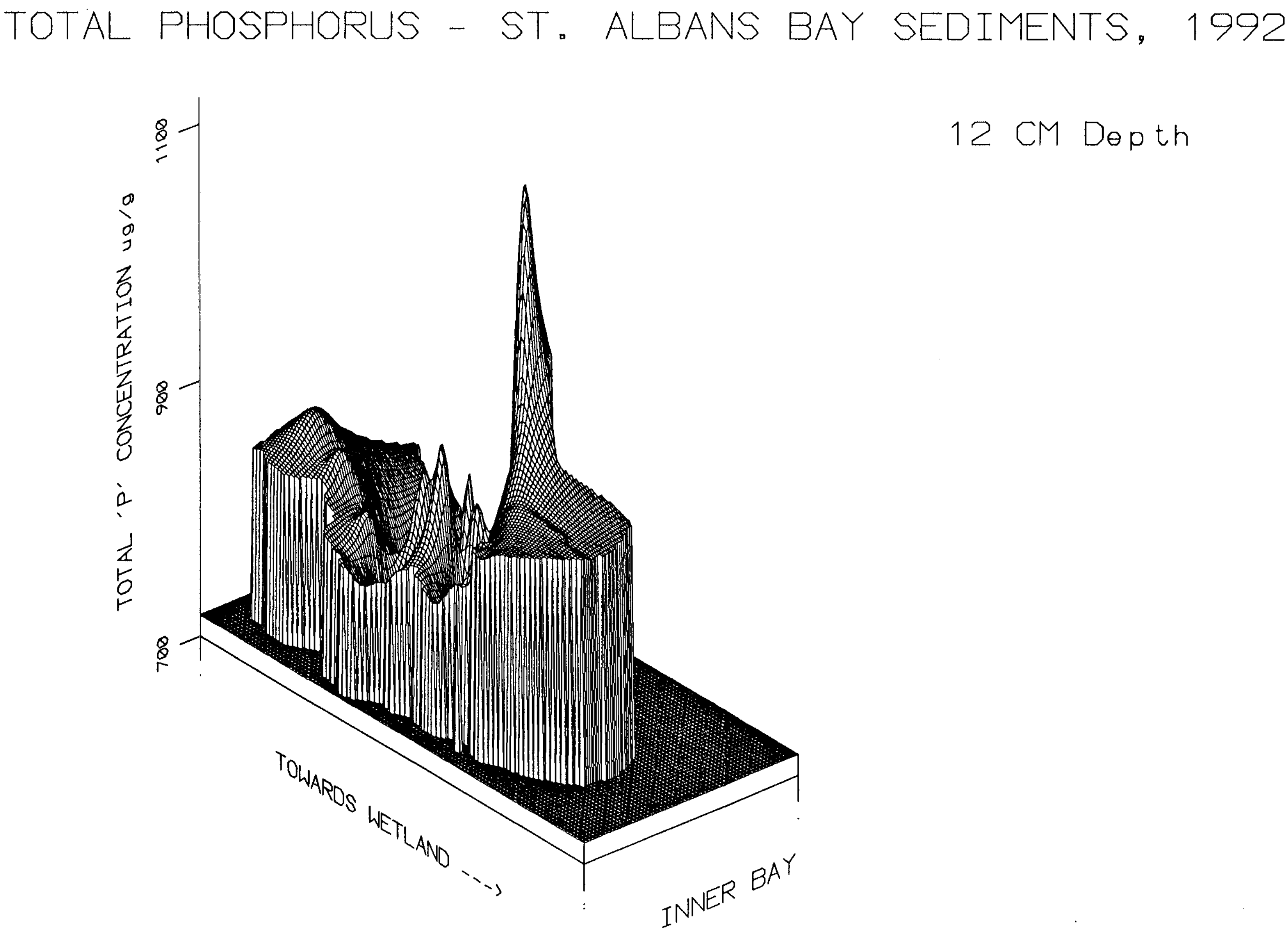

Figure D-16. Three-Dimensional Surface Plot of Total P ($\mu g/g$) at 11-12 cm Depth in St. Albans Bay Bottom Sediments.

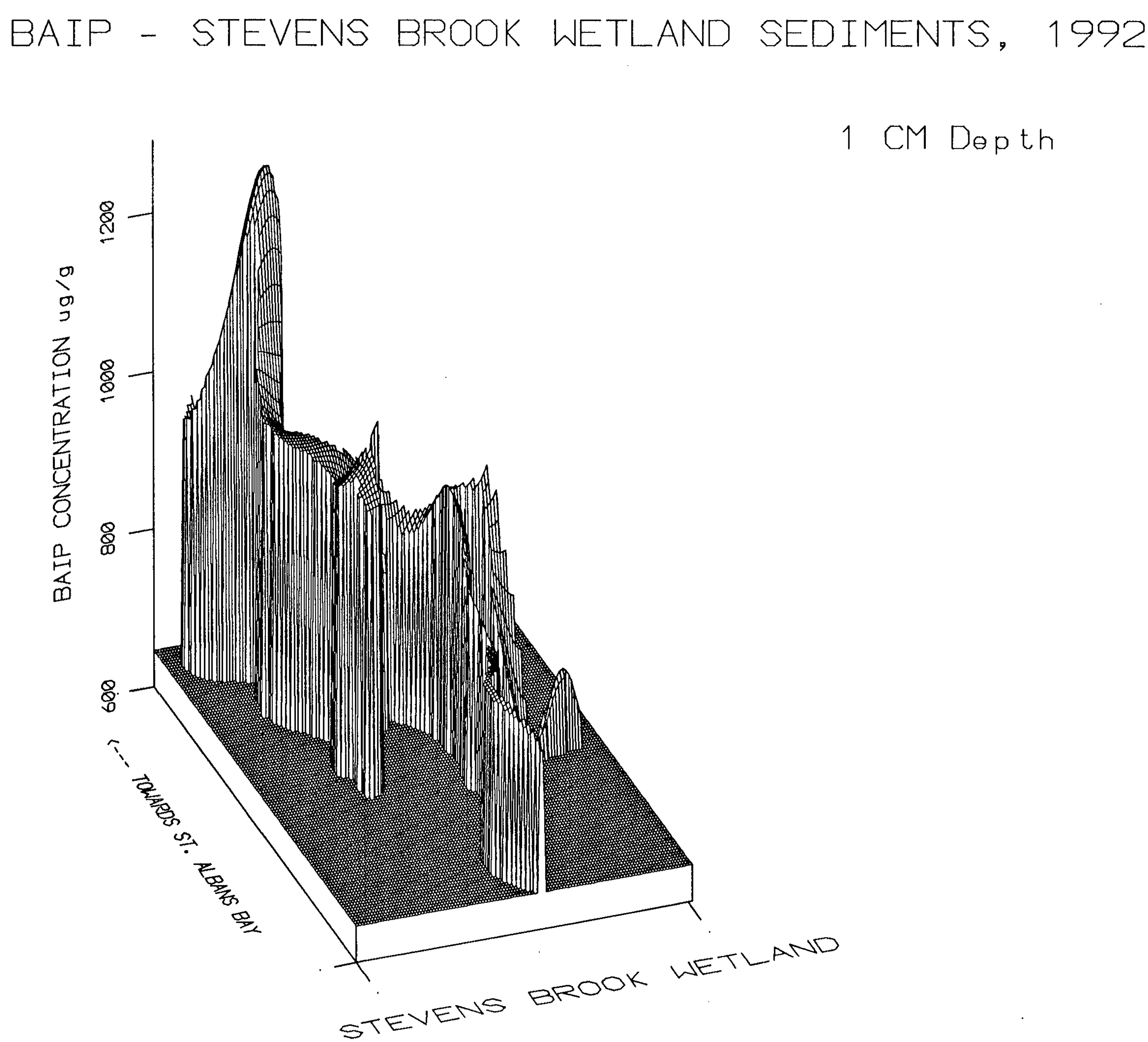

Figure D-17. Three-Dimensional Surface Plot of BAIP ($\mu g/g$) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.

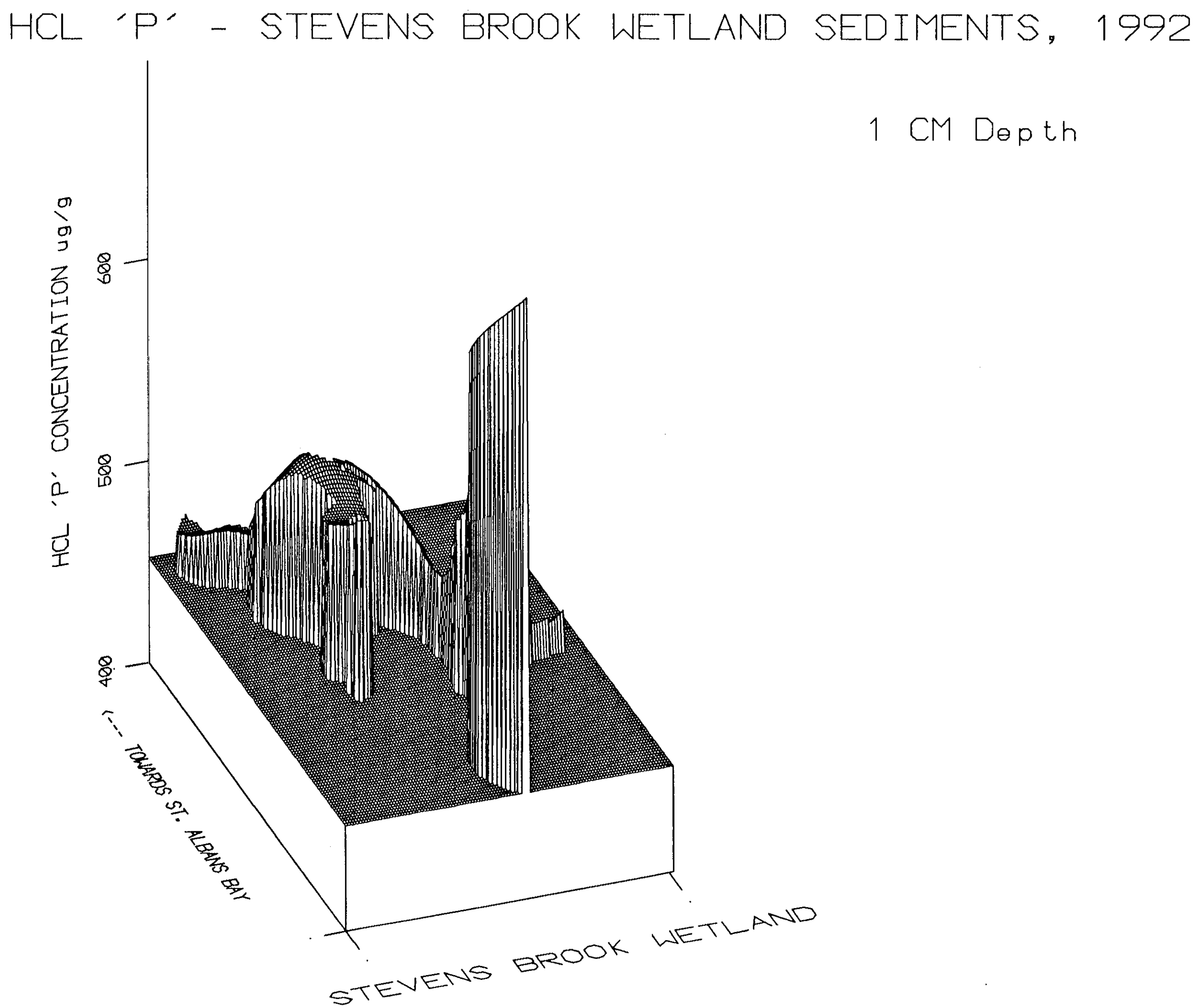

Figure D-18. Three-Dimensional Surface Plot of HCl-P (μg/g) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.

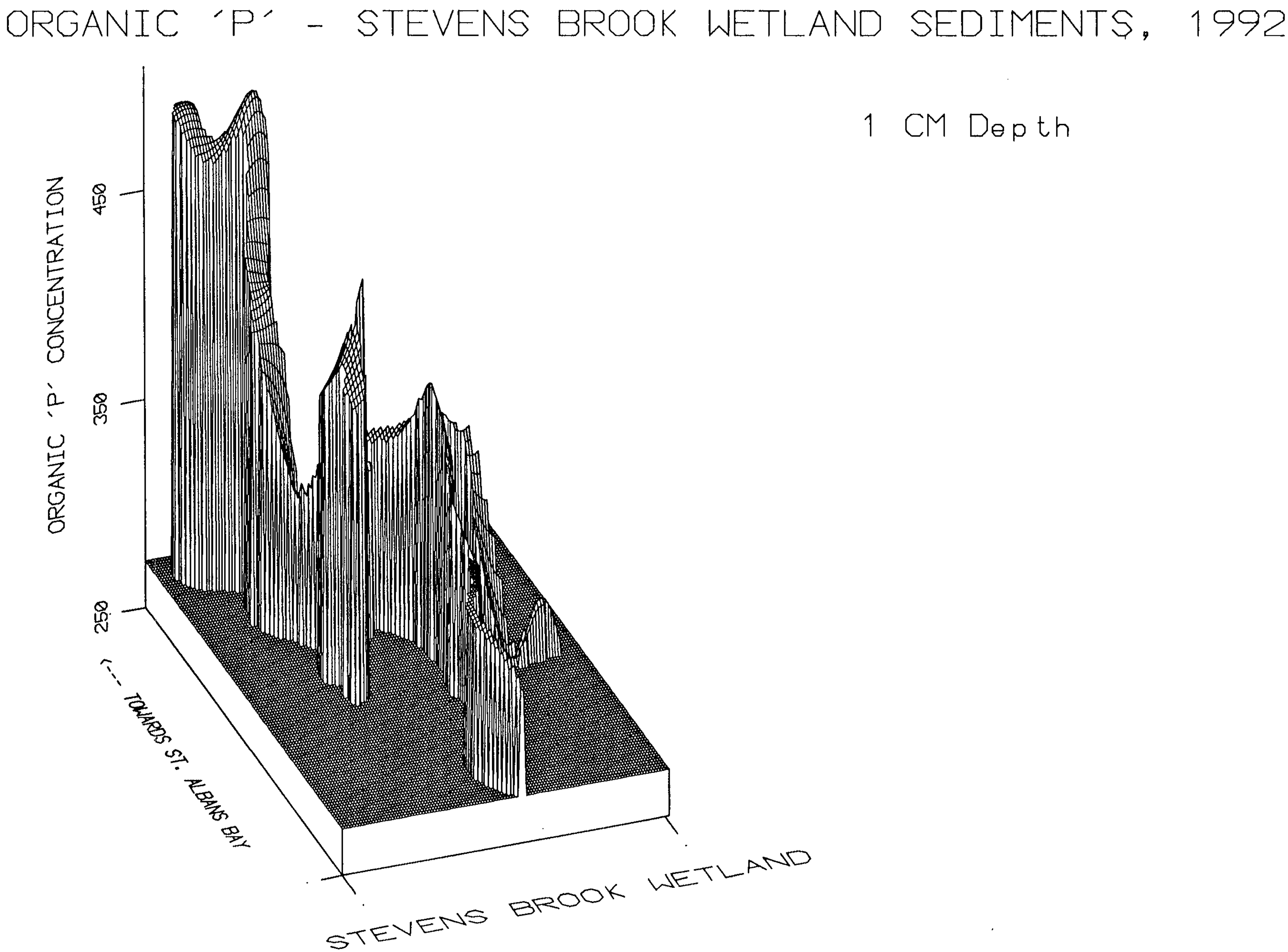

Figure D-19. Three-Dimensional Surface Plot of Organic P (µg/g) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.

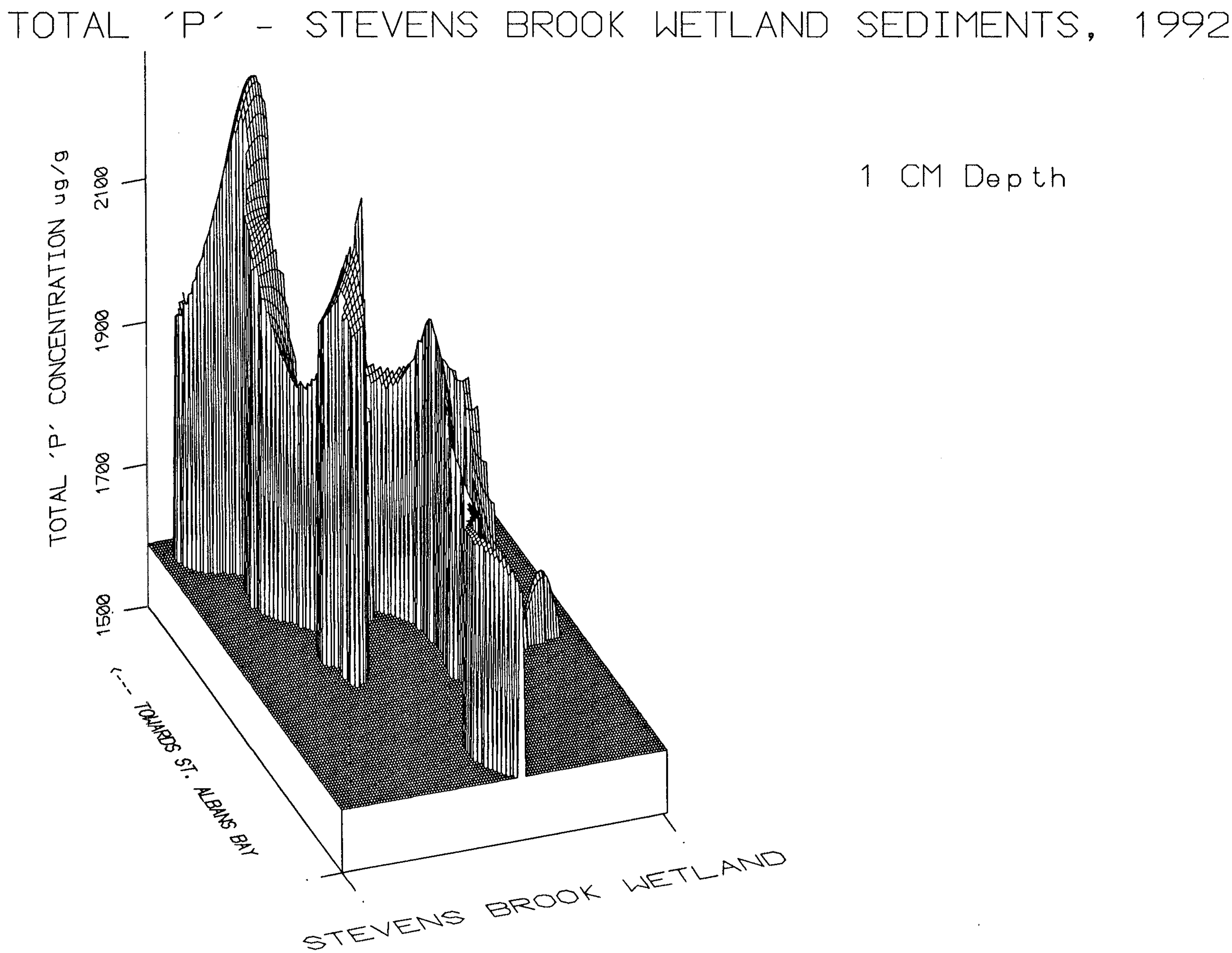

Figure D-20. Three-Dimensional Surface Plot of Total P ($\mu g/g$) at 0-1 cm Depth in Stevens Brook Wetland Bottom Sediments.

Table D-6. Analytical Data Sorted by Location, with Values of BAIP and Organic P Generated from Linear Regression Equations.

Segment	Core Number	Depth (cm)	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Organic P ug/g	Total P ug/g	Organic Matter %	Porosity %	Total Iron ug/g
1	17	1	27.88	1228.1	1256.0	439	1695	440.0	2135	8.42	87.92	30578
1	17	2	24.38	1204.1	1228.5	453	1681	426.4	2108	8.72	86.53	28241
1	17	4	28.54	1187.7	1216.2	436	1652	414.7	2067	8.30	85.66	27908
1	17	8	23.68	1072.9	1096.6	475	1572	369.2	1941	6.40	82.44	26490
1	17	12	30.04	1549.7	1579.7	268	1847	858.6	2706	31.90	91.91	16561
1	18	1	28.63	641.5	670.1	501	1171	438.0	1609	4.95	76.49	19256
1	18	2	16.10	539.7	555.8	501	1057	260.2	1317	3.84	71.54	16422
1	18	4	13.10	507.5	520.6	468	988	224.3	1213	4.23	67.82	15708
1	18	8	15.17	785.8	801.0	278	1079	628.4	1708	16.04	85.31	20079
1	18	12	15.15	795.4	810.5	227	1037	806.7	1844	21.70	89.18	25685
1	19	1	27.39	976.4	1003.8	538	1542	296.4	1838	6.18	85.81	24040
1	19	2	24.63	932.3	956.9	522	1479	329.3	1809	8.37	83.63	22391
1	19	3	21.80	855.6	877.4	552	1429	396.4	1825	8.32	83.44	22577
1	19	4	21.08	939.4	960.4	524	1484	276.2	1760	8.59	83.26	22392
1	19	5	20.13	863.1	883.2	518	1401	423.8	1825	8.41	82.44	22272
1	19	6	21.55	919.3	940.9	520	1461	369.0	1830	8.55	82.54	21976
1	19	7	21.51	895.4	917.0	530	1447	374.4	1821	6.85	82.62	22784
1	19	8	16.27	937.0	953.3	524	1477	356.9	1834	8.70	82.03	22986
1	19	12	16.73	935.0	951.7	565	1517	251.4	1768	5.95	77.64	22339
1	20	1	13.19	933.6	946.8	471	1418	495.9	1914	10.00	91.14	30204
1	20	2	8.61	926.2	934.8	443	1378	515.8	1893	9.47	89.14	29889
1	20	4	9.10	829.8	838.9	571	1410	346.7	1757	7.97	87.61	27339
1	20	8	7.76	565.1	572.9	600	1173	162.9	1336	3.18	74.72	18947
1	20	12	10.42	587.0	597.4	565	1163	157.5	1320	5.13	75.91	10875
1	22	1	11.66	388.4	400.0	765	1165	126.7	1292	3.72	58.47	24835
1	22	2	10.96	407.6	418.6	760	1178	118.0	1296	3.42	57.61	24945
1	22	4	11.06	451.4	462.5	743	1205	55.5	1261	2.83	57.49	22825
1	22	8	9.82	400.9	410.8	778	1189	774.4	1963	3.45	49.61	22604
1	22	12	8.97	503.6	512.6	723	1235	507.1	1742	4.18	58.85	27660
1	23	1	11.22	1113.1	1124.3	675	1799	455.0	2254	2.80	48.25	22295
1	23	4	5.36	477.1	482.4	614	1096	160.2	1256	1.81	39.14	25319
1	23	8	5.73	1008.8	1014.5	723	1737	129.2	1866	2.44	42.04	40801
1	23	12	5.43	793.2	798.6	623	1422	95.0	1516	1.21	39.74	38810
1	34	1	29.23	1262.7	1291.9	477	1769	509.6	2278	10.13	89.34	30641
1	34	2	23.70	1327.6	1351.3	475	1826	474.5	2301	10.07	87.93	30752
1	34	4	18.83	1379.5	1398.3	447	1845	434.8	2280	9.83	86.68	30514
1	34	12	31.15	1394.3	1425.4	506	1932	434.0	2366	8.36	79.85	25174
1	28	1			660.7			463.2	1509	11.19	85.48	26180
1	28	2			659.7			470.2	1507	11.47	85.09	26858
1	28	4			628.3			481.3	1468	11.91	85.10	25346
1	28	8			586.9			469.4	1415	11.44	83.67	25936
1	28	12			327.8			468.3	1087	11.39	80.30	24721
1	29	1			829.1			288.3	1722	4.20	64.18	23031
1	29	2			852.9			287.6	1752	4.18	61.53	23031
1	29	4			759.3			305.4	1633	4.89	69.12	26316
1	29	8			622.7			299.7	1461	4.66	64.41	24480
1	29	12			568.5			315.6	1392	5.29	43.05	29275
1	30	1			722.6			295.2	1587	4.48	73.68	21032
1	30	2			698.9			301.0	1557	4.71	70.37	20333
1	30	3			632.6			299.9	1473	4.67	69.57	21833
1	30	4			614.2			301.7	1450	4.74	69.14	20955
1	30	8			645.1			305.6	1489	4.90	68.16	21955
1	30	12			700.1			299.5	1558	4.65	65.81	22490
1	31	1			910.0			339.6	1824	6.25	74.76	22890
1	31	2			847.7			333.7	1745	6.02	74.80	21893
1	31	3			999.7			354.0	1938	6.83	75.96	24299
1	31	4			928.1			347.8	1847	6.58	76.97	24073
1	31	8			1003.2			318.7	1942	5.42	72.38	23063
1	31	12			984.5			305.8	1918	4.91	70.23	21116
1	32	1			1363.5			626.0	2398	17.69	91.16	29243
1	32	2			1333.1			652.0	2360	18.72	90.42	30462
1	32	4			1370.6			648.2	2407	18.58	90.14	30655
1	32	8			1286.5			655.4	2301	18.86	89.00	30130
1	32	12			1346.6			636.8	2377	18.12	87.59	29549
1	33	1			1142.9			428.5	2119	9.80	85.72	24825
1	33	2			1265.8			445.3	2274	10.48	84.87	26109
1	33	3			959.5			411.1	1887	9.11	80.79	23929
1	33	4			1035.6			417.3	1983	9.36	83.32	24370
1	33	8			1126.8			435.8	2099	10.09	82.74	24518
1	33	12			1331.7			462.9	2358	11.18	82.75	23730

Table D-6. Continued.

Segment	Core Number	Depth (cm)	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Organic P ug/g	Total P ug/g	Organic Matter %	Porosity %	Total Iron ug/g
2	2	1	0.63	251.8	252.4	520	773	170.6	943	6.03	88.78	28051
2	2	2	1.05	219.2	220.3	266	486	390.7	877	5.33	88.77	25326
2	2	4	1.01	245.3	246.3	556	803	110.6	913	5.58	86.44	25922
2	2	8	1.00	179.7	180.7	550	731	69.5	800	4.69	83.96	25770
2	2	12	0.52	17.9	18.4	628	646	37.1	683	1.81	73.96	18705
2	3	1	2.10	143.3	145.4	724	869	124.9	994	0.85	71.50	12376
2	3	2	1.87	138.0	139.9	754	894	53.8	948	1.76	68.94	11674
2	3	4	1.12	104.1	105.3	753	858	9.1	868	1.73	64.87	9794
2	3	12	0.95	57.0	58.0	705	763	10.5	773	1.94	57.47	10252
2	4	1	0.80	404.9	405.7	480	886	272.3	1158	4.02	90.05	33430
2	4	2	0.67	309.3	310.0	482	792	209.6	1002	6.57	89.26	35140
2	4	4	0.85	399.1	400.0	495	895	192.1	1087	7.51	89.15	33968
2	4	8	1.22	233.1	234.3	488	722	231.6	954	7.22	86.10	30542
2	4	12	0.83	149.3	150.1	488	638	199.9	838	5.26	78.84	29710
2	14	1	2.16	322.8	325.0	483	808	343.8	1151	1.45	90.42	34519
2	14	2	2.65	481.0	483.7	516	1000	250.0	1250	5.62	89.45	34009
2	14	8	1.63	197.6	199.2	507	706	246.5	952	5.69	83.76	29560
2	14	12	1.22	111.9	113.1	537	650	108.2	759	4.26	75.29	28780
2	15	1	1.67	299.9	301.5	524	825	306.6	1132	5.98	89.69	32220
2	15	2	1.95	362.5	364.5	523	887	339.5	1227	7.25	88.02	32998
2	15	4	2.13	409.9	412.0	520	932	322.8	1255	6.83	85.99	32219
2	15	8	2.11	376.7	378.8	524	903	253.0	1156	5.87	85.73	31200
2	15	12	1.53	135.3	136.8	504	641	243.9	884	3.74	78.64	31626
2	16	1	8.36	472.8	481.1	497	978	231.6	1210	5.67	82.92	17771
2	16	2	7.62	462.3	469.9	518	988	198.7	1186	5.04	75.99	16233
2	16	4	3.12	190.9	194.1	523	717	72.5	789	2.80	66.50	11454
2	16	8	2.18	142.7	144.8	443	588	107.3	695	1.86	61.97	10047
2	16	12	10.47	347.7	358.2	639	997	122.2	1119	2.42	62.64	14891
2	21	1	10.08	186.7	196.8	575	771	8.0	779	1.89	54.28	9238
2	21	2	10.56	291.6	302.1	585	887	3.2	890	3.58	63.65	10556
2	24	1	0.72	226.8	227.5	477	705	334.8	1040	6.25	88.05	29798
2	24	2	0.58	270.5	271.1	490	762	308.3	1070	6.18	87.79	28478
2	24	4	0.76	300.5	301.2	485	786	277.2	1063	5.15	85.05	26939
2	24	8	0.44	181.1	181.5	538	719	257.7	977	2.91	76.63	23774
2	24	12	0.25	104.3	104.6	577	681	189.6	871	4.02	69.84	21449
2	25	1	0.34	229.2	229.5	599	829	253.7	1082	5.70	86.47	26181
2	25	2	1.04	220.3	221.3	587	808	249.1	1057	5.09	85.03	24679
2	25	4	0.48	278.1	278.6	619	898	218.3	1116	3.47	83.65	23340
2	25	8	1.26	489.8	491.1	611	1102	135.4	1237	5.01	81.83	24255
2	35	1			371.0			301.7	1168	7.75	88.33	28469
2	35	2			333.4			352.6	1111	9.27	86.63	27586
2	35	4			555.4			310.5	1450	8.01	87.50	29012
2	35	8			508.3			276.4	1379	6.99	84.59	25450
2	35	12			157.4			241.3	842	5.95	77.73	23058
2	36	1			198.7			151.6	905	3.28	66.63	13627
2	36	2			216.0			164.0	931	3.65	69.16	14622
2	36	4			193.2			143.2	896	3.03	66.01	13460
2	36	8			183.2			112.8	881	2.12	56.46	14355
2	36	12			164.8			105.6	853	1.91	54.92	14652
2	37	1			59.0			295.1	691	7.55	89.50	26702
2	37	2			181.1			299.6	878	7.69	87.46	26268
2	37	4			146.6			276.3	825	6.99	87.68	25015
2	37	8			124.8			279.2	792	7.08	86.64	25703
2	37	12			90.5			124.4	739	2.47	60.63	17544
2	38	1			300.8			305.2	1061	7.85	88.81	28594
2	38	2			349.9			300.6	1136	7.72	88.45	31156
2	38	4			392.3			298.8	1201	7.66	87.93	32066
2	38	8			299.7			271.7	1059	6.86	85.19	29528
2	38	12			111.2			232.0	771	5.67	79.53	23210
2	39	1			178.9			300.0	875	7.70	88.20	31754
2	39	2			213.1			303.1	927	7.79	87.37	31961
2	39	4			346.5			297.4	1131	7.62	87.16	32468
2	39	8			270.7			235.1	1015	5.76	80.55	28612
2	39	12			192.2			183.5	895	4.23	71.42	21452
2	40	1			146.2			174.5	825	3.96	83.12	16876
2	40	2			162.3			167.6	849	3.75	78.39	17385
2	40	4			187.9			162.6	888	3.61	71.86	17494
2	40	8			165.3			106.6	854	1.94	50.94	16240
2	40	12			107.4			118.6	765	2.29	61.05	24020

Table D-6. Continued.

Seg-ment	Core Number	Depth (cm)	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Organic P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
3	1	1	0.65	421.2	421.8	422	844	245.7	1090	7.00	85.78	35856
3	1	2	0.45	453.8	454.3	358	812	265.0	1077	7.18	90.58	35986
3	1	4	0.63	539.7	540.4	458	998	116.9	1115	6.74	83.34	35961
3	1	8	1.51	618.1	619.6	518	1138	45.0	1183	4.84	82.51	35081
3	1	12	0.20	226.0	226.2	528	755	45.7	800	2.79	77.75	31924
3	5	1	1.78	84.0	85.8	375	460	34.2	495	1.78	73.98	8632
3	7	1	8.61	152.9	161.5	690	851	103.5	954	2.33	71.56	14928
3	7	2	2.95	50.3	53.2	694	747	49.7	797	2.75	57.03	11347
3	7	4	0.48	88.3	88.8	671	760	23.5	783	1.04	48.74	39457
3	7	8	0.76	126.9	127.6	654	782	42.1	824	0.92	54.48	44328
3	7	12	0.63	141.7	142.3	650	793	50.2	843	0.90	54.90	47422
3	8	1	1.14	519.2	520.3	506	1026	491.1	1517	9.49	94.01	30702
3	8	2	0.86	250.5	251.4	488	740	375.4	1115	8.05	92.30	27349
3	8	4	0.63	130.9	131.5	513	645	270.1	915	6.04	88.25	26988
3	8	8	0.53	78.5	79.0	633	712	243.3	955	3.42	76.08	20886
3	8	12	0.81	55.7	56.5	656	713	96.1	809	2.12	71.31	18145
3	9	1	2.00	26.7	28.7	522	550	67.9	618	2.02	68.40	6710
3	9	2	2.05	21.6	23.7	520	544	62.3	606	1.67	64.45	6139
3	9	4	0.16	23.7	23.9	453	476	64.8	541	1.12	52.26	6663
3	9	8	0.15	37.9	38.0	396	434	136.7	571	4.88	71.84	17528
3	9	12	0.16	45.7	45.9	499	545	184.8	729	8.00	79.44	24678
3	10	1	0.16	484.0	484.1	412	896	386.4	1283	8.71	88.88	37331
3	10	2	0.16	532.0	532.2	415	947	373.5	1320	8.32	88.44	37671
3	10	4	0.43	593.6	594.0	447	1041	274.3	1315	6.93	87.69	37301
3	10	8	0.14	218.2	218.4	462	681	276.6	958	4.59	80.04	34518
3	10	12	0.16	125.5	125.7	511	637	238.8	876	4.51	75.31	30620
3	11	1	0.30	51.7	52.0	438	490	98.1	588	1.91	60.98	13056
3	11	2	1.08	44.1	45.2	470	515	88.3	603	1.77	50.86	14629
3	11	4	2.27	36.4	38.7	510	548	17.8	566	1.10	41.02	15029
3	11	8	3.64	27.0	30.6	433	464	14.8	479	0.42	39.91	14287
3	12	1	1.50	371.4	372.9	494	867	309.0	1176	7.63	91.57	34845
3	12	2	1.35	411.3	412.7	474	886	287.7	1174	6.01	90.54	44264
3	12	4	1.62	328.5	330.1	473	803	253.5	1056	7.30	88.74	31969
3	12	8	0.79	148.4	149.2	552	701	175.3	876	4.85	80.89	27214
3	12	12	1.21	95.0	96.2	606	702	120.8	823	7.08	72.67	23723
3	13	1	2.10	70.0	72.1	610	682	19.2	701	0.93	47.73	14223
3	13	2	2.11	45.2	47.4	531	579	45.5	624	1.02	43.31	16516
3	41	1			522.4			333.1	1367	8.66	86.76	38454
3	41	2			337.6			325.2	1083	8.46	90.36	32261
3	41	4			298.0			317.0	1022	8.25	89.61	30667
3	41	8			252.4			309.3	952	8.05	87.31	29478
3	41	12			235.8			293.6	927	7.65	85.52	29333
3	42	1			376.5			322.5	1143	8.39	91.71	29702
3	42	2			520.5			315.2	1364	8.20	86.87	36917
3	42	4			399.4			262.7	1178	6.86	83.88	34833
3	42	8			255.0			235.9	956	6.17	78.94	30942
3	42	12			198.5			206.2	870	5.41	75.58	29551
3	43	1			264.2			300.4	970	7.82	85.18	30681
3	43	2			246.9			272.5	944	7.11	84.60	30110
3	43	4			144.8			180.7	787	4.75	74.79	24745
3	43	8			129.0			111.3	763	2.97	65.91	18786
3	43	12			97.9			175.7	715	4.63	76.29	25285

Table D-6. Continued.

Seg-ment	Core Number	Depth (cm)	NH4Cl-P ug/g	NaOH-P ug/g	NH4Cl-P +NaOH-P ug/g	HCl-P ug/g	Total Extr. P ug/g	Organic P ug/g	Total P ug/g	Organic Matter %	Poro-sity %	Total Iron ug/g
4	27	1	2.50	1057.2	1059.7	533	1593	487.3	2080	9.72	94.15	42759
4	27	2	1.60	699.0	700.6	454	1155	431.7	1586	7.97	91.81	37675
4	27	4	0.35	309.3	309.7	474	784	361.8	1145	6.05	85.77	34553
4	27	8	0.21	248.3	248.5	502	751	271.6	1022	4.79	80.89	34287
4	27	12	0.16	106.2	106.4	533	640	228.4	868	4.02	79.29	28829
4	44	1			699.0			400.3	1611	7.48	88.49	31883
4	44	2			423.0			301.3	1262	5.30	83.82	30504
4	44	4			178.0			231.2	952	3.76	75.94	26838
4	44	8			70.8			205.9	816	3.20	74.16	25933
4	44	12			85.7			201.4	835	3.10	73.15	23822
4	45	1			817.3			480.9	1761	9.25	94.20	37540
4	45	2			559.1			467.1	1434	8.95	93.98	35732
4	45	4			653.8			414.6	1554	7.80	92.63	34331
4	45	8			225.4			286.7	1012	4.98	82.93	29842
4	45	12			123.9			260.0	883	4.39	80.13	32543