Technical Report No. 7

Internal Phosphorus Loading Studies of St. Albans Bay

Lake Champlain Basin Program

Executive Summary

Prepared by
VT Dept of Environmental Conservation

for
Lake Champlain Management Conference

March 1994

PUBLICATION SERIES

THIS PROGRAM IS SPONSORED BY U.S.E.P.A. AND THE STATES OF NEW YORK AND VERMONT.

EXECUTIVE SUMMARY

INTERNAL PHOSPHORUS LOADING STUDIES OF ST. ALBANS BAY

Prepared by the

Vermont Department of Environmental Conservation
103 South Main St.
Waterbury, Vermont 05671-0408

Prepared for the

Lake Champlain Management Conference
Lake Champlain Basin Program
54 West Shore Rd.
Grand Isle, Vermont 05458

March 1994

This technical report is the seventh in a series of reports prepared under the Lake Champlain Basin Program. Those in print are listed below.

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.

This report was funded and prepared under the authority of the Lake Champlain Special Designation Act of 1990, P.L. 101-596, through the U.S. Environmental Protection Agency (EPA grant #EPA X 001840-01). Publication of this report does not signify that the contents necessarily reflect the views of the States of New York and Vermont, the Lake Champlain Basin Program, or the U.S. Environmental Protection Agency.

March 1994

BACKGROUND

St. Albans Bay, located in the Northeast Arm of Lake Champlain in Vermont, has a long history of severe water quality problems related to excessive phosphorus enrichment and resulting algae blooms. Studies have shown that prior to 1987, phosphorus discharged from the City of St. Albans Wastewater Treatment Facility was the major source of phosphorus to St. Albans Bay, particularly during the summer. Agricultural nonpoint sources also contributed to the problem. Water quality modeling studies conducted during the early 1980's predicted that upgrading the St. Albans Treatment Plant to remove phosphorus from the effluent would dramatically reduce phosphorus and algae levels in St. Albans Bay.

As a result of these studies, major efforts were undertaken during the 1980's to control point and nonpoint source phosphorus loading to St. Albans Bay. The upgrade of the St. Albans Treatment Plant was completed in 1987 at a cost of $2.3 million for phosphorus removal processes. Phosphorus loading from this facility was reduced by 90%, and the plant has been successfully operating under a discharge permit limit of 0.5 mg/l for total phosphorus, which is the lowest phosphorus limit required for any municipal treatment facility in Vermont. The St. Albans Bay Rural Clean Water Program was completed in 1991 at a cost of $2.2 million for the implementation of agricultural best management practices throughout the bay's watershed.

Water quality monitoring data have not yet demonstrated significant phosphorus or algae reductions in St. Albans Bay since the treatment plant upgrade was completed in 1987. Recent updated modeling analyses suggested that the reason for the lack of water quality improvement is continued internal phosphorus loading from historical residues stored in the bay and/or wetland sediments. A delay of several years in the recovery of water quality in St. Albans Bay following the treatment plant upgrade had been previously expected because of this stored phosphorus. However, the magnitude of the internal loading problem and the time required for recovery were unknown.

In response to this situation, the Vermont Department of Environmental Conservation proposed that a series of study tasks be initiated under a "Diagnostic-Feasibility Study for the Control of Internal Phosphorus Loading from Sediments in St. Albans Bay", according to an April 1992 workplan. Funding was received from the Lake Champlain Basin Program to complete Tasks 1 and 2 under this workplan, and the results of these studies are summarized here.

Task 1 was to conduct an input/output phosphorus mass balance model of the St. Albans Bay and Stevens Brook wetland system in order to determine the specific location and seasonal timing of internal phosphorus loading. Better knowledge of the spatial extent of the internal loading and the mechanisms involved was necessary before any form of in-lake management intervention to control the internal loading could be considered. Field data were collected and a report titled "*Dynamic mass balance model of internal phosphorus loading in St. Albans Bay, Lake Champlain*" was prepared by Smeltzer *et al.* (1994) to respond to Task 1.

Task 2 was to measure the total quantity of phosphorus stored within the sediments of St. Albans Bay that might be released to the overlying water, and predict through a modeling analysis how long the stored sediment phosphorus might delay the recovery of water quality in the bay. Long-term modeling of past and future internal phosphorus loading rates required estimates of historical phosphorus loadings to the system. A report titled "*History of phosphorus loadings to St. Albans Bay, 1850-1990*" was prepared by Hyde *et al.* (1994) to support the long-term modeling analysis of internal phosphorus loading in St. Albans Bay, and to provide a general historical perspective on the phosphorus problem in the bay.

The results of field data collection and modeling analyses of long-term trends in internal phosphorus loading in St. Albans Bay were presented in a report titled "*Assessment of sediment phosphorus distribution and long-term recycling in St. Albans Bay, Lake Champlain*" by Martin *et al.* (1994). This report compared current sediment phosphorus concentrations with levels measured in 1982 before the wastewater treatment plant upgrade, and developed a model of sediment and water phosphorus processes to predict the long-term future water quality response of St. Albans Bay.

The major findings of each of these three reports are summarized below. The lake management implications of these findings are discussed at the end of this summary.

DYNAMIC MASS BALANCE MODEL OF INTERNAL PHOSPHORUS LOADING IN ST. ALBANS BAY

The central question for the study by Smeltzer *et al.* (1994) was whether internal phosphorus loading to St. Albans Bay was derived primarily from the Stevens Brook wetland, or whether extensive areas of the bay were involved as well. If the major source was localized in the wetland, then some form of in-lake treatment to control the internal loading might be much more feasible and less costly. A better understanding of the seasonal timing and mechanisms of internal loading was also sought to assist in the design of any such treatment. Particular emphasis was placed on analyzing the causes for the peak accumulation of phosphorus and consequent algae blooms which consistently occur in St. Albans Bay during August each year.

The sampling program for this study involved chloride and phosphorus measurements made throughout the bay and wetland during April-November 1992, and included data used to estimate flows and loadings to the system from tributaries and the wastewater treatment facility. A dynamic (time-dependent) mass balance model using the STELLA II ® object-oriented modeling program was calibrated to the field data and used to simulate the effects of reducing internal phosphorus loading in the various segments of the wetland and bay shown in Figure 1.

The results of the modeling analysis shown in Figure 2 indicated that reducing internal loading through some form of sediment treatment in the wetland alone (segments 1 and 2) would do little to eliminate the late summer phosphorus maxima and algae blooms. Internal loading reductions would need to occur throughout a 700 acre region of the bay including segments 1, 2, 3, and 4 for water quality to improve in the bay.

Internal phosphorus loading in St. Albans Bay during the critical August period appears to be a complex interaction of mechanisms including aerobic sediment phosphorus release at high temperature and pH, coupled with seasonally low wind-induced water exchange rates that render the bay more vulnerable to the effects of internal loading during the late summer. The modeling analysis showed that phosphorus concentrations in the bay are highly sensitive to exchange mixing rates. Average wind speeds are normally at their minimum levels in August (see Figure

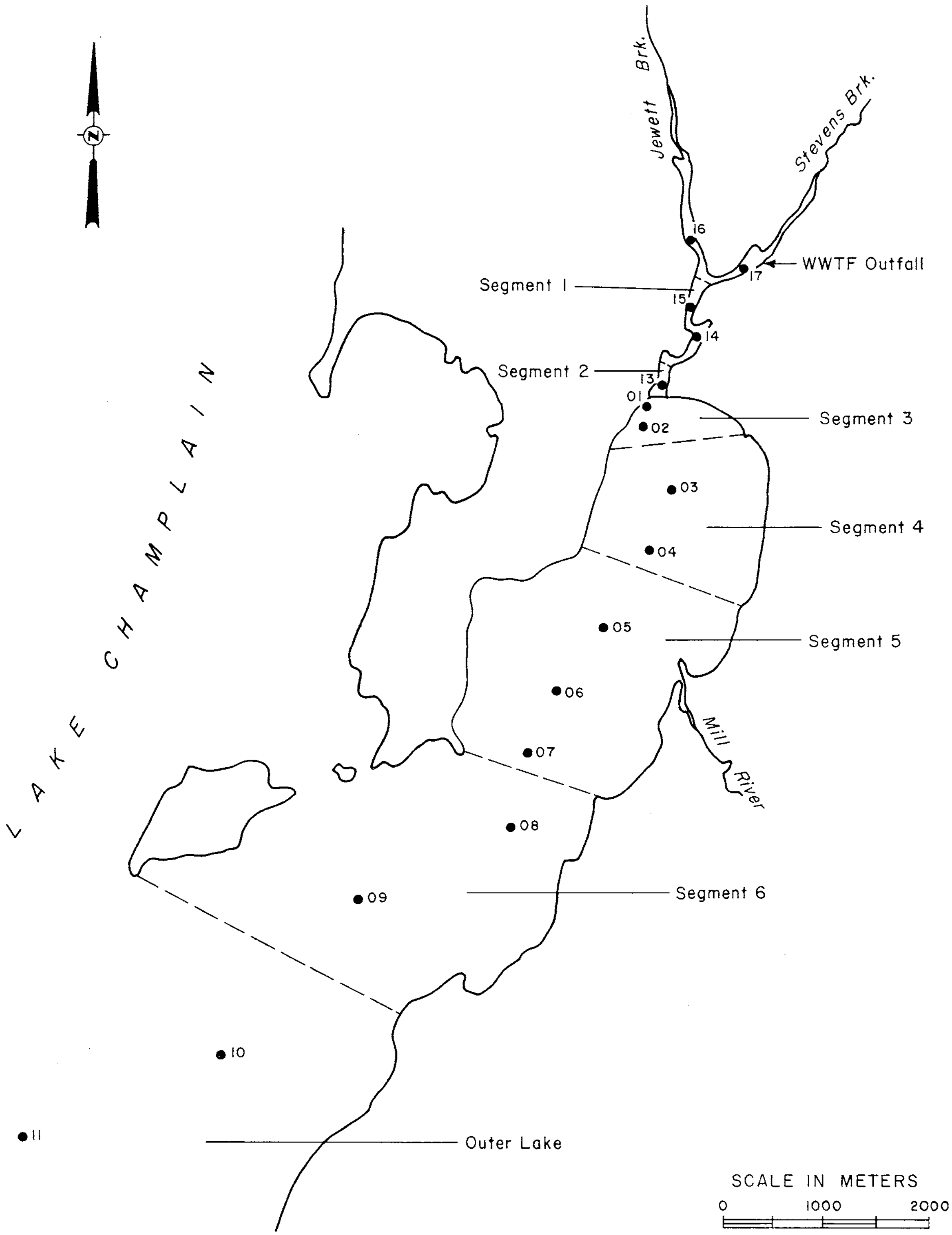

Figure 1. Map of St. Albans Bay showing modeling segments and sampling stations used by Smeltzer *et al.* (1994).

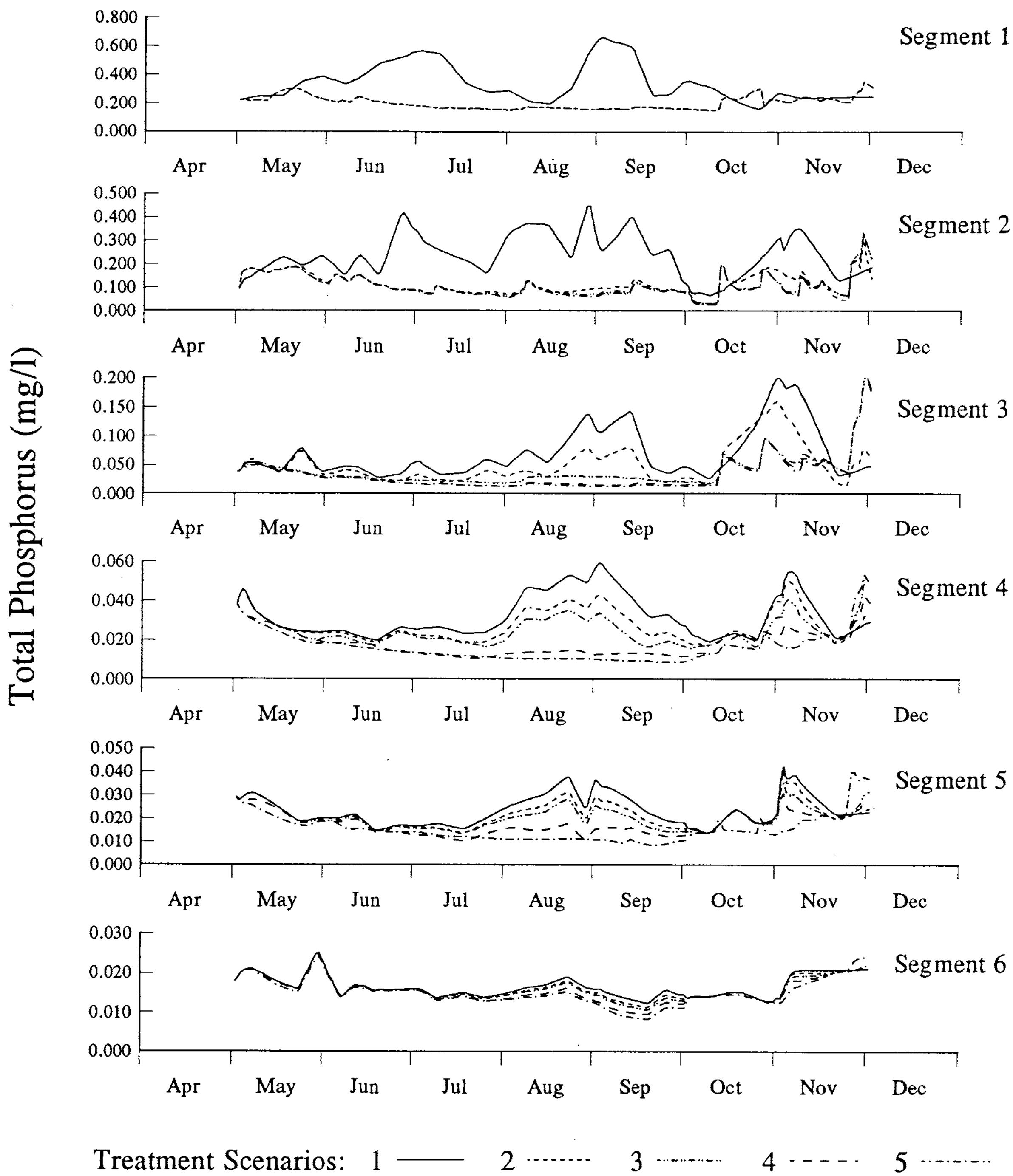

Figure 2. Dynamic mass balance model simulation results for five internal phosphorus loading reduction treatment scenarios (from Smeltzer *et al.*, 1994).

1. No treatment.
2. Treatment of segments 1 and 2 (wetland only).
3. Treatment of segments 1, 2, and 3.
4. Treatment of segments 1, 2, 3, and 4.
5. Treatment of segments 1, 2, 3, 4, and 5.

3), and the relative lack of water exchange is probably the major reason why the internal phosphorus loading has its most severe effect on water quality in the bay at that time of year.

Sediment phosphorus inactivation using aluminum salts may be a practical in-lake management technique to control internal loading in St. Albans Bay, but treating 700 acres of bay would cost approximately $350,000 to $525,000. Before such a project could proceed, additional pilot scale treatments and other feasibility studies would be necessary to determine the stability and longevity of the aluminum floc layer in the shallow, open bay environment. The potential for adverse environmental effects of the treatment would also need to be assessed. It is possible that feasibility studies would conclude that an aluminum treatment of St. Albans Bay would be ineffective or harmful and that no good in-lake treatment alternative exists.

HISTORY OF PHOSPHORUS LOADINGS TO ST. ALBANS BAY, 1850-1990

The purpose of the report by Hyde *et al.* (1994) was to document historical point and nonpoint source phosphorus loadings to St. Albans Bay as quantitatively as possible. These historical phosphorus loading estimates were prepared to support the long term phosphorus modeling analysis by Martin *et al.* (1994), and to provide an historical perspective on some of the water quality management issues regarding St. Albans Bay.

The estimates of historical phosphorus loadings were based on research into the growth of population, industry, and commerce in the City of St. Albans and its surrounding region since 1850. Point source phosphorus loadings were estimated using information on the development of sewers and wastewater treatment facilities in St. Albans, including data on the population and industries served by these sewers. Historical nonpoint source phosphorus loading estimates were based on agricultural statistics maintained for Franklin County, Vermont since 1850 and on nonpoint source phosphorus loading measurements obtained during the St. Albans Bay Rural Clean Water Program.

The combined estimates of domestic and industrial point source phosphorus loadings to St. Albans Bay for the period of 1850 to 1990 are shown in Figure 4. Figure 4 shows that point source loading rates increased steeply to levels over 20,000 kg/yr by the 1930's, and remained at those levels until relatively recently. There was a modest phosphorus loading reduction in 1980 in response to the implementation of the Vermont Phosphorus Detergent Ban, which affected only the domestic component, and a very sharp drop following the treatment plant upgrade in 1986. The treatment plant upgrade reduced point source phosphorus loadings to the lowest levels since the turn of the century.

The combined estimates of historical point and nonpoint source phosphorus loadings to St. Albans Bay are presented in Figure 5. Figure 5 shows that there was a steady increase in phosphorus loadings between 1880 and 1930, followed by sustained loadings of about 50,000 kg/yr for the next several decades. In recent decades prior to the upgrade of the St. Albans City treatment plant, the point source contributed nearly 50% of the total phosphorus loading to the bay. The treatment plant upgrade for phosphorus removal in 1986 resulted in a sharp 30% drop in total annual loading to the bay, with only about 2% of the total now contributed by point sources.

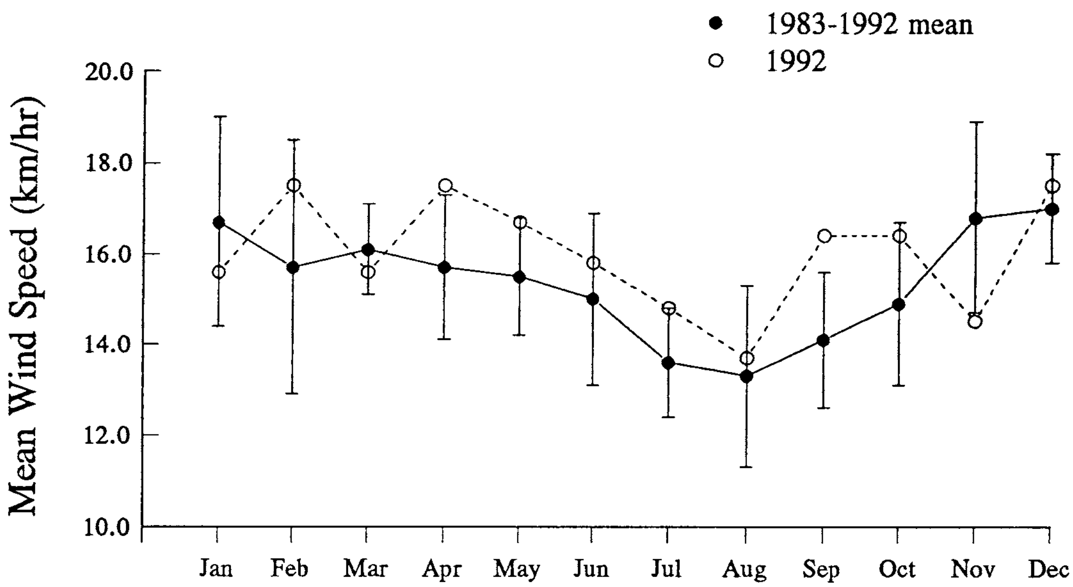

Figure 3. Monthly mean wind speeds recorded at the Burlington, Vermont International Airport during 1983-1992 (N.O.A.A. data). Error bars show standard deviations of the 1983-1992 monthly means (from Smeltzer *et al.*, 1994).

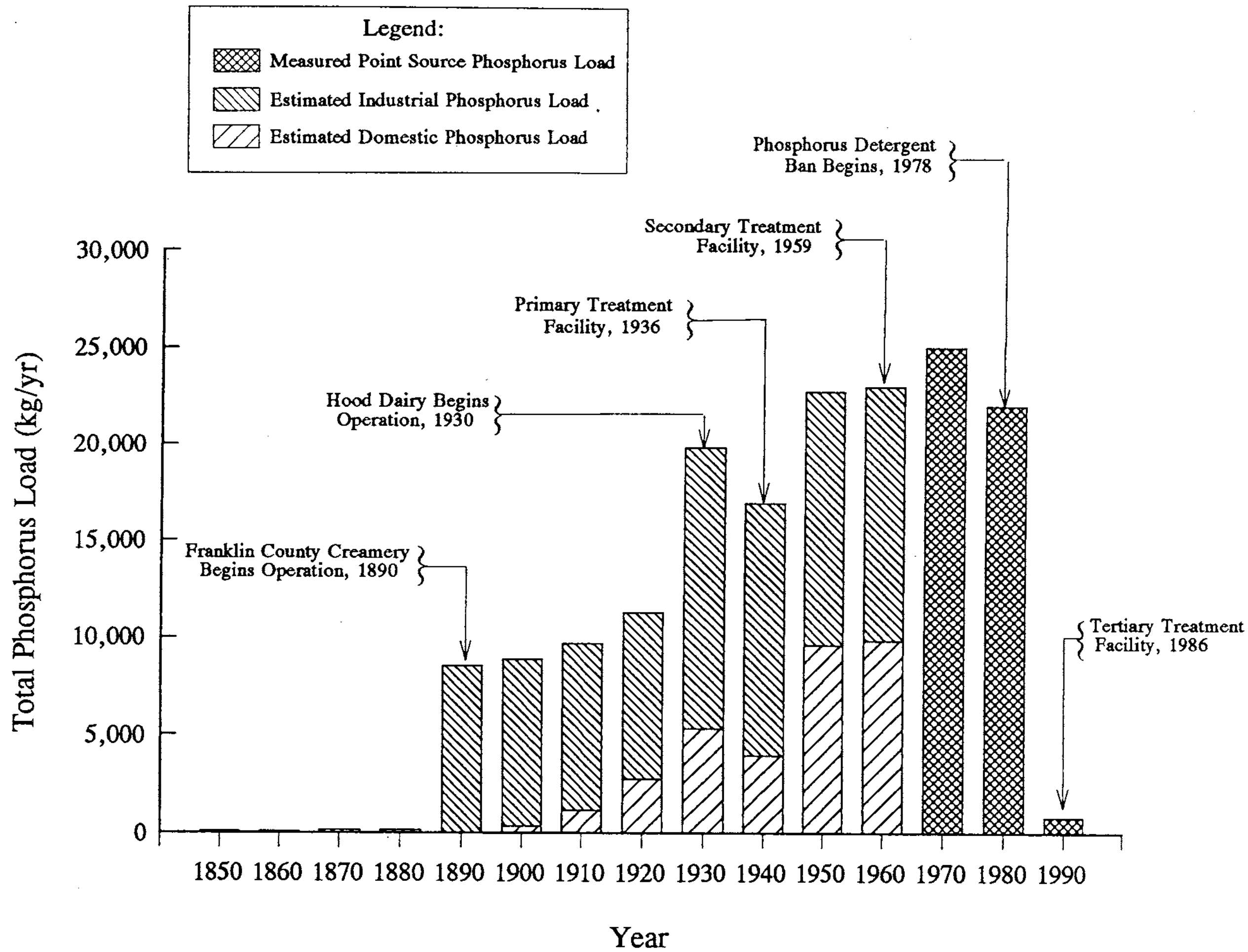

Figure 4. Historical point source loading estimates to St. Albans Bay (from Hyde *et al.*, 1994).
References for actual measurements:

1970: Vermont Agency of Environmental Conservation (1977)
1980: St. Albans Bay Rural Clean Water Program (1991)
1990: Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation (1992)

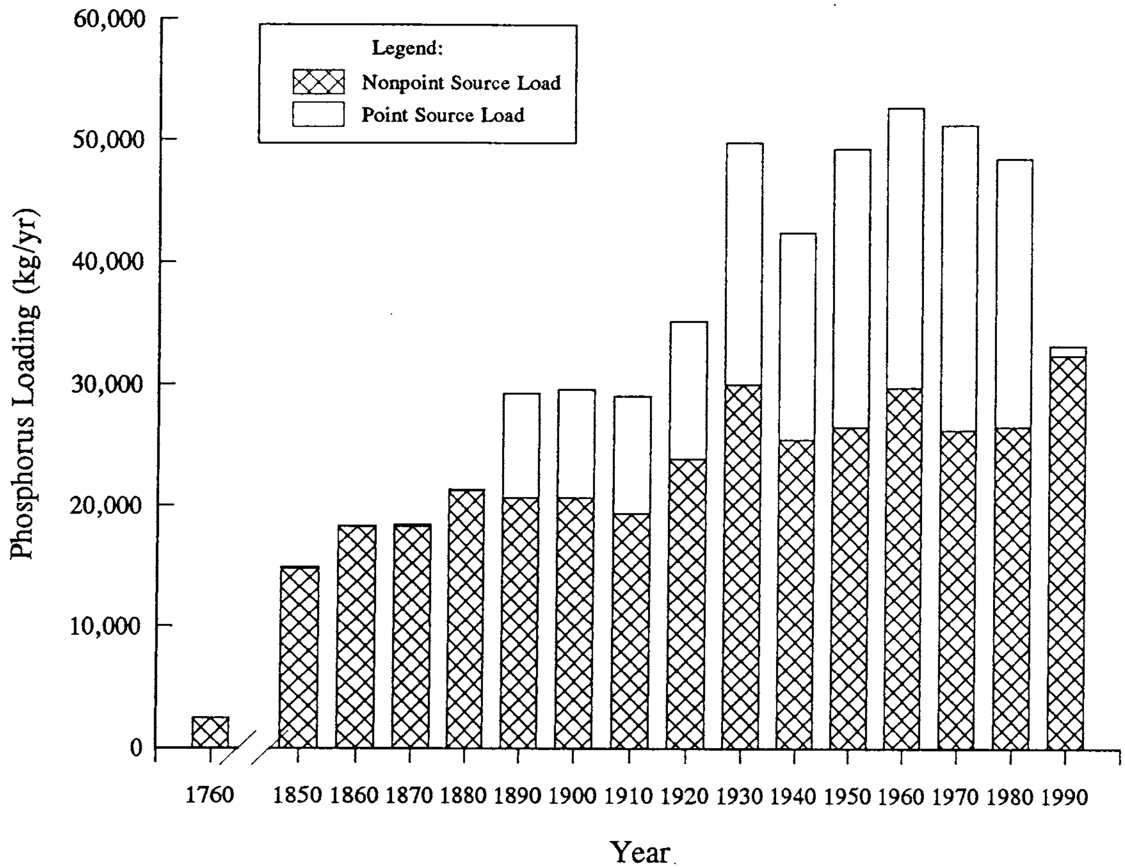

Figure 5. Summary of historical point and nonpoint source phosphorus loading estimates to St. Albans Bay (from Hyde *et al.*, 1994).

The historical phosphorus loading estimates for the St. Albans Bay watershed summarized in Figure 5 provide a valuable perspective on the current eutrophication problem in the bay. Phosphorus loading to the system has been high and sustained for many decades. Phosphorus reductions brought about by the 1986 upgrade of the treatment plant have been in effect for only a relatively few years. If significant portions of the historical phosphorus loads have been retained in the system, stored in the bay sediments or elsewhere, then it may take some time before water quality in the bay improves in response to the recently reduced loading levels.

ASSESSMENT OF SEDIMENT PHOSPHORUS DISTRIBUTION AND LONG-TERM RECYCLING IN ST. ALBANS BAY

The goals of the study by Martin *et al.* (1994) were to determine whether levels of phosphorus in the bottom sediments of St. Albans Bay have declined as a result of point source loading reductions, and to estimate the time frame of any further improvements in water quality in the bay. The study consisted of two major components: (1) phosphorus fractionation studies on bottom sediment cores from St. Albans Bay and the 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.

The results of the sediment phosphorus fractionation work showed that phosphorus levels in the bay and wetland bottom sediments have decreased substantially from concentrations measured by a previous investigation in 1982 prior to the treatment plant upgrade. Sediment total phosphorus concentrations decreased by an average of 350 $\mu g/g$ (23%) between 1982 and 1992. Of this, 50% came from the organic phosphorus fraction, 30% from the biologically available inorganic phosphorus (BAIP) fraction, and 20% from the HCl-P fraction. The measured average reductions between 1982 and 1992 were statistically significant for all phosphorus fractions. The decreases in organic phosphorus and percent organic matter in the sediments since 1982 indicate that, on an annual average basis, primary productivity has declined significantly in the bay and wetland.

Model predictions of future conditions were highly sensitive to uncertainty in the nonpoint source phosphorus loading estimates. The 1982-1989 mean nonpoint source phosphorus loading estimates produced by the St. Albans Bay Rural Clean Water Program were substantially higher than the 1990-1992 estimates produced by the Lake Champlain Diagnostic-Feasibility Study (Vermont Department of Environmental Conservation) and by Smeltzer *et al.* (1994). It is unknown whether the differences are the result of real reductions in nonpoint source loads in recent years, or a consequence of different sampling and data analysis procedures used by the various studies.

Model simulations of future water quality conditions were conducted using two nonpoint source loading scenarios in an effort to bracket the range of uncertainty in the data. Scenario F1 used total phosphorus loading rates estimated for 1992 by Smeltzer *et al.* (1994). Scenario F2 used loading rates at the 1982-1989 mean values reported for the St. Albans Bay Rural Clean Water Program.

Model predictions of future phosphorus concentrations on a volume-weighted average basis in St. Albans Bay are shown in Figure 6. Under loading scenario F1, the model predicted that significant future decreases in phosphorus will occur, and the bay-wide phosphorus goal of 0.017 mg/l would be met by 1995. Under scenario F2, only slight future improvement in water quality would be expected, and the phosphorus goal would not be met without reductions in nonpoint source phosphorus loadings.

A procedure was developed to calculate the "effective" internal phosphorus loading from bottom sediments based on a comparison of predicted concentrations in the water column and bottom sediments at any given time with those at steady-state (i.e. at year 2049). The predicted future declines in the effective phosphorus loading from St. Albans Bay sediments are shown in Figure 6, using the two future loading scenarios. The results shown in Figure 6 indicate that between 12% and 56% of the ultimate decline in effective internal loading has already occurred, as of 1993. About 82-92% of the ultimate decline should occur by the year 2015. Under either nonpoint source loading scenario, substantial further reductions in the effective internal phosphorus loading rate are expected in the future.

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) and when water column phosphorus concentrations are particularly sensitive to internal phosphorus loading. 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. The time frame for most of the water quality improvements resulting from the treatment plant upgrade to occur is on the order of ten to twenty years from the present.

CONCLUSIONS AND LAKE MANAGEMENT IMPLICATIONS

The three related studies summarized here were conducted to help decide what lake management steps should be taken next to improve water quality in St. Albans Bay. The phosphorus modeling analysis by Smeltzer *et al.* (1994) showed that internal phosphorus loading was widespread throughout the bay and wetland system, and that an in-lake treatment to control the internal loading would need to be a large scale project involving approximately 700 acres. The historical research by Hyde *et al.* (1994) revealed that point and nonpoint source phosphorus loading to St. Albans Bay has occurred at sustained high rates for many decades. Significant loading reductions have occurred only in the last few years as a result of the treatment plant upgrade, and it would not be realistic to expect an immediate recovery of water quality in the bay.

The sediment core analysis and modeling work by Martin *et al.* (1994) showed that phosphorus levels in the sediments of St. Albans Bay have declined significantly since the treatment plant loading reductions were implemented. Further reductions in the internal phosphorus loading rate to the bay from its sediments and improvement in water quality in the bay are expected to occur over the next twenty years. However, because of uncertainty in the magnitude of current nonpoint source phosphorus loading rates, it is unclear whether water quality in the bay will improve fully to acceptable levels. Nuisance algae blooms could continue to occur during late summer, although at less frequent and widespread levels than have existed in the past. Reductions in nonpoint source phosphorus loadings would improve the chances of attaining acceptable water quality in the future.

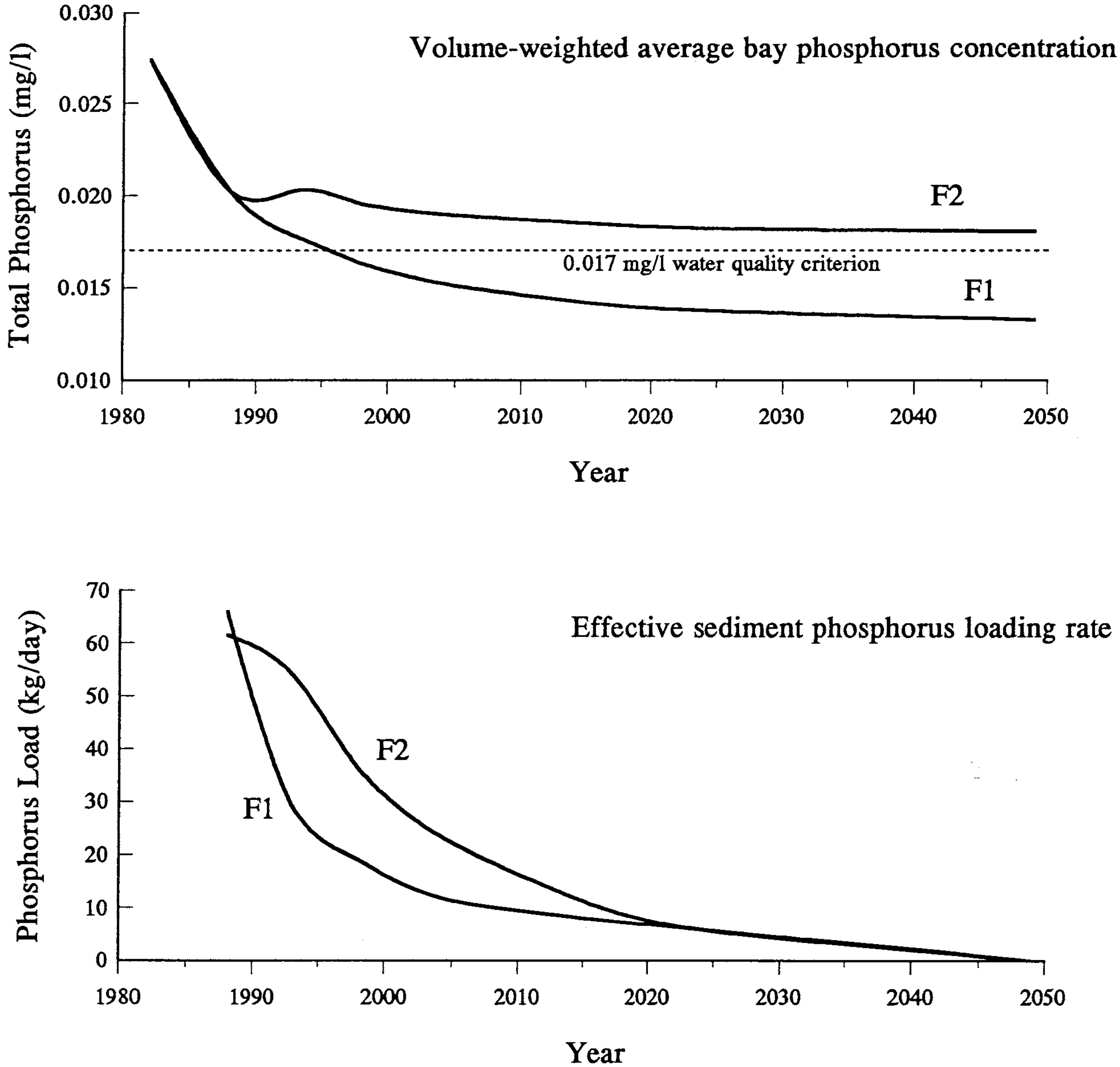

Figure 6. Model predictions of future volume-weighted average total phosphorus concentrations in St. Albans Bay (upper figure), and effective phosphorus loading from bottom sediments of St. Albans Bay (lower figure) under two different loading scenarios, F1 and F2, as defined in the text (from model results given in Martin *et al.*, 1994).

These findings suggest that one or more of the following three possible management actions should be considered:

1. Continue monitoring water quality in St. Albans Bay to determine whether the expected further phosphorus concentration declines over the next ten to twenty years result in acceptable environmental conditions in the bay.

2. Renew efforts to reduce nonpoint source phosphorus loading from agricultural and urban sources in the St. Albans Bay watershed.

3. Initiate feasibility studies for a sediment aluminum treatment to control internal phosphorus loading in the bay, recognizing that it is possible that feasibility studies could conclude that such a treatment of St. Albans Bay would be ineffective or harmful and that no good in-lake treatment alternative exists.

REFERENCES

Hyde, K., N. Kamman, and E. Smeltzer. 1994. History of phosphorus loadings to St. Albans Bay, 1850-1990. Lake Champlain Basin Program Tech. Rep. No. 7b. Grand Isle, VT.

Martin, S.C., R.J. Ciotola, P. Malla, N.G. Subramanyaraje Urs, and P.B. Kotwal. 1994. Assessment of sediment phosphorus distribution and long-term recycling in St. Albans Bay, Lake Champlain. Lake Champlain Basin Program Tech. Rep. No. 7c. Grand Isle, VT.

Smeltzer, E., N. Kamman, K. Hyde, and J.C. Drake. 1994. Dynamic mass balance model of internal phosphorus loading in St. Albans Bay, Lake Champlain. Lake Champlain Basin Program Tech. Rep. No. 7a. Grand Isle, VT.