# Special Report to the Vermont General Assembly on the Effectiveness of the Phosphorus Detergent Prohibition in Household Cleansing Products and Compliance with a 1.0 Milligram Per Liter Discharge Limitation.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

## SUMMARY AND CONCLUSIONS

### Legislation

Vermont's Water Pollution Control Legislation (10 V.S.A., Chapter 47) was amended in April, 1977 to include:

1. A prohibition, effective April 1, 1978, on the sale of household laundry detergents containing phosphorus in amounts greater than trace levels, the so-called Phosphorus Detergent Ban (10 V.S.A §1381-1384) and

2. the requirement that after June 30, 1981, no wastes which contain a phosphorus concentration in excess of 1.0 milligram per liter (mg/l) be discharged to Lake Champlain or other waters designated in adopted river basin water quality management plans (10 V.S.A. §1266a).

The purpose of the 1977 amendments is to reduce the amount of phosphorus entering waters of the State. Phosphorus is a nutrient which stimulates the growth of algae and aquatic plants, a process referred to as eutrophication. Excessive algal and weed growth greatly reduces a lake's recreational potential.

Research has shown that in many Vermont lakes phosphorus is the key nutrient which must be reduced to limit the growth of algae and aquatic plants. Thus, a strategy of limiting the quantity of phosphorus entering Vermont's lakes reaches to the source of the eutrophication problem.

### Legislative Mandate

In addition to the phosphorus management strategies included in the 1977 amendments, a requirement was included that:

During the first half of the 1981-1982 legislative session the Department of Water Resources shall report to the general assembly on:

1. The effectiveness of the prohibition enacted under Section 1 of this act (the Phosphorus Detergent Ban), and

2. compliance with 10 V.S.A. §1266a.

This report has been prepared by the Department of Water Resources and Environmental Engineering in response to this legislative mandate.

### Report Content

Section I of this report is an introduction which explains why, in general, phosphorus is important in managing lake water quality and specifically why the sale of phosphorus detergents has been restricted. Section II of the report addresses the effectiveness of the Phosphorus Detergent Ban; Section III includes a discussion of the municipalities in Vermont required to remove

phosphorus to the 1 mg/l effluent level and a schedule of anticipated planning and construction deadlines.

To evaluate the effectiveness of the Phosphorus Detergent Ban, two methods of analysis were undertaken. The first was an empirical analysis based on the results of a sampling program conducted from 1977 to 1980. The purpose of the sampling program was to compare pre-ban conditions (1977) with data collected from 1978-1980 and to identify significant trends which may be attributed to the Phosphorus Detergent Ban.

Numerous municipal wastewater treatment facilities were sampled intensively during summer time study periods to assess the effectiveness of the Phosphorus Detergent Ban in reducing the quantity of phosphorus discharged to rivers and lakes from these point sources.

Major tributaries to Lake Champlain and Lake Memphremagog were sampled weekly during the entire ice-free season to evaluate if phosphorus concentrations measured in 1978-1980 were reduced compared to 1977 levels. The same sampling schedule was undertaken for nine locations on Lake Champlain and one location on Lake Memphremagog.

The second approach used to determine the effectiveness of the Phosphorus Detergent Ban was the application of a recently developed mathematical water quality model to two lake areas. The purpose of the model was to determine how important the Phosphorus Detergent Ban may be in future years as the population of Vermont's major urban areas continues to grow. The lake areas modeled were Shelburne Bay in Lake Champlain and Newport Bay in Lake Memphremagog. This model was also used to test what impact can be expected from implementation of the 1 mg/l phosphorus effluent concentration at facilities discharging to these embayments.

## Conclusions

The results of the sampling and analyses undertaken by the Department of Water Resources and Environmental Engineering show that present day water quality in Lakes Champlain and Memphremagog is generally good, although certain areas in each lake exhibit serious water quality degradations due to municipal wastewater discharges. The Phosphorus Detergent Ban and projections of the present day effect of removal of phosphorus to a 1 mg/l level show a small, but significant, beneficial effect on present day lake water quality.

Future wastewater discharge levels will increase as a result of continued population growth. At future discharge levels, analyses have shown that the

Phosphorus Detergent Ban and removal of phosphorus to a 1 mg/l level will be highly effective in protecting lake water quality. Without these control measures existing water quality will be seriously degraded. With these measures, existing water quality can be maintained and in some instances improved.

Specific conclusions follow.

1. The Phosphorus Detergent Ban has substantially reduced the quantity of phosphorus discharged from Vermont's municipal wastewater treatment facilities to waters of the State.

An analysis of selected municipal wastewater treatment facilities revealed that implementation of the Phosphorus Detergent Ban has resulted in a 40% reduction in the effluent phosphorus concentration.

2. Future operating costs to be paid solely by municipalities for the removal of phosphorus to a 1 mg/l effluent concentration may be reduced by as much as 50% as a direct result of the Phosphorus Detergent Ban.

3. A detailed statistical analysis of river sampling data indicates that the Phosphorus Detergent Ban has had a significant effect on those rivers receiving relatively large amounts of wastewater treatment facility effluent.

4. Lake sampling data collected during the 1977-1980 study period were analyzed using a statistical method which compared lake areas most affected by point source discharges to lake areas less affected. The results of the four year study showed that the Phosphorus Detergent Ban has had a significant impact on lake phosphorus concentrations at locations most affected by treatment facility effluents.

5. A mathematical water quality modeling analysis was undertaken to predict water quality trends in future years when wastewater treatment facilities reach their design capacity as a result of continued population growth. The lake areas modeled were Shelburne Bay in Lake Champlain and Newport Bay in Lake Memphremagog. The results show that:

a. If the Phosphorus Detergent Ban were discontinued, phosphorus concentrations are predicted to increase over present day levels by as much as 30% for Shelburne Bay and 80% for Newport Bay when wastewater treatment facilities discharging to these embayments reach their design capacity.

With the Phosphorus Detergent Ban in effect, however, predicted increases in the phosphorus concentrations over present day levels are only 5-10% for

Shelburne Bay and 25% for Newport Bay.

b. In Shelburne Bay, future phosphorus concentrations can, through the implementation of a 1 mg/l effluent requirement, be maintained at present day levels even with increased wastewater treatment facility discharges.

Phosphorus removal to 1 mg/l at the City of Newport Wastewater Treatment Facility is predicted to result in phosphorus levels 40% below present day levels. This reduction should occur even at the design discharge capacity of the Newport Wastewater Treatment Facility.

6. Modeling analysis of the Main Lake region of Lake Champlain shows that phosphorus removal to a 1 mg/l level will be effective in protecting lake water quality. Without removal to a 1 mg/l effluent limit phosphorus concentrations are projected to increase by 10% over present day levels as a result of continued population growth. Implementation of the phosphorus removal requirement should offset this 10% projected increase and, in addition, lower phosphorus concentrations by another 7%. Thus, phosphorus removal should result in lake phosphorus concentrations that are 17% lower than would otherwise occur.

7. It has been shown that algal abundance and water clarity in Lake Champlain and Memphremagog are closely linked to phosphorus concentrations. Therefore, projected increases in phosphorus levels will mean more algal growth and reduced water clarity. Conversely, reductions in phosphorus levels due to the Phosphorus Detergent Ban and/or phosphorus removal to a 1 mg/l level will lessen algal growth and increase water clarity.

## RECOMMENDATIONS

1. The Phosphorus Detergent Ban should be continued as a means of protecting water quality in Vermont lakes. The water quality benefits of the Phosphorus Detergent Ban have been demonstrated by both an empirical data analysis and a mathematical water quality model. The cost of the Phosphorus Detergent Ban is minimal.

2. Continuation of the planning, design, and construction for phosphorus removal at selected Vermont waste treatment facilities should continue. Through such action it should be possible within the next decade or so to either maintain or improve upon existing water quality. Without phosphorus removal to the 1 mg/l level a degradation in water quality will occur. The severity of the degradation will depend on the particular lake area of interest. Projections for Shelburne Bay in Lake Champlain and Newport Bay in Lake Memphremagog show the potential exists for severe degradations in water quality due to accelerated eutrophication.

## Section I
## INTRODUCTION

Vermont's Water Pollution Control Legislation (10 V.S.A., Chapter 47) was amended in April, 1977 to include:

1. A prohibition, effective April 1, 1978, on the sale of household laundry detergents containing phosphorus in amounts greater than trace levels, the so-called Phosphorus Detergent Ban (10 V.S.A. §1381-1384).

2. The requirement that after June 30, 1981, no wastes which contain a phosphorus concentration in excess of 1.0 milligram per liter (mg/l) be discharged to Lake Champlain or other waters designated in adopted river basin water quality management plans (10 V.S.A. §1266a).

In addition to the phosphorus management strategies included in the 1977 amendments, a requirement was included that:

During the first half of the 1981-1982 legislative session the Department of Water Resources shall report to the general assembly on:

1. The effectiveness of the prohibition enacted under Section 1 of this act (the Phosphorus Detergent Ban), and

2. compliance with 10 V.S.A. §1266.

This report has been prepared by the Vermont Department of Water Resources and Environmental Engineering in response to this legislative mandate.

The Phosphorus Detergent Ban legislation arose from a concern for water quality in Vermont lakes, particularly in Lakes Champlain and Memphremagog. These two lakes, the largest in Vermont, have recreational and commercial value to Vermonters and others. Both lakes receive considerable inputs of wastewater effluent and both have shown evidence of accelerated eutrophication in recent years, including algal scums, decreased transparency, and proliferation of aquatic weeds.

It is widely accepted in the scientific community that phosphorus is the single most important factor controlling the eutrophication process (Vallentyne, 1970 and Likens, 1972). Algal abundance in lakes, as measured by chlorophyll-a concentrations increases as concentrations of phosphorus increase (Jones and Bachman, 1976). Water transparency declines as chlorophyll concentrations increase (Rast and Lee, 1978). It has been demonstrated that enrichment of a lake with phosphorus through wastewater discharges can cause severe eutrophication and that removal of the discharges can reverse the process (Edmondson, 1972). Furthermore, it has been shown specifically for both Lakes Champlain and Memphremagog that phosphorus is the key element in

controlling algal growth (U.S. Environmental Protection Agency, 1974, Henson and Gruendling, 1977, and Carlson et al 1979).

Phosphorus is supplied to lakes from a variety of sources, including point sources (e.g. municipal wastewater treatment facility discharges) and diffuse sources (e.g. agricultural and urban runoff) Point sources are generally easier to control because of their localized nature, and the Phosphorus Detergent Ban was regarded as a simple and inexpensive way to substantially reduce the contribution of phosphorus to lakes from wastewater discharges.

There is good reason to focus on detergents as a major source of phosphorus in municipal wastewater. There has been a considerable increase in the average phosphorus content of domestic wastewater, from about 3 mg/l in the early 1900's to about 10 mg/l in the late 1960's (Hetling and Carcich, 1972). This increase corresponds to a per capita phosphorus contribution to wastewater of less than 2 lbs/capita/year in the early 1900's to over 3 lbs/capita/year by 1960. The increased phosphorus loading has been attributed to the increased use of detergents containing a high percentage of phosphorus. It was estimated that from 50-70 percent of the phosphorus in domestic wastewater in the late 1960's came from phosphorus detergents.

The evidence cited above indicates that control of phosphorus by means of the Phosphorus Detergent Ban should considerably reduce the phosphorus content of wastewater. Substantial further reductions can be achieved through advanced wastewater treatment for phosphorus removal. Both management strategies can be expected to protect water quality in lakes strongly affected by wastewater discharges.

This report will be presented in the following two sections. Section II concerns the effectiveness of the Phosphorus Detergent Ban. It includes a description of sampling locations, methods, and results. The results address the effectiveness of the Phosphorus Detergent Ban at three levels.

1. The extent to which phosphorus loading from municipal wastewater treatment facilities has been reduced.

2. The extent to which phosphorus concentrations in river receiving wastewater effluent have been reduced.

3. The extent to which phosphorus concentrations in Lakes Champlain and Memphremagog have been reduced.

Section III reviews compliance with the legislative requirement limiting the phosphorus concentration in wastewater effluent at selected treatment facilities

to 1.0 mg/l.

All data collected during this study is available from Vermont Department of Water Resources and Environmental Engineering files.

## Section II

## ASSESSMENT OF EFFECTIVENESS OF THE PHOSPHORUS DETERGENT BAN

### Location and Description of Study Area

The sampling program undertaken by the Department of Water Resources and Environmental Engineering included both river and lake sampling stations. This section describes the location of the study area (Figure 1 and 2), important characteristics of the lake area or river basin, and comments relevant to the phosphorus control issue.

#### Rivers

The rivers sampled include the Lamoille and Winooski in the Lake Champlain Basin, and the Black, Barton and Clyde in the Lake Memphremagog Basin. General hydrologic information and an assessment of the impact of municipal point source discharges on the phosphorus concentrations in the rivers is presented in Table 1.

The Lamoille River, located in western Vermont, discharges to Malletts Bay in Lake Champlain. The drainage basin can be characterized as primarily forested with considerable agricultural development in the lowlands adjacent to the river and its tributaries. Residential development is moderate.

Flows are highly regulated by impoundments in the lower reaches of the river. There are no point discharges to the Lamoille River downstream of the last impoundment, Peterson Dam, located in Milton, Vermont. Impoundments have generally been shown to be efficient at trapping nutrients by allowing settling to occur. Therefore it is likely that much of the upstream phosphorus discharged to the Lamoille River is retained in the impoundments and may not reach Lake Champlain.

The Winooski River discharges to Lake Champlain just north of Burlington, Vermont. The higher elevations of the drainage basin are primarily forested. The lowlands adjacent to the river and its tributaries receive heavy agricultural usage. Urban, residential and industrial development is also quite intense, particularly along the lower reaches of the river in Chittenden County.

The Black River, located in northern Vermont, discharges to South Bay of Lake Memphremagog near Newport, Vermont. Land use in the basin is heavily agricultural with very little residential development.

The Barton River, located in northern Vermont, also discharges to South Bay of Lake Memphremagog near Newport, Vermont. Land use in the basin is heavily agricultural at lower elevations and primarily forested at the higher elevations. Residential development is moderate.

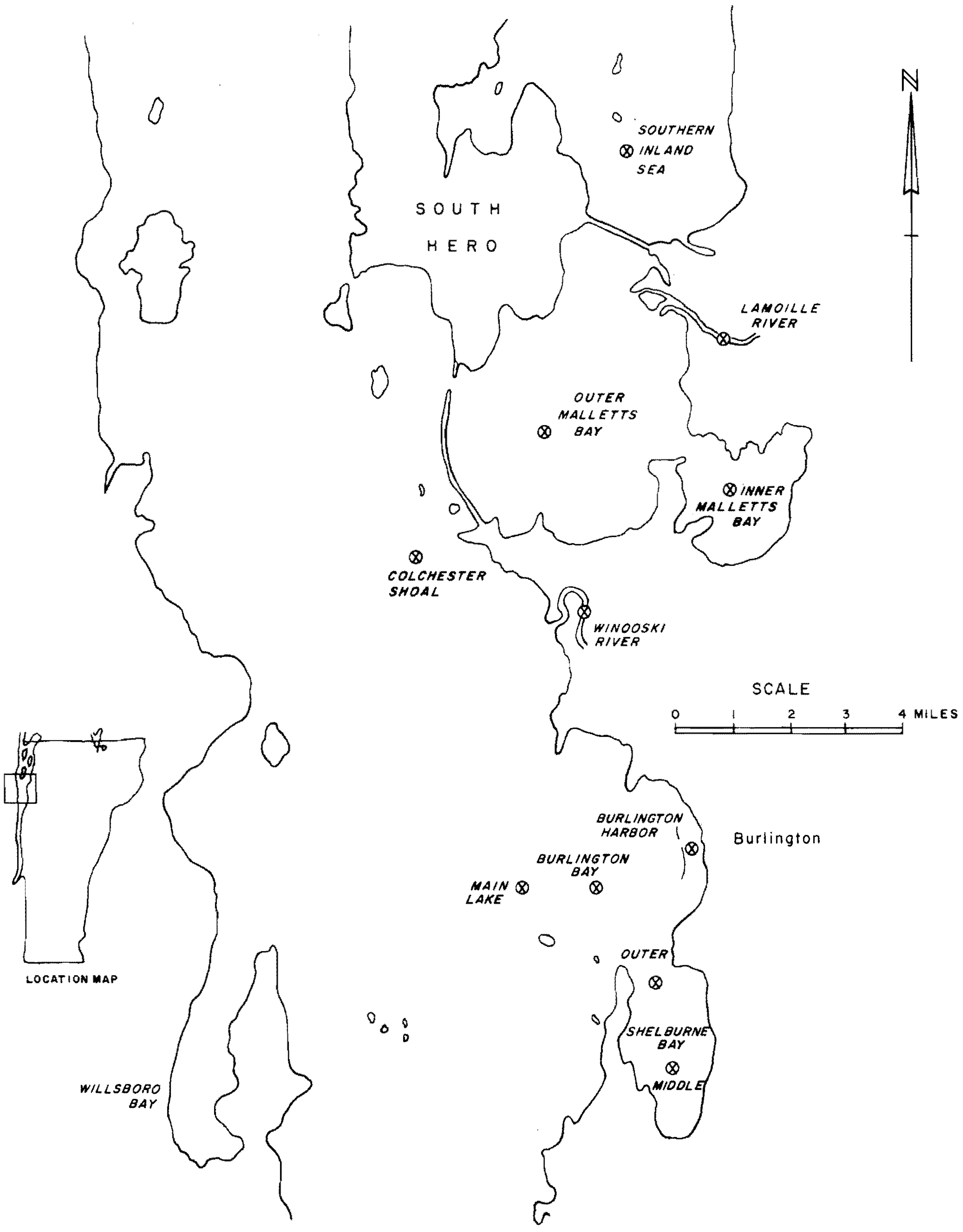



FIGURE I
Lake Champlain study area indicating sampling stations

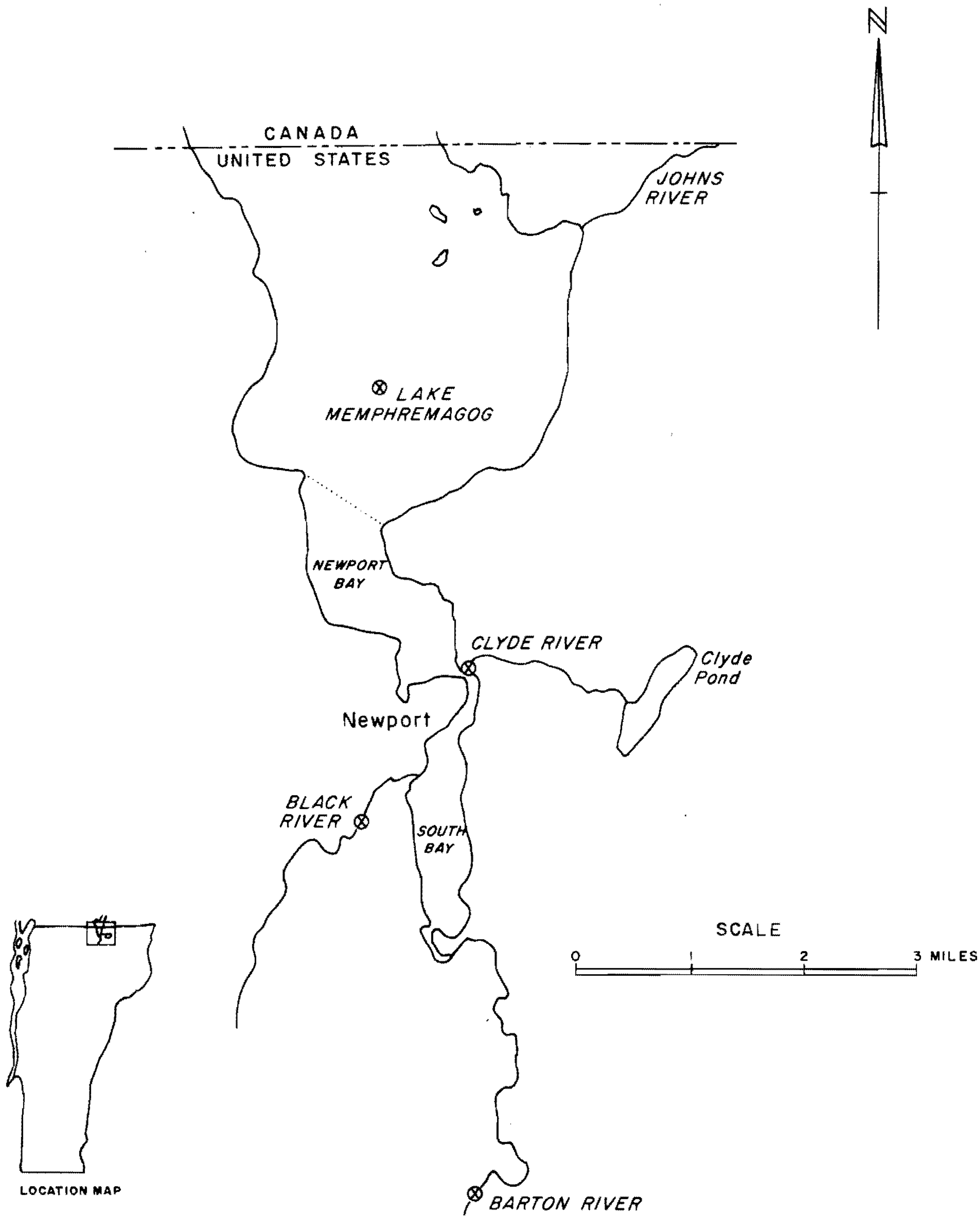



FIGURE 2
Southern Lake Memphremagog indicating sampling stations

Table 1. Drainage area, average daily discharge and point source impacts for five river stations.

| River | Drainage Area ($mi^2$) | Average Daily Discharge ($ft^3/sec$) | Point Source Impacts 1/ |
|---|---|---|---|
| Lamoille | 740 | 1240 | low |
| Winooski | 1100 | 1700 | high |
| Black | 135 | 204 | very low |
| Barton | 186 | 240 2/ | moderate |
| Clyde | 144 | 216 | high |

1/ Description of the impact of point source discharges to the river on the total phosphorus loading entering a lake as follows:

| Description | % of phosphorus loading from point sources |
|---|---|
| high | 60-80 |
| moderate | 40-60 |
| low | 20-40 |
| very low | 0-20 |

2/ Estimated using runoff coefficients (discharge per square mile of drainage area) from the Black River.

The Clyde River, located in northern Vermont, discharges to Lake Memphremagog at Newport, Vermont. The drainage basin is characterized by several large impounded lakes. Land use is basically forested with light agricultural and residential development in some areas. Flow is highly regulated by a series of hydropower impoundments which probably reduce the effect of upstream discharges on the phosphorus loading in the lower reaches of the river. There is a major municipal point discharge (Newport Wastewater Treatment Facility) downstream of the last impoundment on the river.

Lakes

One station in Lake Memphremagog and nine stations in Lake Champlain were sampled during the study as shown in Figures 1 and 2. The location and description of these stations are explained below.

The Lake Memphremagog station is located outside the mouth of Newport Bay, approximately half-way between Horseneck Island and Whipple Point in approximately 23 feet of water. This area is affected by the phosphorus load from Newport Bay which receives the discharges from the Clyde River and the Black and Barton Rivers through South Bay.

Burlington Harbor, partially separated from Burlington Bay by a breakwater, is relatively shallow (station depth about 30 feet) and well-mixed due in part to heavy traffic from Lake Champlain ferries, large pleasure craft, commercial barges and tugboats. It receives considerable wastes from the City of Burlington in the form of treated effluent from the Burlington Main Treatment Facility as well as stormwater runoff from combined sewer overflows discharging into the harbor. During periods of heavy precipitation, the Harbor area receives an increased phosphorus load from untreated sewage when combined sewers overflow and the hydraulic capacity of the Burlington Wastewater Treatment Facility is exceeded.

Inner and Outer Malletts Bay are separated almost totally from the Main Lake and the Northeast Arm of Lake Champlain by man-made causeways and also from each other by a fairly narrow opening between Malletts Head and Red Rock Point. Outer Malletts Bay is larger and deeper (90 ft.) than the Inner Bay (60 ft.) and receives water directly from the Lamoille River. Both the Inner and Outer Bays receive a high degree of recreational usage in terms of boat traffic and vacation homes.

The primary input of phosphorus to Outer Malletts Bay is the Lamoille River. Because the Lamoille Drainage Basin includes several large impoundments,

much of the phosphorus originating from point sources within the basin is likely trapped within these impoundments. Consequently the impact of point source discharges on Malletts Bay is minimized.

The Middle and Outer Shelburne Bay stations are located in 70 feet and 100 feet of water, respectively. Shelburne Bay is subject to phosphorus loadings from the LaPlatte River, two municipal wastewater treatment facilities discharging directly to the bay, as well as several small brooks around the periphery of the bay. Shelburne Bay is important for recreational use, particularly boating.

The Southern Inland Sea sampling station is located in the extreme southern portion of the Northeast Arm of Lake Champlain. Because this station is relatively distant from the major external sources of phosphorus loading that enter the Northeast Arm, St. Albans Bay and Missisquoi Bay it may not be heavily affected by point source phosphorus discharges. This area of the Northeast Arm is relatively open water and over 100 feet in depth.

The Colchester Shoal station is located just south of the Colchester lighthouse in approximately 65 feet of water. Because of its proximity to the mouth of the Winooski River, it is likely that water quality in the Shoal area is influenced to a large extent by water quality of the river.

The Main Lake and Burlington Bay stations are characterized by deep open water areas. Lake depths for these areas are well over 100 feet, with the Main Lake station approximately 250 feet deep. In contrast to near shore sampling stations, the Main Lake and Burlington Bay stations should generally reflect water quality conditions for the central basin of the Main Lake.

## Methods

Presented in this portion of the report is a brief summary of the methods employed during the four year study period.

### Sampling Methods

#### Wastewater Treatment Facilities

Numerous treatment facilities on the Lower Winooski River were intensively sampled during three day study periods in 1977, 1978 and 1979. Sampling was conducted over a three day time span in each year (July-12-15, 1977; July 14-17, 1978; August 3-6, 1980). Grab samples of effluent were collected every four hours during a 72 hour sampling period, for a total of 18 samples each year. The samples were analyzed for total phosphorus and biochemical oxygen demand. Flow data at the individual facilities was provided by the facility operators.

Rivers

The sampling stations on the five rivers included in the study were located near the confluence of each river with its receiving body of water. Grab samples were collected in duplicate either at mid-stream from bridge or boat using a Kemmerer water sampler, or from the streambank using a hand-held dip sampler. Samples were analyzed for total phosphorus.

During 1977 samples were collected from the Winooski and Lamoille River at three points on a transect across each river. Analysis of the data showed no significant difference between the transect stations and so in subsequent years (1978-1980), samples were collected only at the mid-stream station.

Sampling frequency during 1977 was twice weekly. Analysis of the data determined that the advantage of sampling twice per week did not warrant continuation, and subsequent sampling was conducted at a frequency of once per week.

The extent of the sampling season was regulated by ice-free water periods on Lakes Champlain and Memphremagog. Sampling generally commenced early in April and ended in late November.

Lakes

Nine sampling stations on Lake Champlain and one on Lake Memphremagog were established and sampled from 1977 to 1980 during the ice-free period. Sampling frequency was generally twice weekly during the spring runoff period and once a week for the remainder of the sampling season.

Secchi disc transparency was measured at each station using a standard diameter black and white Secchi disc. Water samples for total phosphorus and chlorophyll-a were collected in duplicate with a 5/8 inch I.D. rubber hose. The weighted hose was lowered to twice the depth of the Secchi transparency, pinched off, raised, and emptied into a polyethylene sampling bottle.

## Analytical Methods

Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand was determined as specified in Section 507 of Standard Methods (1976).

Total Phosphorus

Water samples were analyzed for total phosphorus using a Technicon Autoanalyzer II in accordance with colorimetric automated ascorbic acid method described by U.S. Environmental Protection Agency (1979).

Chlorophyll-a

Chlorophyll-a concentrations were measured *in vitro* using a Turner Model III fluorometer according to the fluorometer procedure as outlined in Section 1002 of Standard Methods (1976). Membrane filters were used, and corrections were made for pheophytin-a interference.

## Results

### Wastewater Treatment Facilities

Presented in this portion of the report are the results of the sampling program that was undertaken to evaluate the impact of the Phosphorus Detergent Ban on phosphorus inputs from wastewater treatment facilities.

Several treatment facilities were sampled intensively during three day study periods in the summers of 1977, 1978, and 1979. Flows and total phosphorus concentrations were averaged for the 72 hour period providing a mean total phosphorus concentration and flow for each year at each facility. Daily total phosphorus loading for each facility was calculated from these figures.

In addition to the collection of samples for total phosphorus, samples for Biochemical Oxygen Demand (BOD) were also analyzed to determine if the relative treatment efficiencies for any facilities changed from one year to the next. Because changes in treatment efficiencies would bias any observations regarding the impact of the Phosphorus Detergent Ban, those facilities exhibiting such changes were excluded from the analysis.

The sampling results from five treatment facilities where treatment efficiencies remained relatively constant are presented below. These facilities are: Essex Junction Village, South Burlington-Airport Parkway, Winooski, Burlington-Northend and Burlington Riverside. All of these facilities discharge to the Winooski River.

The results of the wastewater treatment facility sampling program clearly demonstrates that the Phosphorus Detergent Ban has substantially reduced the amount of phosphorus discharged from these sources.

During the periods of study there was an average 41% reduction (ranging from 8-65%) in total phosphorus concentrations in the effluents of those five facilities.

The phosphorus loading and concentration results are presented in Figures 3 and 4.

When the Phosphorus Detergent Ban was originally proposed, a 50 percent reduction in total phosphorus concentrations and in loading from municipal facilities was predicted. This prediction was based on values from the

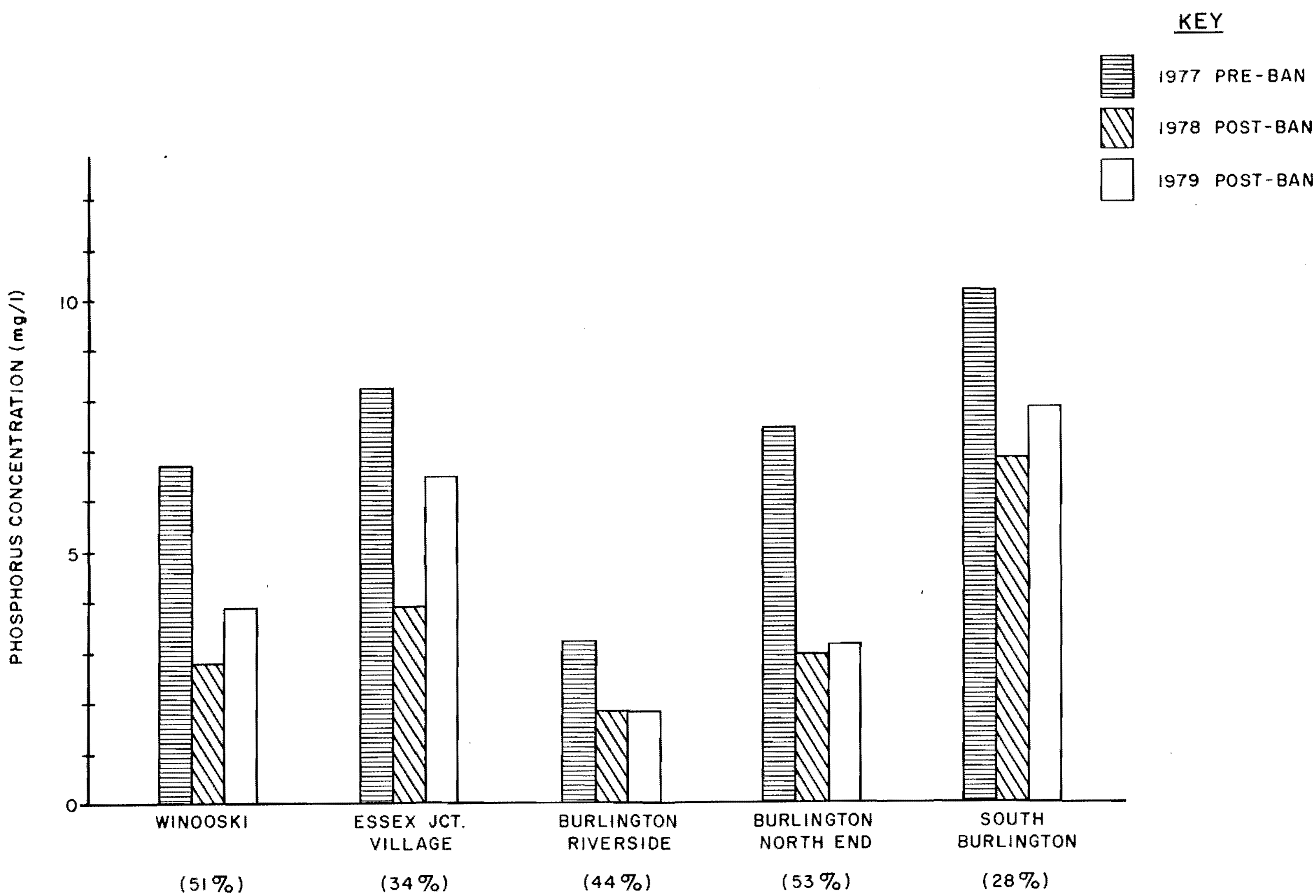



Figure 3. Comparison of wastewater treatment facility phosphorus concentrations for 1977 to 1979. Percentages represent the reduction in phosphorus concentration from pre-ban (1977) to post-ban (1978-1979).

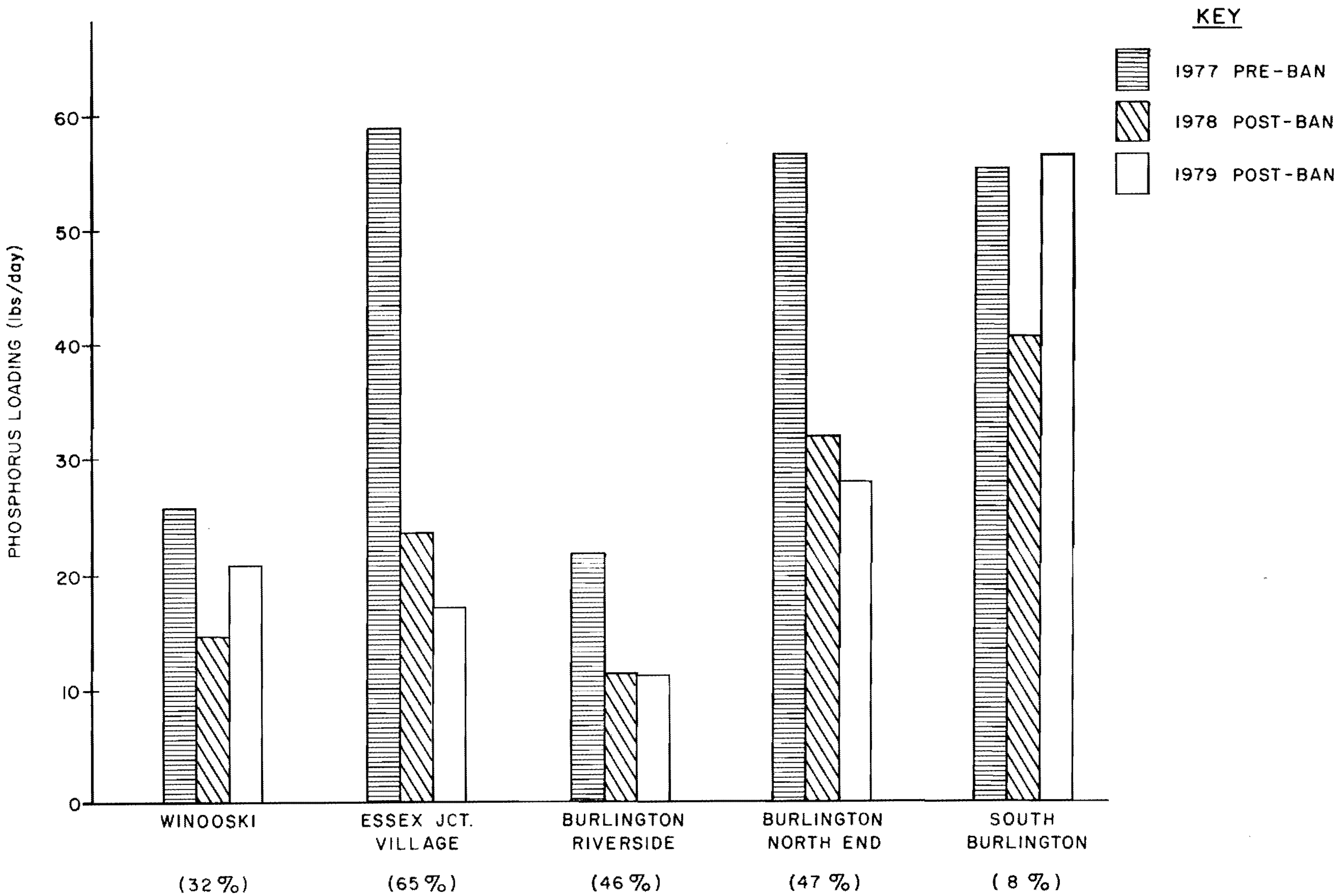



Figure 4. Comparison of wastewater treatment facility phosphorus loading for 1977 to 1979. Percentages represent the reduction in phosphorus loading from pre-ban (1977) to post-ban (1978-1979).

literature, mainly studies conducted outside Vermont and dealing with phosphorus detergents containing over 10 percent phosphorus by weight.

In the year prior to the implementation of the Phosphorus Detergent Ban in Vermont, detergents containing more than 10 percent phosphorus by weight were virtually nonexistent in the retail outlets of Vermont. A survey of the first quarter 1977 sales by a major Vermont wholesale distributor showed the following breakdown of the total detergent handled (by weight) by this company according to phosphorus content.

1. 77 percent of the total was in the form of household laundry detergents containing an average of 7.2 percent phosphorus by weight.

2. 15 percent of the total was in the form of dishwashing detergents exempt from the detergent phosphorus restrictions and with an average phosphorus content of 8.4 percent by weight.

3. 8 percent of the total was in the form of household laundry detergents containing trace levels of phosphorus (less than 0.5 percent by weight).

Considering the availability of low to moderate phosphorus containing detergents prior to the implementation of the restrictions, it is reasonable to expect a reduction somewhat less than the predicted 50 percent, as was observed in the analysis of the data.

In addition to benefits of the Phosphorus Detergent Ban in terms of reduced phosphorus inputs from wastewater treatment facilities, there exists strong evidence that the Phosphorus Detergent Ban will substantially reduce the costs for those facilities required to remove phosphorus to a 1 mg/l effluent concentration. There are currently 20 facilities in Vermont so mandated.

To remove phosphorus to the 1 mg/l level it is generally agreed that the most economical method is by the precipitation of phosphorus with salts of iron and/or aluminum. Aside from the capital costs for equipment associated with the storage and application of chemicals, the major costs of phosphorus removal by chemical precipitation are annual operating and maintenance expenditures. Furthermore, the bulk of the operating and maintenance costs are for the purchase of chemicals and the handling of increased sludge volumes generated by the precipitation process. Recent studies in Canada (Schmidtke, N.W., in U.S.E.P.A., 1980) have shown a strong correlation between influent total phosphorus concentration and optimum dosage of precipitating chemicals required to achieve a desired level of phosphorus removal. The implication of this relationship is that reductions in influent total phosphorus concentrations may

decrease the chemical dosage rate required for phosphorus removal, resulting in annual operation and maintenance cost savings to the municipalities where phosphorus removal is required.

Several pilot studies conducted by the Department of Water Resources and Environmental Engineering on Vermont facilities has shown influent phosphorus concentrations of approximately 5 mg/l, a level far below the 9-10 mg/l characteristic of influent concentrations prior to the Phosphorus Detergent Ban. At an influent concentration of 10 mg/l, for example, it is estimated that the cost of chemicals necessary to meet a 1 mg/l effluent concentration is $55 per million gallons of effluent. At a 6 mg/l influent concentration this cost is reduced to $30 per million gallons of effluent. Since the operating costs for phosphorus removal must be paid for solely by the municipalities, rather than through State or Federal funding, these cost savings are of direct local benefit.

Rivers

The results of the river sampling are given in Table 2. It is apparent from this table that considerable year to year variability exists in summer mean phosphorus levels in these rivers. This variability is largely a result of differences in weather and runoff conditions from one year to the next. The observed reduction in wastewater treatment facility effluent phosphorus concentrations following the Phosphorus Detergent Ban suggests that phosphorus levels in the rivers receiving effluent should decline as well. However, the variability in yearly runoff makes a simple comparison between river phosphorus levels before and after implementation of the ban difficult and potentially misleading. Therefore, it is important to compare phosphorus changes in rivers receiving treatment facility effluent with phosphorus changes during the same years in "control" rivers that are minimally affected by effluent phosphorus loading. It can be determined from such a comparison whether phosphorus levels in rivers affected by wastewater effluent changed in a different manner than did phosphorus levels in the control rivers. Any observed trends in reduced phosphorus loading in the affected rivers can then be attributed to the Phosphorus Detergent Ban since yearly fluctuations in runoff have been accounted for by comparison with the control rivers.

To analyze the data in this manner, the five rivers sampled for this study were separated into two groups. Rivers affected by treatment facility discharges included the Winooski, Clyde, and Barton Rivers. The Lamoille and Black Rivers

Table 2. Summer (June-Sept.) mean total phosphorus concentrations (ug/l) in the study rivers

| River Stations | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|
| Winooski River | 59 | 48 | 43 | 51 |
| Lamoille River | 14 | 13 | 12 | 14 |
| Black River | 23 | 22 | 20 | 29 |
| Barton River | 28 | 21 | 17 | 32 |
| Clyde River | 70 | 9 | 55 | 79 |

Table 3. Analysis of variance table for total phosphorus changes in the study rivers

| Source | Degrees of Freedom | Mean Square | F Value | Prob>F |
|---|---|---|---|---|
| Group | 1 | 2060 | | |
| Rivers (group) | 3 | 546 | | |
| Treatment | 1 | 95 | | |
| Group X Treatment | 1 | 50 | 6.86 | 0.079 |
| Residual Error | 3 | 7.2 | | |

were used as controls. Summer (June-Sept.) mean river total phosphorus levels during 1977, the pre-ban year, are compared with the three-year (1978-1980) post-ban mean for each river in Figure 5. Figure 5 indicates that the three affected rivers showed declines in phosphorus concentrations between 1977 and later years, whereas the control rivers showed little change during this period.

To determine whether the trends observed between the two river groups were significantly different, a statistical test was applied. This test, a two-factor split plot design analysis of variance procedure, was used to compare differences in summer mean river phosphorus concentrations. The first factor was river groups, with two levels: rivers affected by the detergent ban vs. control rivers. The second factor was phosphorus treatment applied over time, also with two levels: pre-ban (1977) vs. post ban (1978-1980). The interaction between group and treatment was tested with an F test using the residual error term. A significant interaction would indicate that the three affected rivers did indeed respond differently than the control rivers following implementation of the Phosphorus Detergent Ban. The results of the analysis of variance are shown in Table 3. The interaction between group and treatment was significant with a probability of error of 8%. Therefore, it can be concluded, with a small probability of error, that the detergent phosphorus restrictions had a significant impact on phosphorus loads carried by rivers receiving treatment facility effluent.

Lakes

The lake results will be presented in three sections. The first section, the phosphorus sampling results, will describe and discuss the lake phosphorus data collected during the course of this study. The second section, the modeling results, will extend the analysis of the data to predict how both existing and future lake phosphorus levels may change as a result of various phosphorus control measures. The third section will discuss changes in chlorophyll concentrations and Secchi disc transparency that can be expected with changes in phosphorus levels. The results will be limited to summer (June-Sept.) levels because it is during summer that water quality conditions are of greatest concerns to lake users, and because point source phosphorus control measures such as the Phosphorus Detergent Ban should have more influence on lake conditions during summer than during other times of the year when diffuse sources may be a more dominant influence on phosphorus loading.

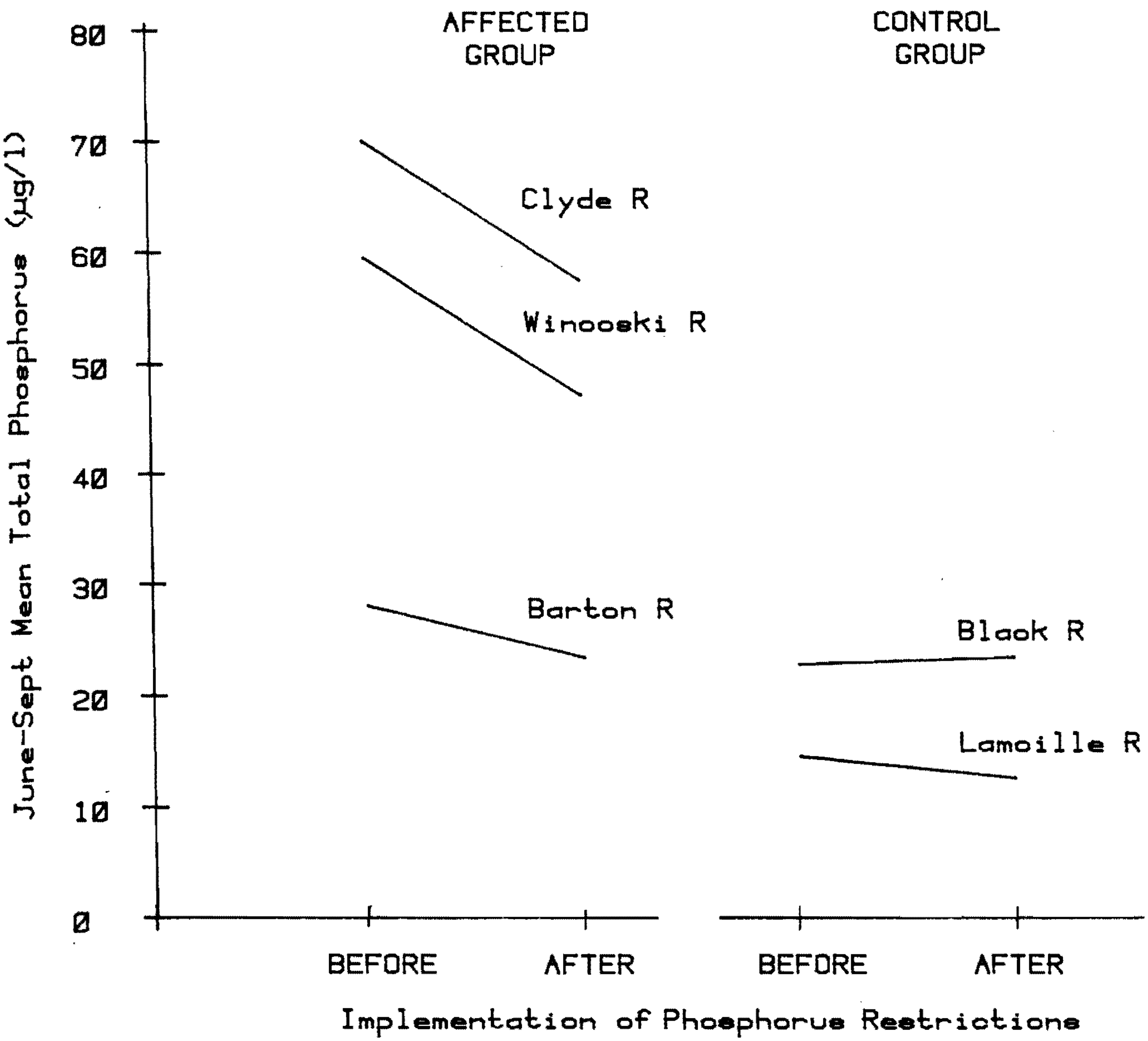



Figure 5. Comparison of summer (June-Sept.) mean total phosphorus concentrations in affected and control rivers before and after the implementation of the Phosphorus Detergent Ban.

Phosphorus Sampling Results

The results of the lake phosphorus sampling are given in Table 4. As with the case of the river data, natural variability in yearly mean summer lake phosphorus concentrations is large, and therefore could mask an effect of the detergent phosphorus restrictions when comparisons are made for only a few years. As with the river results, the lake stations were divided into two groups, those that were considered most likely to be affected by phosphorus control measures at municipal discharges, and control stations that should be relatively unaffected during the short term period of the study.

It is recognized that since many of the lake stations are part of the same waterbody, Lake Champlain, effects of the Phosphorus Detergent Ban or any management action will ultimtely influence almost all stations. However, for the purposes of analyzing the results of this short term study, the differentiation between affected and control stations seems to be a reasonable approach.

| Affected Stations | Control Stations |
|---|---|
| Lake Champlain | Lake Champlain |
| Burlington Harbor | Inner Malletts Bay |
| Colchester Shoal | Outer Malletts Bay |
| Outer Shelburne Bay | Southern Inland Sea |
| Middle Shelburne Bay | Main Lake |
| Lake Memphremagog | Burlington Bay |

The purpose of this grouping was to test whether phosphorus levels at the affected lake stations responded differently than the levels at the control stations between 1977 and the three later years. A different response between the two groups would indicate a significant impact due to the Phosphorus Detergent Ban. Summer (June-Sept.) mean total phosphorus concentrations during 1977, the pre-ban year, were compared with the three year (1978-1980) post-ban mean for each lake station in Figure 6. An examination of Figure 6 reveals that the lake stations most affected by treatment facility effluent showed either declines or modest increases in phosphorus concentrations between 1977 and later years. The control stations, on the other hand, generally showed sharp increases in phosphorus levels during this period.

To test whether the trends observed between affected and control groups were significantly different, the same statistical test used to analyze the river data was applied to the lake results. A two-factor split plot design analysis of variance was done to compare summer (June-Sept.) mean total phosphorus concentrations among the two groups of lake stations. A significant

Table 4. Summer (June-Sept.) mean total phosphorus concentrations (ug/l) at the lake stations

| Lake Stations | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|
| Lake Champlain | | | | |
| Burlington Harbor | 17 | 16 | 14 | 18 |
| Inner Malletts Bay | 8 | 8 | 7 | 9 |
| Southern Inland Sea | 11 | 14 | 14 | 17 |
| Outer Malletts Bay | 8 | 9 | 7 | 11 |
| Colchester Shoal | 10 | 11 | 11 | 14 |
| Main Lake | 9 | 12 | 10 | 13 |
| Burlington Bay | 10 | 13 | 11 | 13 |
| Outer Shelburne Bay | 12 | 14 | 11 | 13 |
| Middle Sherburne Bay | 12 | 13 | 11 | 13 |
| Lake Memphremagog | 18 | 17 | 16 | 20 |

Table 5. Analysis of variance table for total phosphorus changes at the lake stations

| Source | Degrees of Freedom | Mean Square | F Value | Prob>F |
|---|---|---|---|---|
| Group | 1 | 71.1 | | |
| Stations (group) | 8 | 12.5 | | |
| Treatment | 1 | 6.38 | | |
| Group X Treatment | 1 | 3.28 | 3.82 | 0.086 |
| Residual Error | 8 | 0.86 | | |

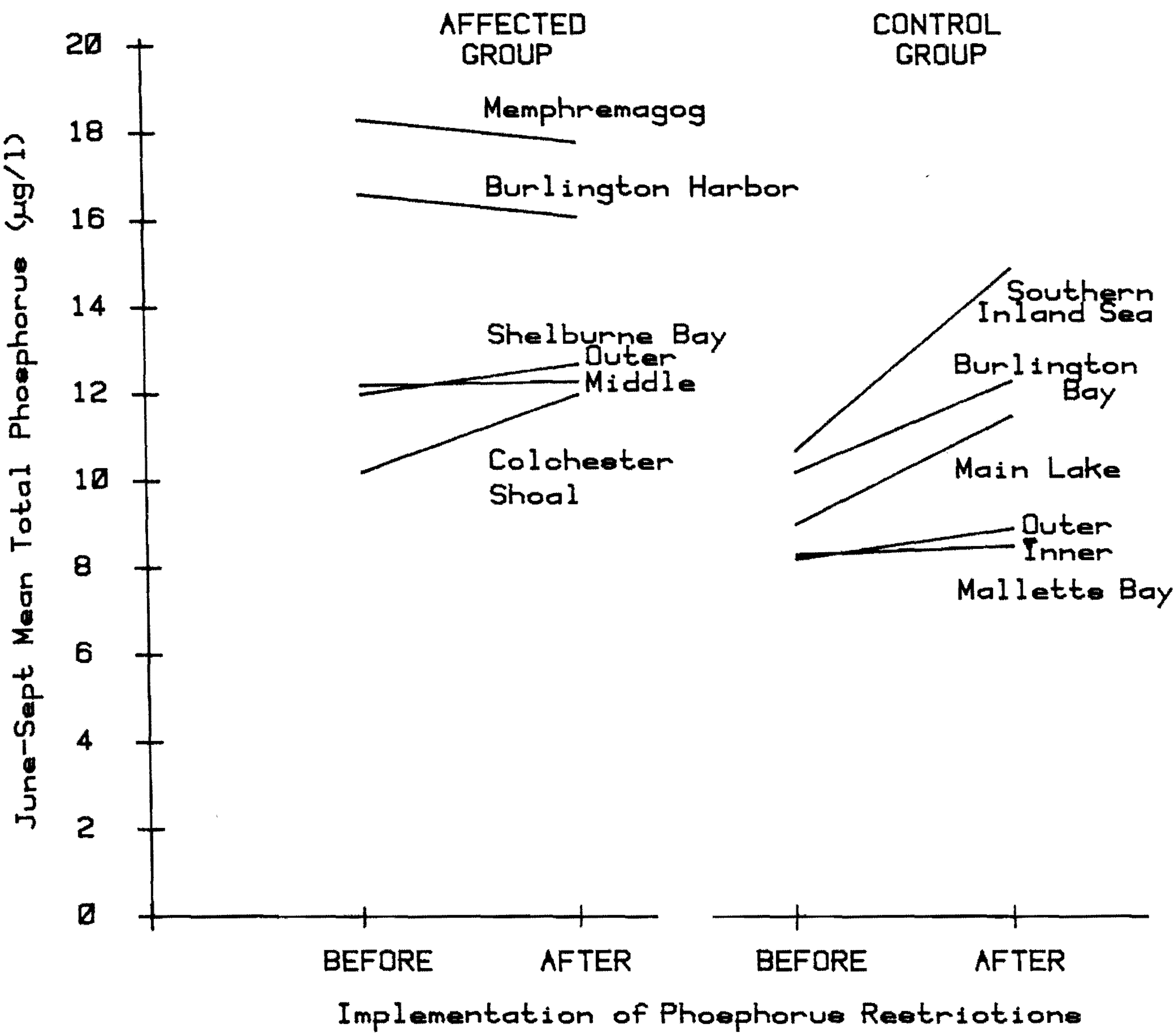



Figure 6. Comparison of summer (June-Sept.) mean total phosphorus concentrations in affected and control lake stations before and after the implementation of the Phosphorus Detergent Ban.

interaction between group and treatment would indicate that the phosphorus levels at the affected lake stations responded differently to the implementation of the Phosphorus Detergent Ban than did phosphorus levels at the control stations. The results of the analysis of variance are shown in Table 5. The interaction was significant with a probability of error of 9%. Therefore, it can be concluded, with a small probability of error, that the Phosphorus Detergent Ban had a significant impact on lake phosphorus concentrations at the locations most affected by treatment facility effluents.

Phosphorus Modeling Results

The empirical results discussed above demonstrated a significant impact of the Phosphorus Detergent Ban on lake phosphorus levels. However, for the purpose of assessing the impact of the ban on lake water quality, the empirical approach has two major limitations. First, because of yearly variability in phosphorus levels that existed during the study period, it cannot provide reliable estimates of the magnitude of the long-term average change in lake phosphorus levels that should occur in response to the ban. It can only demonstrate that a significant change, of unknown magnitude, did occur. Second, it does not provide the basis for evaluation of the impact of the ban when factors such as population growth and the implementation of advanced wastewater treatment for phosphorus removal are considered. For these reasons, the analysis of the lake results were extended with the use of predictive mathematical water quality models.

Two bay areas were chosen for detailed modeling analysis: Shelburne Bay, Lake Champlain and Newport Bay, Lake Memphremagog. These areas where chosen for the following reasons.

1. Both bays are recreationally important to Vermonters.
2. Both receive large amounts of wastewater effluent.
3. Both were relatively simple systems, amenable to modeling.
4. There existed adequate hydrologic and water chemistry data for the modeling analysis.

Complete documentation of the procedures used in the development, verification, and application of these models is provided by Van Benschoten and Smeltzer (1981) and Smeltzer (1981). A summary of the model results for each bay is given below.

Shelburne Bay Model Results

1. A recently published water quality model (Chapra, 1979) was applied to Shelburne Bay. The model was calibrated and verified using data collected

during the four year study period. Excellent agreement was found between predicted and observed values.

2. In analyzing the existing data base it was found that at current point source loading rates the dominant mechanism affecting phosphorus concentrations in Shelburne Bay is the mixing between the bay and the main portion of Lake Champlain. The amount of phosphorus entering and leaving the bay via this mechanism is significantly greater than inputs from point and nonpoint sources or losses due to settling or outflow.

3. The verified model was used to predict how water quality in the bay might be expected to change for several management scenarios. These predictions are illustrated in Figure 7. It was found that:

a) At existing loading levels the model predicts that the Phosphorus Detergent Ban should only minimally improve water quality in Shelburne Bay. This is in agreement with measured water quality data.

b) The continuation of the Phosphorus Detergent Ban should result in about a 5-10% increase in nutrient concentrations in the bay over present levels when treatment facilities reach design loadings. This is in contrast to as much as a 30% increase if the Ban is discontinued and no other phosphorus management strategies are implemented.

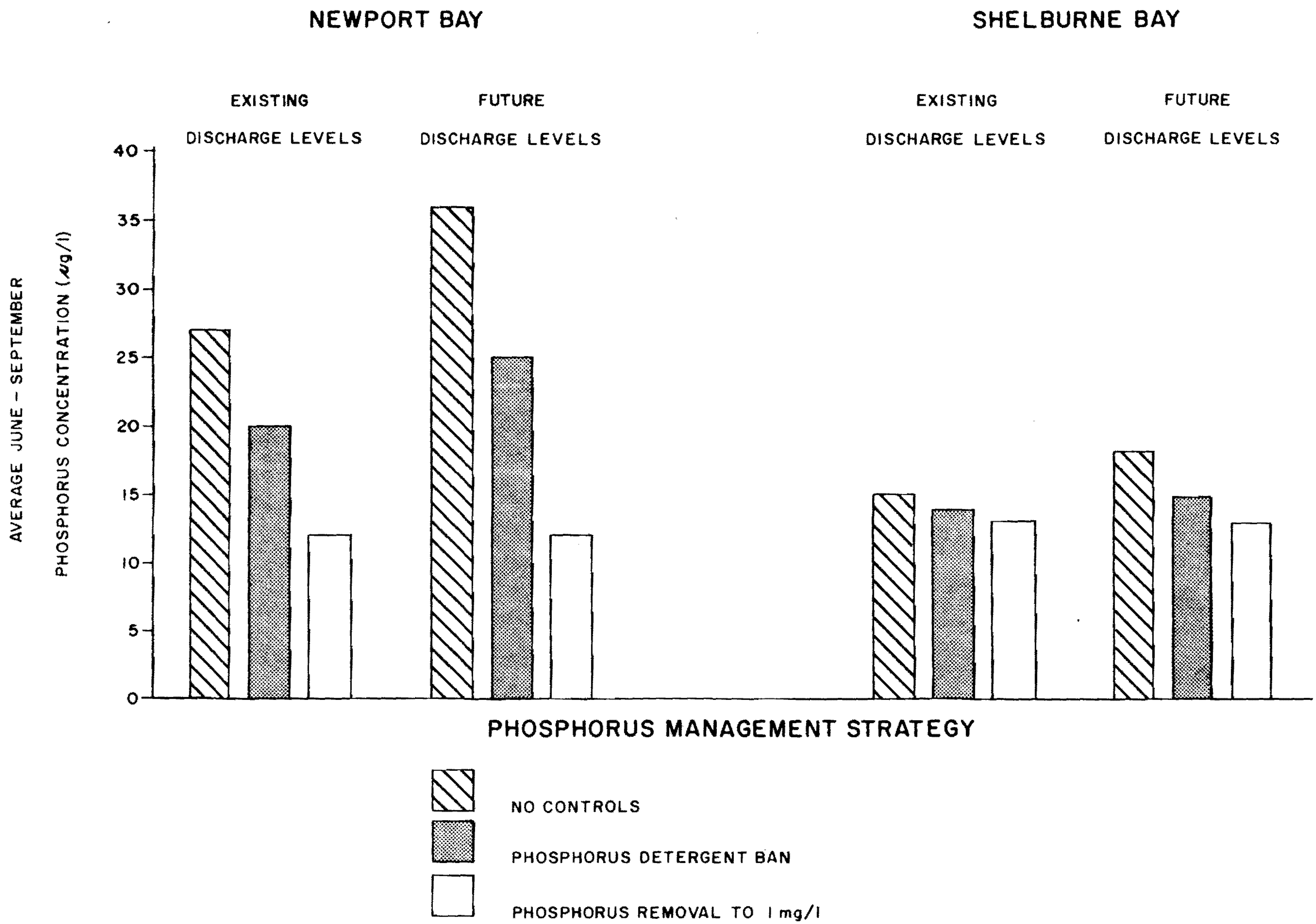
c) It is predicted that if, in addition to the Phosphorus Detergent Ban, the treatment facilities in the Shelburne Bay Basin remove phosphorus to the 1 mg/l level, the concentration of phosphorus in the bay at design loading should be approximately the same or slightly below present day levels.

Newport Bay Model Results

1. A phosphorus model for Newport Bay was developed that incorporates water and phosphorus loading estimates to predict month by month changes in bay phosphorus concentration. The model predictions were verified indirectly by comparing the predictions with phosphorus levels observed at the Lake Memphremagog station during the 1977-1980 study. The model was then used to predict the impact of phosphorus control measures on phosphorus levels in Newport Bay. These predictions are illustrated in Figure 7.

2. Based on 1978 hydrologic and phosphorus loading conditions, the model predicted a substantial (26%) reduction in summer total phosphorus levels in the bay as a result of the Phosphorus Detergent Ban. In addition to the effect of the ban, a further 40% reduction can be expected if phosphorus removal to 1 mg/l effluent concentration occurs at the City of Newport Wastewater Treatment Facility.

**Figure 7: Predicted Phosphorus Concentrations in Shelburne and Newport Bays for Three Management Strategies**



3. If the Phosphorus Detergent Ban is discontinued and wastewater treatment plant loading rates increase to design levels with no other phosphorus control measures applied, the bay summer phosphorus concentrations can be expected to increase by 80% over present levels. The continuation of the ban should reduce this increase at design flows to about 25% over present levels.

In addition to the modeling analysis of Shelburne and Newport Bays, changes in phosphorus concentrations in the Main Lake region of Lake Champlain have also been simulated using a mathematical water quality model (Van Benschoten, 1980). The results of this analysis show that at existing wastewater treatment facility flows, removal of phosphorus to a 1 mg/l level should reduce Main Lake phosphorus concentrations by about 10% from present levels. At treatment facility design capacity, phosphorus levels in the Main Lake should increase by about 10-12% over existing levels if phosphorus removal is not required. The implementation of phosphorus removal should not only offset this 10-12% increase, but in addition reduce phosphorus levels another 6-7%. Thus, a 17% reduction from future predicted phosphorus levels is possible by phosphorus removal at wastewater treatment facilities whose discharge enters the Main Lake region of Lake Champlain. There are eleven treatment facilities in the greater Burlington region required to remove phosphorus to a 1 mg/l level (see Table 6, Section III).

Chlorophyll and Transparency

Thus far, the discussion of the lake results has been limited to observed and predicted changes in lake phosphorus levels. Obviously, other water quality parameters such as chlorophyll concentrations and Secchi disc transparency are of more direct significance to lake users. Measurements of chlorophyll, Secchi disc transparency, and dissolved oxygen were made in Lake Champlain and Memphremagog during the course of this study. Preliminary analysis of this data indicated that chlorophyll and transparency conditions at the lake stations affected by wastewater effluent did not consistently improve, relative to conditions at the control stations, following the implementation of the Phosphorus Detergent Ban.

The lack of a simple and direct response of chlorophyll and transparency to phosphorus changes is not surprising in view of the modest phosphorus changes observed (see Figure 6), and the considerable imprecision that exists in the

relationships between these parameters. Data obtained from Lakes Champlain and Memphremagog does provide, however, a convincing basis for expecting that substantial reductions in phosphorus levels in these lakes will lead to corresponding improvements in chlorophyll and transparency. Summer chlorophyll and phosphorus levels for several stations in Lakes Champlain and Memphremagog are plotted in Figure 8. This figure shows that a strong positive relationship exists between chlorophyll and phosphorus levels observed at the various locations in these two lakes. Furthermore, the Lake Champlain and Memphremagog data conforms to the chlorophyll-phosphorus relationship of Jones and Bachman (1976), which was based on a global sample of 143 lakes. Thus, it can be concluded that the abundance of algae in these two lakes will decline as phosphorus concentrations are reduced.

The relationship between Secchi disc transparency and chlorophyll concentrations in Lakes Champlain and Memphremagog was examined in a similar manner in Figure 9. This figure shows that a negative relationship exists between transparency and chlorophyll at the various lake stations. Furthermore, the data conforms to the transparency-chlorophyll relationship of Rast and Lee (1978), which was based on a broad sample of North American lakes. Therefore, it can be concluded that phosphorus reductions in these lakes will lead to lower chlorophyll levels, and that chlorophyll reductions will, in turn, result in increased water transparency. It should be noted, however, that transparency in certain areas of these two lakes may not respond as expected to changes in chlorophyll levels. For example, the water in the Southern Arm of Lake Champlain is highly turbid as a result of suspended inorganic matter. Data from this section of the lake was excluded from Figure 9 for this reason. The same situation may exist in Southern Lake Memphremagog. An analysis of data obtained solely from the lake station sampled for the present study indicates that transparency at this site is very insensitive to changes in chlorophyll concentrations (Smeltzer, 1981).

Figure 8. The relationship between summer mean chlorophyll and total phosphorus concentrations at several stations in Lakes Champlain and Memphremagog. The curve indicates the relationship of Jones and Bachman (1976), based on a global sample of 143 lakes. Data was obtained from the present study, from the Vermont Department of Water Resources and Environmental Engineering Lay Monitoring Program and from Carlson <u>et al</u> (1979).

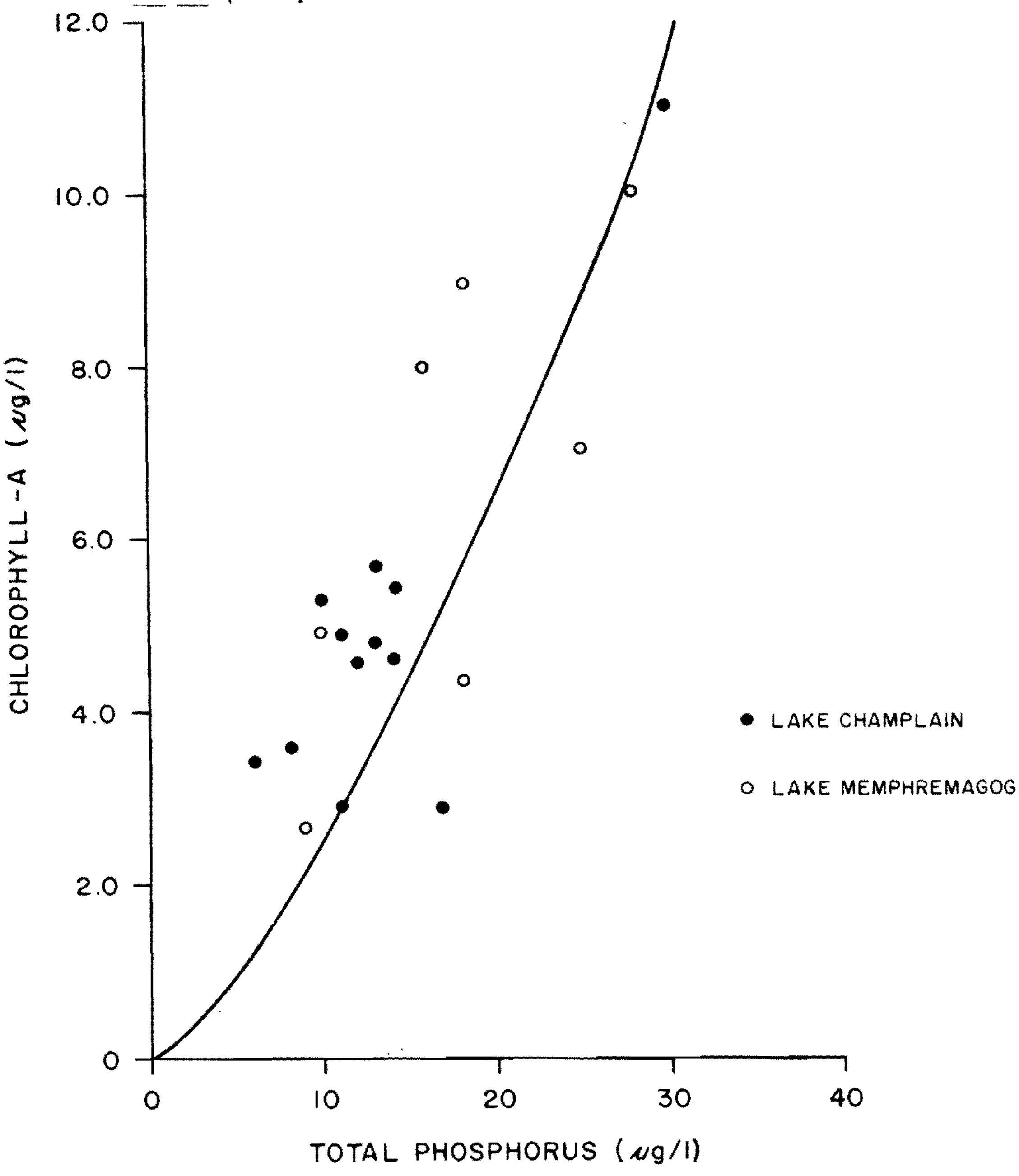
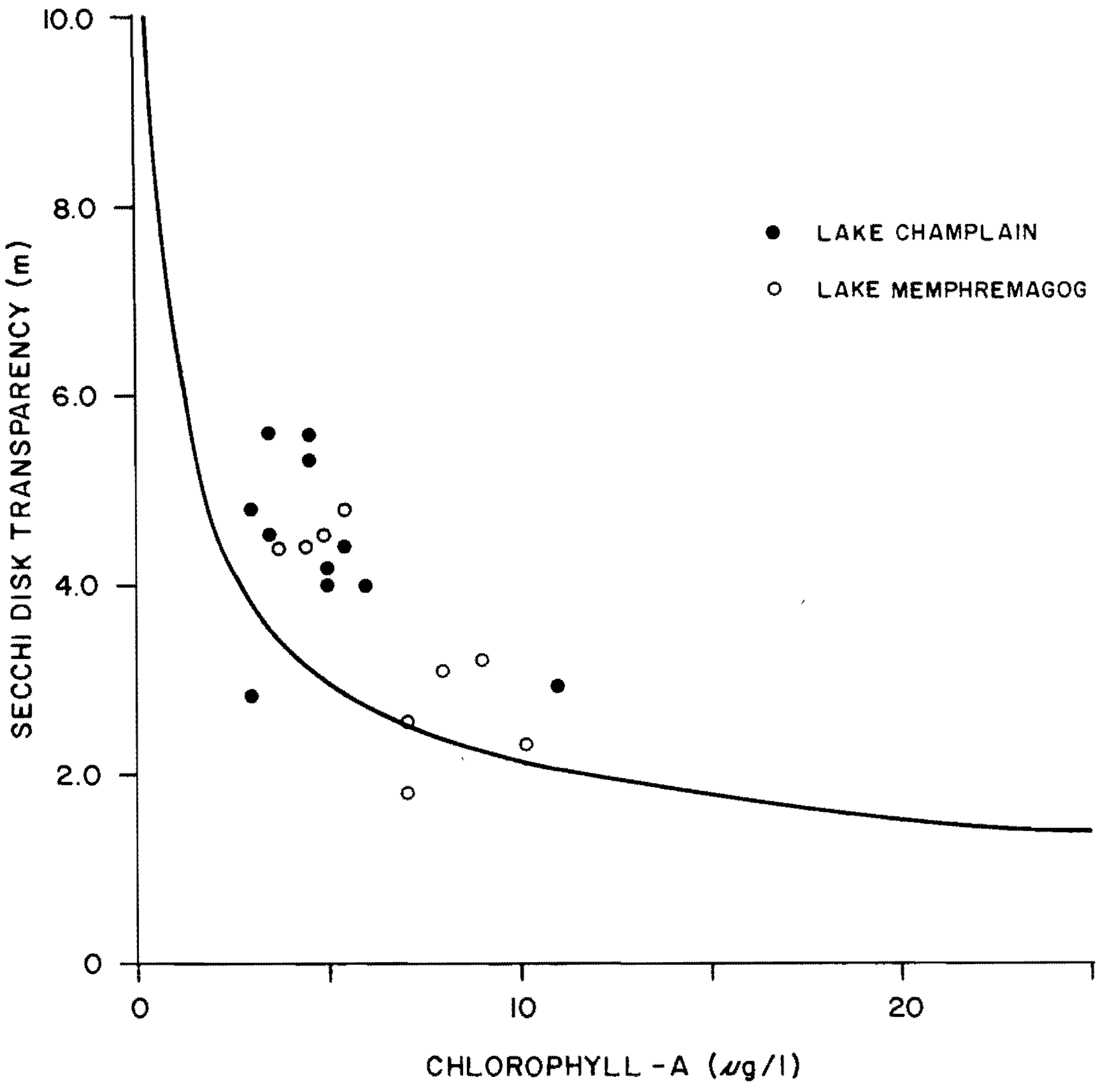


Figure 9. The relationship between summer mean Secchi disc transparency and chlorophyll-a concentrations at several stations in Lakes Champlain and Memphremagog. The curve indicates the relationship of Rast and Lee (1978), based on a broad sample of North American lakes. Data was obtained from the present study, from the Vermont Department of Water Resources and Environmental Engineering Lay Monitoring Program and from Carlson <u>et al</u> (1979).



## Section III

## COMPLIANCE WITH THE PHOSPHORUS REMOVAL REQUIREMENT

In 1973 the Water Resources Board for the State of Vermont adopted Regulations Governing Water Classification and Control of Quality which stated in part(Rule 9). . . . there shall be no discharge of wastes originating after May 27, 1971 containing any form of nutrients which would encourage eutrophication or growth of weeds and algae in any lake, pond or reservoir, natural or artifical. Any waste discharge existing prior to May 27, 1971 and containing soluble or other nutrients which would encourage eutrophication or growth of weeds and algae in any lake, pond or reservoir shall be treated so as to remove such nutrients to the maximum extent that such removal is or may become technically or reasonably feasible ....

Likewise, in April of 1977 the Vermont General Assembly adopted legislation 10 V.S.A. §1266a, which stated that after June 30, 1981 no person discharging to Lake Champlain or to other waters of the State which are designated by the Secretary of the Agency of Environmental Conservation through adoption of a river basin water quality management plan under 33 U.S.C. Sections 1288 or 1313(e) shall discharge any waste into these waters when the wastes contain a phosphorus concentration in excess of 1 mg/l.

The following table summarized the present status of Vermont municipalities which have been directed through an adopted river basin water quality management plan to remove phosphorus from their respective water pollution control facilities to less than 1 mg/l.

It is observed from Table 6 that most of the facilities required to meet the 1 mg/l effluent requirement will not meet the June 30, 1981 deadline of 10 V.S.A. §1266a. The reasons for these delays are explained in the following paragraphs.

### Lake Memphremagog Basin

The Barton and Orleans treatment plants are nearing completion and are expected to be operational by mid-summer of 1981. The Village of Glover project to connect to Barton will start construction in early summer and the connection should be completed by early summer of 1982. This project was delayed by a lack of construction funds and by the necessity of conducting a detailed evaluation of land application alternatives.

Table 6. Municipalities required to remove phosphorus at Wastewater Treatment Facilities.

Lake Champlain Drainage Basin

| Municipality | Operational | Under Construction | In Final Planning | In Preliminary Planning |
|---|---|---|---|---|
| Alburg spr | X | | | |
| Burlington City (three facilities) | (11/83) | | (8/81) | X |
| Colchester F.D. #1 | (7.82) | | (6/81) | X |
| Essex Junction | (10/83) | (11/81) | X | X |
| Essex Town | (10/83) | (11/81) | X | |
| St. Albans | (9/84) | (9/82) | (7/81) | X |
| St. George | (11/85) | (4/84) | (8/81) | X |
| Shelburne F.D. #1 | (7/82) | (9/81) | (6/81) | X |
| Shelburne F.D. #2 | (8/82) | (10/81) | (8/81) | X |
| South Burlington (Airport Parkway) | (8/85) | (3/83) | (8/81) | X |
| South Burlington (Bartletts Bay) | (8/82) | (10/81) | (8/81) | X |
| Stowe | X | | | |
| Swanton | (9/83) | (4/82) | (6/81) | X |
| Vergennes | X | | | |
| Williston | (6/84) | (8/82) | X | |
| Winooski | (8/82) | (10/81) | (9/81) | X |
| Lake Memphremagog Drainage Basin | | | | |
| Barton | (8/81) | X | | |
| Glover | (10/82) | (8/81) | X | |
| Newport | (8/83) | (8/81) | X | |
| Orleans | (8/81) | X | | |

X = current status

The City of Newport project underwent a major revision during the final design stage in order to reduce costs and improve operational reliability. This delayed the bond vote until the spring of 1980 when it was defeated twice. The bonds were finally approved during the spring of 1981 and construction is expected to start this summer. The Derby Center connection to Newport City was delayed by the 1980 Federal fund deferral. The project is now under construction and will be completed in early 1982. Phosphorus removal will not begin until the Newport City plant is upgraded. Derby Line has been substantially delayed by negotiations in the International Agreement involving treatment of this waste at Rock Island, Quebec. This project is now underway and construction will be completed by late fall of 1981.

Lake Champlain Basin

In the Champlain Basin, the phosphorus upgrades at secondary plants were delayed while a method of funding the pilot plant studies was worked out between the Department and the U.S. Environmental Protection Agency (EPA). The pilot studies were started and are now being completed. Phosphorus removal equipment has been installed at Shelburne F.D.#1 and F.D.#2, South Burlington Bartletts Bay, Winooski and Colchester F.D.#1. This equipment is now operational but long term phosphorus removal at these plants will require upgraded sludge handling facilities. It is anticipated that this work will be completed within the next 18 months. The Burlington project suffered the same initial delay as the other projects and has seen further postponements as a result of the request by Burlington for a reevaluation of the need for phosphorus removal. Temporary phosphorus removal equipment should be installed in these plants this summer. The South Burlington Airport Parkway and Essex Junction plants have required lengthy preliminary engineering and final design work. The Essex Junction project should go to construction this summer, but the Airport Parkway project has been slowed down by funding restrictions. The Swanton project has been delayed by engineering evaluations of alternative removal schemes but should be under construction by the Fall of 1981. The St. Albans project was delayed while the Department and the EPA decided which alternatives should be studied. Following a very lengthy grant application review process, an initial grant was approved. At the present time, the land application alternative has been deemed infeasible. The project will not go to construction for at least 15 months.

## REFERENCES


CARLSON, R.E., KALFF, J. and LEGGETT, W.C., 1979. The phosphorus and nitrogen budgets of Lake Memphremagog (Quebec-Vermont); with a predictive model of its nutrient concentration following sewage removal.
Final Report Contract OSU5-0157.
Inland Waters Directorate. Fisheries and Environment Canada. Ottawa.

CHAPRA, S.C., 1979. Applying phosphorus loading models to embayments. Limnol. Oceanogr. 24: 163-167.

EDMONDSON, W.T., 1972. Nutrients and phytoplankton in Lake Washington. In G.E. Likens, ed. Nutrients and Eutrophication: The Limiting Nutrient Controversy. Spec. Syrup. Amer. Soc. Limnol. Oceanogr. 1: 172-193.

HENSON, E.B. and GREUNDLING, G.K., 1977. The trophic status and phosphorus loadings of Lake Champlain. U.S. Environmental Protection Agency. N.T.I.S. Report EPA - 600/3-77-106.

HETLING, L.J. and CARCICH, I.G., 1972. Phosphorus in Wastewater. New York Department of Environmental Conservation. Tech. Paper 22. 19 pp.

JONES, J.R. and BACHMAN, R.W., 1976. Prediction of phosphorus and chlorophyll levels in lakes. J. Water Poll. Cont. Fed. 48: 2176-2182.

LIKENS, G.E., ed. 1972. Nutrients and Eutrophication: The limiting Nutrient Controversy. Spec. Symp. Amer. Soc. Limno. Oceanogr. 1. 328 pp.

RAST. W. and LEE, G.F., 1978. Summary analysis of the North American (U.S. portion) O.E.C.D. eutrophication project: Nutrient loading lake response relationships and trophic state indices. U.S. Environmental Protection Agency. 600/3-78-008.

SCHMIDTKE, N.W., 1980. Nutrient removal technology - the Canadian connection. pp. 1-32. In Control of Nutrients in Municipal Wastewater Effluents. Proceedings of an Internation Seminar. Vol. I. Phosphorus. Municipal Environmental Research Laboratory. Office of Research and Development. Cincinnati, Ohio.

SMELTZER, E., 1981. Use of a predictive model for Newport Bay, Lake Memphremagog to assess the effectiveness of the Vermont Phosphorus Detergent Ban and other management strategies. Lake and Reservoir Modeling Series. Report No. 3. Vermont Department of Water Resources and Environmental Engineering, Montpelier, Vermont.

Standard Methods for the Examination of Water and Wastewater, 1976. American Public Health Association. Washington, D.C.

U.S. Environmental Protection Agency, 1974. Report on Lake Champlain New York and Vermont. E.P.A. Region I and II working paper no. 154.

U.S. Environmental Protection Agency, 1979. Methods for Chemical Analysis of Water and Wastes. Environmental Monitoring and Surveillance Laboratory. Cincinnati, Ohio. EPA - 600/479020.

VALLENTYNE, J.R., 1970. Phosphorus and the Control of Eutrophication. Can. Res. Development (May-June, 1970).

VAN BENSCHOTEN, J., 1980.Modeling analysis of Point Source Impacts on the Main Lake Region of Lake Champlain.
Lake and Reservoir Modeling Series. Report No. 1, Vermont Department of Water Resources and Environmental Engineering, Montpelier, Vermont

VAN BENSCHOTEN, J., and SMELTZER, E., 1981. Use of a predictive model for Shelburne Bay, Lake Champlain to assess the effectiveness of the Vermont Phosphorus Detergent Ban and other management strategies. Lake and Reservoir Modeling Series. Report No. 2. Vermont Department of Water Resources and Environmental Engineering, Montpelier, Vermont.