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Ecological Research Series

THE TROPHIC STATUS AND PHOSPHORUS LOADINGS OF LAKE CHAMPLAIN

Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Corvallis, Oregon 97330

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THE TROPHIC STATUS AND PHOSPHORUS LOADINGS OF LAKE CHAMPLAIN

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DISCLAIMER

FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report summarizes information on the trophic status and phosphorus inputs to Lake Champlain and suggests the degree of phosphorus control needed in various portions of the Lake Champlain basin to control cultural eutrophication.

A. F. Bartsch
Director, CERL

EXECUTIVE SUMMARY

Information on the trophic status of the several basins of Lake Champlain is summarized, the amounts and distribution of total phosphate-phosphorus loading into the lake are evaluated, and recommendations for further study are made. The general objective is to provide basic background information to assist in the development of nutrient control policies for the proper management of the lake. There is a short discussion of the role of phosphorus in the lake ecosystem, how recent thinking is leading to studies of eutrophication models, and a presentation of estimated historical phosphorus loadings. It is shown that Lake Champlain is a phosphorus controlled lake.

The morphometric and hydrographic description of the lake and its basin is given. An inventory of the 292 tributaries draining into the lake is presented, and then an explanation of how the lake and its drainage basin is partitioned into 12 distinct hydrographic units to be treated as components of the total watershed. A mass water transport model is presented to illustrate the mass water movements through the lake basin involving an annual flow of nearly 10,000 X 10^6 m^3/yr. This is followed by a short discussion of the demographic and land use patterns found in the entire drainage basin.

A limnological overview of Lake Champlain summarizes some of the physical, chemical, and biological conditions of each region of the lake. Ranges and average values for basic parameters such as Secchi disc readings, dissolved oxygen, pH, alkalinity, cation concentrations, chlorophyll concentrations, nitrogen and phosphorus concentrations are tabulated. Observations on the biological indices of phytoplankton, zooplankton, and benthos are included.

Evidence that accelerated eutrophication is taking place in Lake Champlain is discussed. Aside from visual observations of an increasing amount of Cladophora growth along the shores, increasing turbidity, increasing evidence of aquatic weed growth in shallow regions of the lake, beach closings because of bacterial contamination, and specific toxins reported found in the water, there have been some documented non-visual changes in the lake over a fairly short period of time. Diatom sequence analyses of sediment core samples indicate an increase in the relative abundance of the mesotrophic-eutrophic diatom species in the more recent sediments. There are indications that there have been significant changes in the phytoplankton populations in the lake in recent years, with members of the blue-green algae becoming more important. The Secchi disc readings have declined in the past decade, as has also the dissolved oxygen concentration of the deeper waters of the lake. There has also been a trend for an increase in the total dissolved solids in the lake, and the concentration of dissolved oxygen in the epilimnion during the early summer. All of these symptoms lead to the conclusion that the lake is in fact deteriorating.

In Section 6 there is a detailed discussion of the loadings, transport, and budgets of phosphorus. Previous studies are reviewed, and estimates indicate that background, or natural loading is significant. Based primarily on a previous study of material inputs into the lake, phosphorus loadings were calculated for each region of the lake. From these estimates the total loading of total PO_4-P amounts to 748 metric tonnes per year, with 90% of this being derived from surface drainage, and 5% from waste treatment plants discharging directly into the lake. Only about 20% of this loading is discharged through the lake outlet, which means that about 80% of the loading, or nearly 600 metric tonnes are retained in the lake per year.

The 1976 Vollenweider model was applied to the data presented for each region of the lake. First, calculations were made for the critical concentrations of PO_4-P, $(P)_c^{Sp}$P, given the input into the equation the calculated loading of total phosphorus from each district. In this analysis, a critical concentration of phosphorus (P)c of 10 µg/l or less would suggest oligotrophy, and 20 µg/l or more would suggest eutrophy. Secondly, the same equation was used by calculating for the critical loading (L_C) with the given values of $(P)_C$ of 10, 15, 20 and 30. The resulting analyses indicated that, for Lake Champlain as a whole, the value of $(P)_C$ amounted to 31.5 µg/l, indicating a very high level of phosphorus loading. For the 12 regions of the lake, the calculated critical P concentrations ranged between 7 and 48 µg/l, with 5 of the 12 districts having a $(P)_C$ value above 30 µg/l, and only four of the regions below the eutrophic level of $(P)_C$-20 µg/l.

For the lake as a whole, the phosphorus loading would have to be reduced by 68% to bring the loading down to the (P)10 level (oligotrophic), 53% down to the (P)15 (mesotrophic) level, and 37% to the base of the eutrophic level. The percent reductions vary for the 12 lake regions.

The individuality of phosphorus loading from each region discussed in the previous section is elaborated in Section 7 of the Report. Point source loadings are inventoried for the streams draining each region of the drainage basin. Some districts are rural and have less than 25% contribution of phosphorus from point sources while some of the urbanized districts have up to 80% of the phosphorus derived from point sources. For the entire lake, 42% of the phosphorus loading is from point sources.

In some of the regions of the lake high phosphorus loadings are not expressed in the usual eutrophic conditions. Missisquoi Bay retains only 5% of the entering load, and some of this goes into a very large fish population, and some is being utilized in building up a large area of emergent plant growth. St. Albans Bay reflects the concentrated and local loading in that area, with excessive weed growth that has been chemically treated for more than a decade. In some instances it is not known how much of the estimated stream loading actually reaches the lake since the streams flow through extensive wetlands between the point of sampling and the lake. Because of the high clay turbidity and high phosphorus concentration in the waters of the south end lake, coupled with the very high retention of phosphorus entering the southern sector of the main lake, much of the phosphorus in this part of the lake is probably adsorbed on the suspended particles, and sedimented out.

General recommendations are that phosphorus input levels should be reduced by variable amounts, and attempts should be made to obtain a better understanding of the fate of phosphorus entering the lake; where it goes, and how it is utilized. Major point source loadings along the contributing streams and directly into the lake should be reduced by constructing advanced waste treatment plants. Since about two-thirds of the phosphorus loading is derived from non-point sources, investigations should proceed to evaluate these diffuse sources to better develop management procedures.

This report was submitted in fulfillment of Purchase Orders CC6991931-J by Dr. E. B. Henson and CC6991932-J by Dr. Gerhard K. Gruendling under the sponsorship of the U. S. Environmental Protection Agency.

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SECTION 1

INTRODUCTION

As the Champlain basin became more populated, the phosphorus input of Lake Champlain increased excessively. Phosphorus has a demonstrated effect on the deterioration of a lake but it can be controlled significantly. In reviewing the history of eutrophication of the Great Lakes, it is well documented that even very large, clear, and clean lakes can become seriously deteriorated in a relatively short time due to cultural influences; and these Great Lakes give warning that other large, deep, oligotrophic lakes are vulnerable to the same influences.

Lake Champlain is the largest of the deep cold-water and near-oligotrophic lakes in the United States other than the Great Lakes. Though the main deeper part of Lake Champlain is considered to be somewhere in the oligotrophic-mesotrophic range; the lake does exhibit a number of warning symptoms such as Cladophora growths along portions of the shoreline, oxygen deficits in some of the bays, heavy plankton blooms, and abundant bottom weed beds. In the main lake, warnings are shown by the trend toward reduced oxygen concentration in sub-surface waters and very high oxygen values in the upper waters in the springtime. The evidence leads to the conclusion that the lake is undergoing rapidly deteriorating changes in our own time, and some expedient remedial action must be taken.

It has been demonstrated that the lake is in fact a phosphorus limited lake (EPA, 1974; Gruendling, 1976a) and therefore policy development, legislation, and proper management are vital in reducing and controlling the quantity of phosphorus entering the lake. However, any information about the phosphorus loadings, the fate of phosphorus in the lake, and the phosphorus budgets in general, if available, is scattered, fragmentary, and insufficiently coherent for the Agencies to develop an appropriate strategy for the control of phosphorus in the basin.

The two authors have been asked to examine the status of the nutrients in the lake, with special emphasis on phosphorus. Dr. Henson has taken the responsibility of examining the matter of phosphorus loadings, and transport within the lake, while Dr. Gruendling has examined the trophic conditions within the lake considering a vast array of indicators of trophic status. The section on "Interaction" was written jointly.

The authors endorse the decision to initiate protective management of the lake. Both authors have had scientific experience on the lake and are abundantly aware of impending changes that are taking place. For readers of this document who are unfamiliar with the geography of the Champlain Valley, we wish to point out in Figure 1 that Lake Champlain is the recreational hub for

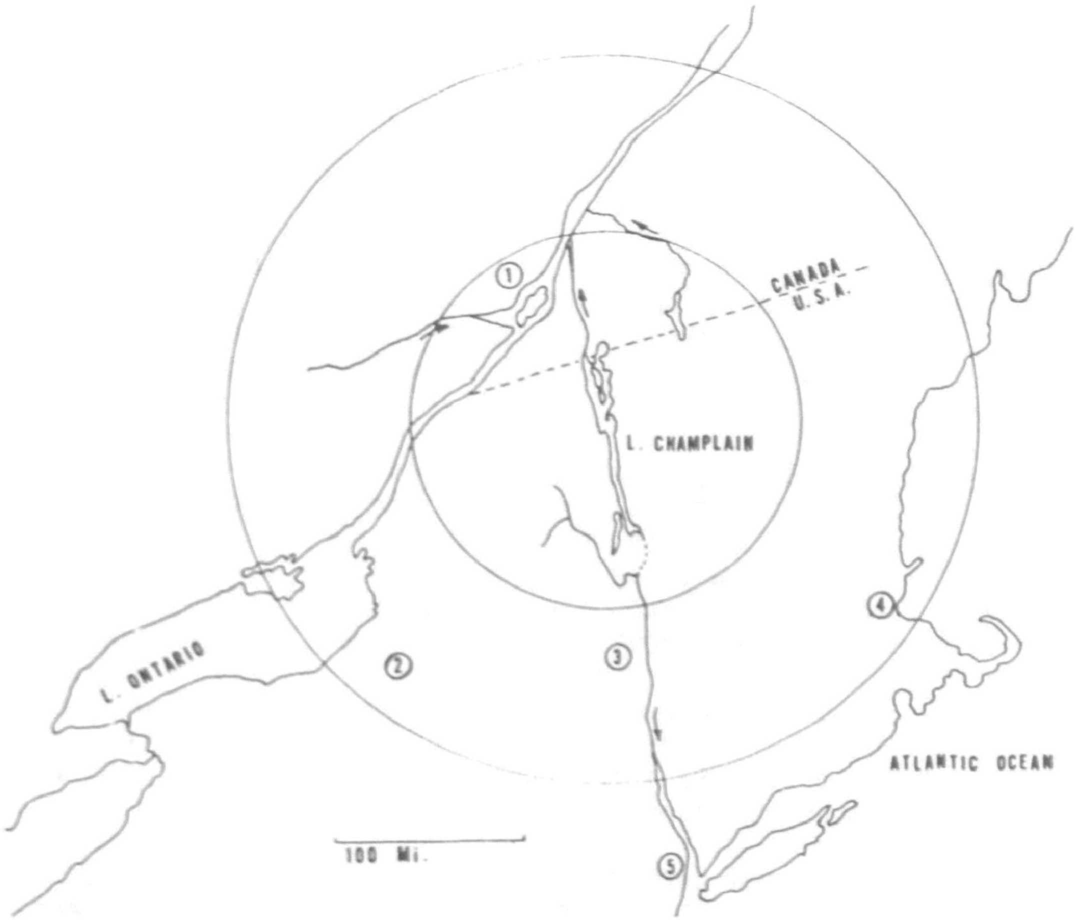


Figure 1. Orientation map of the Lake Champlain basin showing the proximity to large urbanized areas: (1) Montreal, Canada; (2) Syracuse, N.Y.; (3) Albany, N.Y.; (4) Boston, Mass.; (5) New York City. The concentric circles represent distances of 100 and 200 miles from Burlington, Vt., located on the middle of the eastern shore of Lake Champlain.

a number of large metropolitan areas. The pressure from expanding populations from these not-so-remote urban areas are being felt in the Champlain Valley in terms of influx of tourists, boaters, skiers, and escapees. This also has an impact on the increasing amounts of phosphorus imported into the basin.

PHOSPHORUS IN THE CHAMPLAIN BASIN

The Ecological Need For Phosphorus

Since phosphorus is the primary topic of this document, a few words are in order to explain why this element assumes such an important position. Phosphorus is an essential component for all living things; however, excessive amounts are disruptive. The chemical bondage of phosphorus provides the necessary energy for biological processes, and it can be looked on as the battery for all biological activities. A plant or animal body needs a large supply of this element in order to function, and this amounts to approximately 0.2 mg for every 100 mg of tissue. When one multiplies this by the total weight of algae, zooplankton, and fish in a lake, the total amount of phosphorus in the biosphere can become relatively large.

In contrast, the amount of phosphorus available to the algae (the primary producers) in the lake, is relatively small, on the order of 0.01 mg/1000 grams compared to the 2 mg/1000 grams in the plant or animal. The demand is great, the supply is small for phosphorus. For the other essential elements, there is a greater supply. Therefore, phosphorus becomes the critical element. Under normal conditions the utilization is in balance with the input of phosphorus. Excessive amounts of phosphorus added to the system become disruptive.

Phosphorus Loading Models

Because of the growing awareness of the role of phosphorus in the eutrophication of lakes, there has been in the last decade a considerable amount of research into the practical applications of lake response to various doses of phosphorus. This has culminated in certain mathematical models that are intended to provide guidelines for possible control. The conclusion of this work is that the mean depth of a lake, the rate at which the water and phosphorus are carried through the lake, and the amount of nutrient added to the lake per unit time, are the essential parameters that control the trophic state of the lake. From these studies, Vollenweider (1976) has derived an equation where one can predict with fairly good probability, the trophic status of a lake having measures of the essential parameters. These concepts are here applied to data from Lake Champlain. In the Vollenweider model, there is a formula that intends to state whether the loading into a lake is "dangerous" or not. It also can be used to determine whether the loading places the lake in a eutrophic, oligotrophic, or mesotrophic condition. The authors are of the opinion that it is premature at this time to take the numeric values from the model as absolute; but the model, after empirical testing with a fairly large number of world wide lakes, certainly demonstrates the relative influence of estimated phosphorus loading on a lake. In this respect, the value of this model should not be underestimated.

Background And Historical Phosphorus Loadings

There are no data available on the historical phosphorus loadings of Lake Champlain; but it would be desirable, in terms of contemporary perspective, to have evaluations showing how much phosphorus had been entering the lake before the basin was heavily populated and how it then changed in the past 150 years.

To have some speculative evaluations of this information, we have made some approximations of these matters. In Section 6 we have made an estimate of what the natural "background" loading would have been were there no human inhabitants in the basin. This estimate was not corrected for phosphorus input from the contemporary atmosphere, but it does provide an order of magnitude when phosphate loading control is discussed. It has been estimated that the "natural" background loading amounts to 128,763 kg/yr.

In Section 6 the phosphorus loading is also estimated on the basis of population in each subdrainage basin and a loading estimate was derived that was on the same order of magnitude as several other estimates. Using the same technique, we have estimated the phosphorus loading for the period between 1810 and 1970.

The literature (Vollenweider, 1968; Patalas, 1972) suggests that the average person contributed between 1.5 and 1.7 kg of phosphorus annually to the environment, and this includes the normal use of fertilizer and other demophoric additives (Wetzel, 1975). Patalas used the higher value because of the higher P utilization in modern society. For the purpose here, we will use the more conservative value of 1.5 kg/C/yr. The question of how much of this phosphorus enters the lake cannot be answered at present. Some of it obviously becomes intrapped in the terrestrial biosphere; but our contemporary loading data matches very closely with present population estimates. A refined model might use a sliding scale of capita loading, but for the present we will simply estimate that all of the culturally derived phosphorus eventually reaches the lake.

Estimates, accordingly, have been made of the total population in the Champlain basin for each year, from 1810 through 1970 (Appendix B). These population values were then multiplied by 1.5 to derive the estimated phosphorus loading into the lake in kg/yr, and these data are presented graphically in Figure 2.

From Figure 2 it can be observed that there has been a general increase in the phosphorus loading from the beginning, with decreasing and increasing rates reflecting the general economic conditions of the area at the time. The rate of loading increase was about the same in the periods 1820-1850, 1900-1920, and 1940-1970. The dashed horizontal line at 128,763 kg/yr marks the estimated background loading to the lake. It is interesting to note that the cultural curve intersects the edaphic plot at the beginning, in the

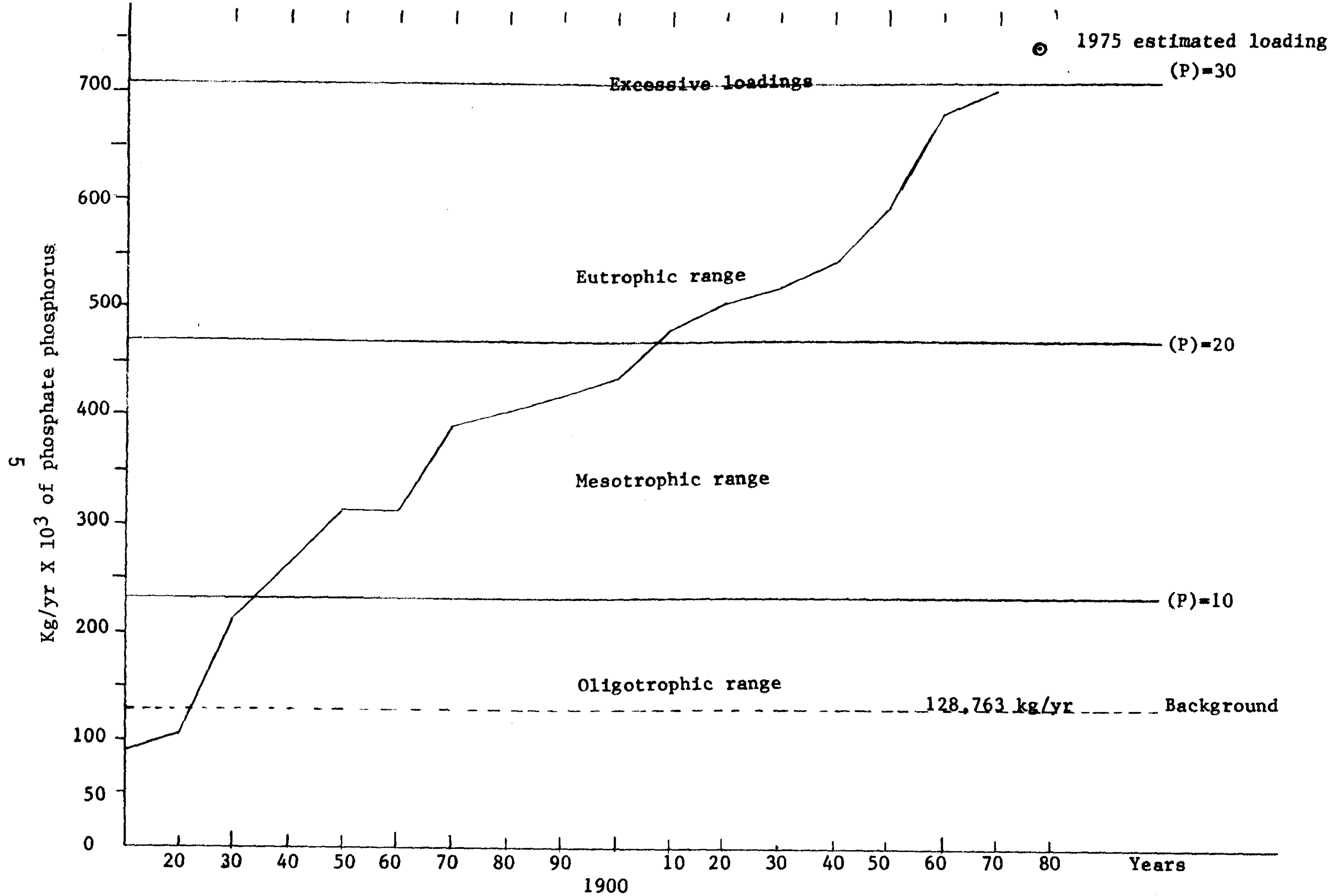


Figure 2. Historical estimates of loadings of phosphorus into Lake Champlain, 1810-1975.

year 1810* which would presumably be the time that the cultural influence began to dominate over the natural edaphic loading balance.

Figure 2 also shows three horizontal guidelines labeled $(P)_c$ = 10, 20, and 30. As developed fully in Section 5 of this report these are three levels of loading derived from the 1976 Vollenweider model; where the $(P)_{10}$ level separates oligotrophy from mesotrophy, $(P)_{20}$ can be considered the upper level of the mesotrophic-eutrophic boundary, and $(P)_{30}$ represents a severe and unacceptable eutrophic level. Our calculated loading of 747×10^3 kg/yr is above the $(P)_{30}$ level. Considering that shallow peripheral embayments theoretically express the signs of eutrophication earlier than the main deeper lake, and they are in fact presently expressing this state, the prognosis is clear; Efforts must be made as soon as possible to reduce the phosphorus loading into the lake. It is the intent of this document to assist in this endeavor.

* It is assumed that since the population diverts natural waters that already contain edaphic P for utilization; edaphic P is then incorporated under the heading of cultural dishcarge.

SECTION 2

RECOMMENDATIONS FOR ADDITIONAL STUDY AND RESEARCH

1. Since the State of Vermont will be instituting point-source phosphorus control at the major discharge facilities into St. Albans Bay, Shelburne Bay, and Burlington Bay, a study should be implemented to determine the response of these areas and their tributaries to this management practice. The study should be designed to determine the water quality conditions in the tributaries and the receiving waters before and after the implementation of the nutrient control. The sampling program must be comprehensive and frequent enough to provide meaningful data. The water quality parameters that should be measured in the receiving waters are dissolved oxygen, total and dissolved phosphorus, biological oxygen demand, and plankton biomass and productivity estimates. Nutrient content of the tributaries should also be measured.

2. It is anticipated that in the near future the State of Vermont will institute a ban on phosphate detergents. A study should be developed to examine the success of this management program. Changes in phosphorus levels before and after the detergent ban should be monitored at point sources, in point source and non-point source segments of a tributary, and in the receiving body. Results from these test areas could then be applied to other tributaries in the basin.

3. Cumberland Bay, Northwest Bay and the region near Port Henry are areas of water quality impairment and significant nutrient loading in New York State. Since these areas have significant point-source loadings, it is concluded that the existing controls are possibly ineffective. A review should be made of the effectiveness of present nutrient controls in New York portion of Lake Champlain and a determination of the cost and net benefit of upgrading these point source controls.

4. The amount of phosphorus loading to the lake has been estimated using limited nutrient data and based on the normalized flow of the tributaries. Additional studies are needed to develop and refine a model for estimating phosphorus from selected streams utilizing a minimum of sampling. With good gaging and monitoring, using U.S.G.S. procedures for collecting water quality samples, and a communication system for announcing significant flow data, loading estimates could be developed on an event basis and adequately measured by taking as few as 20-25 water samples/year. This refined model could then be used as a basis for future point and non-point loading and response studies that will be needed in order to evaluate various management practices.

5. Utilizing the present phosphorus loading estimates or the future refined estimates, it is presently not possible to accurately predict the impact of

specific phosphorus loading on the lake or determine the possible effects of reducing phosphorus loadings. In order to predict these effects, it is necessary to understand the fate of phosphorus once it enters the lake. A study should be initiated to investigate the amount of phosphorus being incorporated into productivity, the amount being lost to the sediments, and the rate of phosphorus recycling in the lake.

6. It is important to understand the potential impact of the heavy phosphorus loading from the south lake upon the main lake north of Crown Point, New York. The hypothesis that phosphorus is being lost to the sediments by absorption to clay particles in the main lake should be tested. It should also be determined if there is any accumulation of phosphorus in the sediments of the region. Such a study would help in determining whether phosphorus control in the south lake is a necessary management practice.

7. In order to determine how far up the drainage basin to apply nutrient controls, it is necessary to determine the phosphorus transport loss downstream from point and non-point sources in the tributaries. Such a study should be initiated for a few sample areas in the Lake Champlain Drainage.

8. The in-lake monitoring program should be extended to gather data from each of the 13 drainage regions in order to improve the phosphorus transport model for the lake. The minimal data needed are total phosphorus, dissolved phosphorus, nitrogen, and chlorophyll A values collected during the spring turnover period. It is recommended that this monitoring program be expanded to a year-round basis.

9. The problem of the severe oxygen depletion in the hypolimnion of Mallets Bay should be studied further. There is a need to define the actual cause(s) of the depletion condition. Possible sources of BOD entering via the Lamoille River and the in-lake contribution of organic matter should be investigated. Once the cause of the problem has been determined, a management strategy should be developed to help alleviate the source of the problem.

SECTION 3

GEOGRAPHY AND HYDROGRAPHY OF THE BASIN

DESCRIPTION OF LAKE CHAMPLAIN

Lake Champlain (Figure 3) occupies a large north-south valley that extends from the St. Lawrence River, near Montreal, Quebec, to New York City. The elevation of the lake is ± 29 meters (95 feet) A.T.; it has a maximum depth of 122 meters (400 ft.), and therefore occupies a cryptodepression of some 91 meters. The lake drains to the north through the Richelieu River into the St. Lawrence River at Sorel, Quebec. The total lake area is 1,269.1 Km^2 (490 sq. mi.), including a number of large and small islands. The water surface is 1,130.2 Km^2 (436.4 Mi^2). The land drainage is 19,881.08 Km^2 (7,676.1 Mi^2) so that the ratio of drainage area to lake area is 17.8 : 1. The Adirondack Mountains rise precipitously close to the western side of the lake, and the lake itself is in the rain shadow influence of the mountains. The eastern basin is a broad plain with the Green Mountains of Vermont located about 32 km to the east of the lake. The southern portion of the lake is narrow and shallow, and water connection is made at the southern end to the Hudson River through the Hudson-Champlain Canal. The volume of the lake is estimated to be 25,802.074 X 10^6 m^3 (912 X 10^9 Ft^3) (Hunt et al., 1972).

HYDROGRAPHY

Precipitation

Precipitation is the source of the waters of Lake Champlain, and there is a relationship between the amount of precipitation and the loading of the nutrients. About 9% of the water enters the lake directly, but the remaining 91% enters the lake after moving through and over the approximately 8000 square miles of drainage basin (Henson and Potash, 1969; Henson and Vibber, 1969). On its way to the lake the water picks up much dissolved and particulate material.

The Champlain Valley has the lowest amount of precipitation of anywhere in all of New England or New York State. The lowest mean annual precipitation in this sector of the United States is near the mouth of the Bouquet River. This is attributed to the fact that the lake is in the rain shadow of the Adirondack Mountain range to the west.

Precipitation generally increases with altitude in the Champlain Valley, and generally more on the eastern side of the lake than on the west (Ingram and Wiggins, 1968). At Burlington, at an elevation of approximately 800 feet, the mean annual precipitation is between 30-35 inches annually. On the top of Mt. Mansfield it is approximately 45 inches. Fillin (1970) estimated

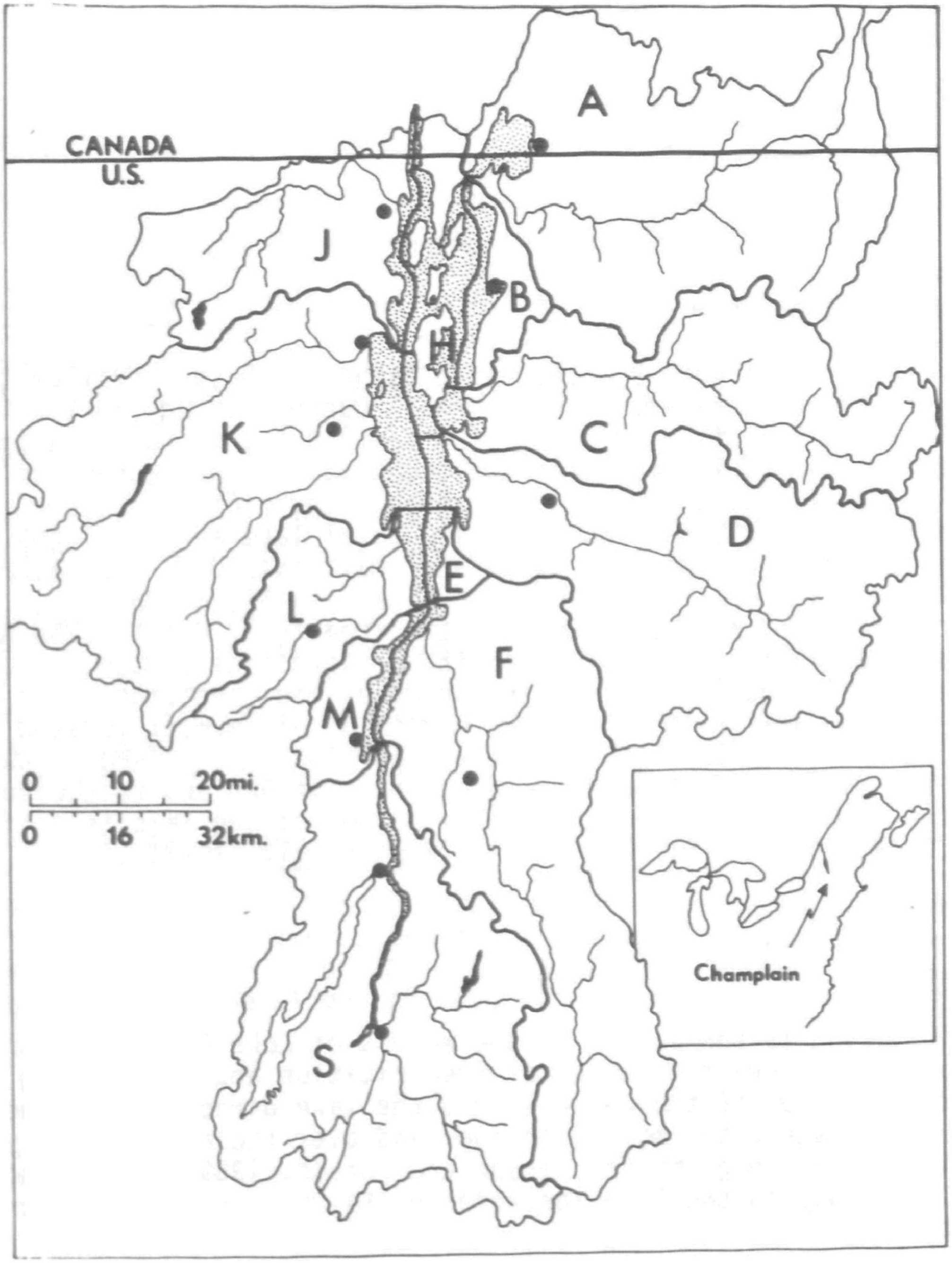


Figure 3. Map of Lake Champlain and its drainage basin illustrating the subdivisions into the major watershed Districts and lake Regions. Morphometric values for these subdivisions are to be found in Table 1 and more detailed presentation is found in Figures 7 - 18. Subdivisions are: (S) Missiquoi, (B) St. Albans, (C) Lamoille-Malletts Bay, (D) Winooski-Burlington, (D) Charlotte, (F) Otter Creek-Vergennes, (S) South End Lake, including Poultney, Matawee, and Lake George Subdistricts, (M) Port Henry, (L) Bouquet, (K) Ausable-Saranac, and (J) Chazy.

that 24% of the precipitation fell below 1000 ft; 55% between the 1000 ft and 2000 ft contours, and 21% above the 2000 ft level in the Missisquoi River basin.

Stream Discharge

Most of the larger tributaries of the lake have been gaged (U.S.G.S. - 1973, 1974). In 1968 a number of the critical stations in New York were discontinued after many years of valuable service. The location of many of these gaging stations are not located near the mouths of the streams. Only two of the small valley streams (Stone Bridge Brook and Salmon Creek) have been gaged, and both have recently been discontinued. There is a sound need for augmenting the stream discharge monitoring in the Champlain basin to eventually obtain a better estimate of the nutrient loading to the lake.

Lake Levels

After a period of extreme low lake levels in the 1963-1968 period, there followed a very wet period in the 1970's when the lake attained all time highs for several years. A report on the statistics of lake levels has been offered by Downer (1971) and Gillespie (1976). The International Joint Commission is presently investigating the problems concommitant with the high lake levels, and the possibility of lake level regulation. Such regulation could exert some influence on the nutrient status of parts of the lake.

The Lake Outlet

The outlet for the lake is the Richelieu River that drains north from Rouses Point, N. Y., to Sorel, Quebec (Fig. 1), and it there empties into the St. Lawrence River. The water depth is approximately 20 feet at Rouses Point, but the sill depth is a ledge at an elevation of 92 feet at Chambly, Quebec.

The maximum mean daily discharges of the Richelieu since 1938 have ranged from 13,300 (1965) to 43,700 cfs (1947) whereas the minimum range extends from 1,410 (1941) to 5,410 cfs (1945). The mean discharge (at 96 ft. lake level at Rouses Point) is about 10,500 cfs (Fischer, 1976).

Good discharge data are not available for Lake Champlain. Though the level is monitored at Rouses Point, this is not reportably converted to flow units. Most of the flow data are derived from Chambly, Quebec, many miles downstream. There may be 1000 cfs separating these two localities.

PARTITIONING OF THE BASIN INTO HYDROGRAPHIC UNITS

Inventory of the Tributary Streams

An inventory was made of all of the tributaries that drain directly into Lake Champlain. Utilizing copies of the contourless drainage maps used by the EPA for the STORET facilities, topographic maps of the U.S.A. and Canada, the lake charts, information from the New York State Conservation report of 1928, and actual field visits, we have listed each stream entrance to the lake.

The arrangement of this list follows the procedures for identifying streams in the STORET MANUAL. Beginning on the east side of the Richelieu portion of the lake at the Canadian border across from Rouses Point, the shoreline is followed proceeding down Alburg Tongue, around the islands, up into and around Missisquoi Bay, and on down the east side of the lake to the Hudson-Champlain Canal. These streams are coded with odd numbers in agreement with the STORET numbers. A total of 156 outlets were listed from the eastern side. On the western side, beginning at the Canadian border above Rouses Point, N. Y., the shoreline was followed in a similar manner, and each outlet was given an even code number.

A total of 292 streams and subwatersheds were thus inventoried. South Bay was counted as a single point source, and counting the 23 brooks that drain into this bay, the total number of tributaries draining into the lake is 315. Those 34 streams with drainage areas exceeding 10 sq. miles (Appendix C) drain 97% of the entire watershed. The remaining 158 tributaries are small but could be of local significance. The four largest rivers are in Vermont, and together they drain about half of the total Champlain basin.

Partitioning the Lake Basin into Hydrographic Units

Lake Champlain is geologically divisible into a number of distinct basins that contain waters of individual character (Potash et al., 1969). The narrow southern part of the lake, Missisquoi, and Malletts Bay, and the body of water to the east of the islands are physiographically distinct. The main lake forms a large unit, and this also could be subdivided. We have divided the lake into a number of physiographic Regions adjacent to, and influenced by, the discharges being received from the associated Districts of the watershed (Figure 3).

The areas of the District watersheds were calculated as a working base. Some minor (up to 3%) discrepancies occured when our figures were compared with calculations made by others. These inconsistencies are generated by problems in locating the divide on the maps, especially in the flat lands.

Table 1 summarizes the information about these areas. Two-thirds of the Champlain watershed lies east of the lake, and one-third is to the west. The ratio of the areas of drainage basin to lake area is about 18:1 for the entire Lake Champlain, but within District and Region boundaries the ratio varies between 0.3:1 (H) to 54:1 for the south end.

Most Districts are drained either by a single major tributary, or two somewhat equally sized basins. The Islands District (H) is poorly represented by stream discharges, and District M is drained predominantly by consequential streams. Though about 80% of District S is drained by three streams (Poultney, Ticonderoga, and Metawee), we have considered the South End Lake as a tributary. Drainage from the small District E (9 sq. mi.) is dominated by Holmes Creek which was frequently dry, yielding little data. The drainage from the other districts can be monitored for 60-96% of its area by sampling no more than two streams per District.

Table 1. VALUES FOR AREAS, VOLUMES, AND OTHER STATISTICAL INFORMATION FOR THE REGIONS AND DISTRICTS OF THE CHAMPLAIN DRAINAGE BASIN.

Region, District	a Region Area (km^2)	A District Area (km^2)	V_r Water Volume ($m^3 \times 10^6$)	$\bar{Z}$ Mean Depth (m)	Ratio of areas Distr/region	No. of tributaries	% of drainage basin	K (cfs/sq. mi.)
A	77.50	2,963.96	220.444	2.8	38.2	9	14.8	1.3
B	134.23	191.17	1,730.930	12.9	1.4	16	1.0	1.1
C	54.20	2,032.29	699.319	12.9	37.5	15	10.1	1.4
D	117.22	3,009.08	3,019.146	25.8	25.7	13	15.0	1.4
E	63.77	23.99	3,545.902	55.6	0.4	6	0.1	1.1
F	48.69	2,934.87	1,193.963	24.5	60.3	26	14.6	1.3
H	271.92	87.85	4,502.458	16.6	0.3	24	0.4	1.1
J	114.92	1,029.50	939.019	8.2	9.0	13	5.1	1.15
K	78.39	3,548.42	5,055.552	64.5	45.3	32	17.7	1.1
L	63.77	744.57	3,545.902	55.6	11.7	9	3.7	1.15
M	48.69	242.09	1,193.963	24.5	5.0	40	1.2	1.2
S	56.90	3,073.25	155.575	2.7	54.0	89	15.3	1.2
TOTAL	1,130.20	19,881.08	25,802.074	22.8	17.6	292	99.0	

MASS TRANSPORT OF WATER THROUGH LAKE CHAMPLAIN

Some knowledge of the basic movements of the waters of Lake Champlain is essential for evaluating the effects of nutrient loadings and dispersal. We speak here of long-term transport rather than short-term displacements caused by winds or seiche activity, or local current patterns. Over the past decade we have made observations of water movements of the lake, allowing us to derive a general description of these transports; and from this, a mathematical model can be constructed so that variables can be treated in future studies.

This circulation pattern is shown in Figure 4. Three tributaries can be considered as headwaters. The South end lake contributes about 41 m^3/sec. into the southern part of the lake, and the lake then receives drainage from the adjacent Districts as it moves northerly down the lake. Regions A and C are also terminal in that water received is in excess to the receiving basin volume resulting in a net outflow to other parts of the lake. The flow from Missisquoi flows south and then splits, some of the water flows directly south through the Alburg Passage between Alburg Tongue and North Hero Island, while the remainder moves into the northern part of the northeast arm of the lake. The prevailing southerly winds carry some of this water into Maquam Bay. Discharge into Malletts Bay (31 m^3/sec.) can escape by a small portal under the Sandbar Bridge into the northeast arm, or by two portals in the railroad embankment to the main lake. Sundberg (1972) found that most of the water left the bay through the two portals to the west, and the study of Myer et al. (1976) makes some interesting observations regarding this. Our observations have indicated that most of the time the water in the northeast arm flows westwardly through the Gut into the main lake, and these have been confirmed in winter by LANDSAT imagery and field observations. The only evidence of general flow eastwardly from the main lake into the northeast arm is when the lake level is well below normal, causing main lake water to flow to the lower level. Myer et al. (1976) has reported that seiche activity can induce temporary reverse flows through to the northeast arm.

As the water flows from these three origins, the water will flow from Region to Region and be augmented by discharge from the adjacent Districts, and finally be discharged through the Richelieu River in Region J. The lake also gains water by precipitation directly onto the lake, and water is lost by evaporation. Precipitation onto the lake for each region was determined by drawing isohyets through the mean annual precipitation for eleven stations (1971 data), and examining the patterns existing over the lake regions (Henson and Vibber, 1969; Henson and Potash, 1969; 1973; Potash and Henson, 1974). These precipitation values should be updated.

The schematic diagram in Figure 5 is a representation of the water transport pattern in Lake Champlain and will serve as a basis for developing a mathematical model. We assume that the water delivered to a Region from several sources is mixed before proceeding to the next Region. For the model we have assumed that half of the water from Region A goes to each of Regions H and B; and that 75% of the water from Region C moves to H and 25% to Region B. The configuration of the Regions in the broad lake is complex, but by extending Region H south of the islands to Colchester Point, half of D flows

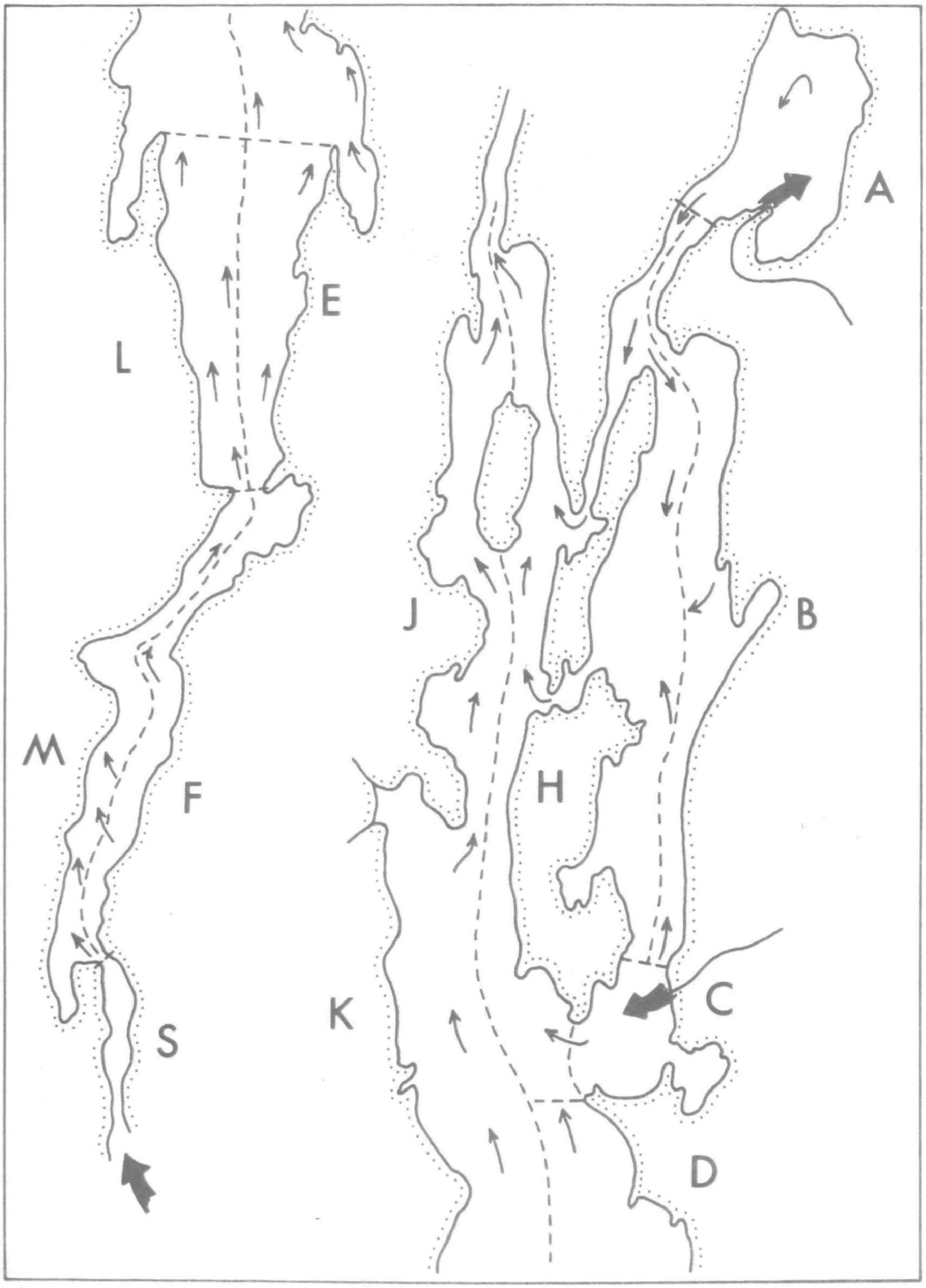


Figure 4. Net annual water transport patterns in Lake Champlain. Headwater influents are Missisquoi River (A), Lamoille River (C), and the South End Lake (S). Arrows indicate net movement.

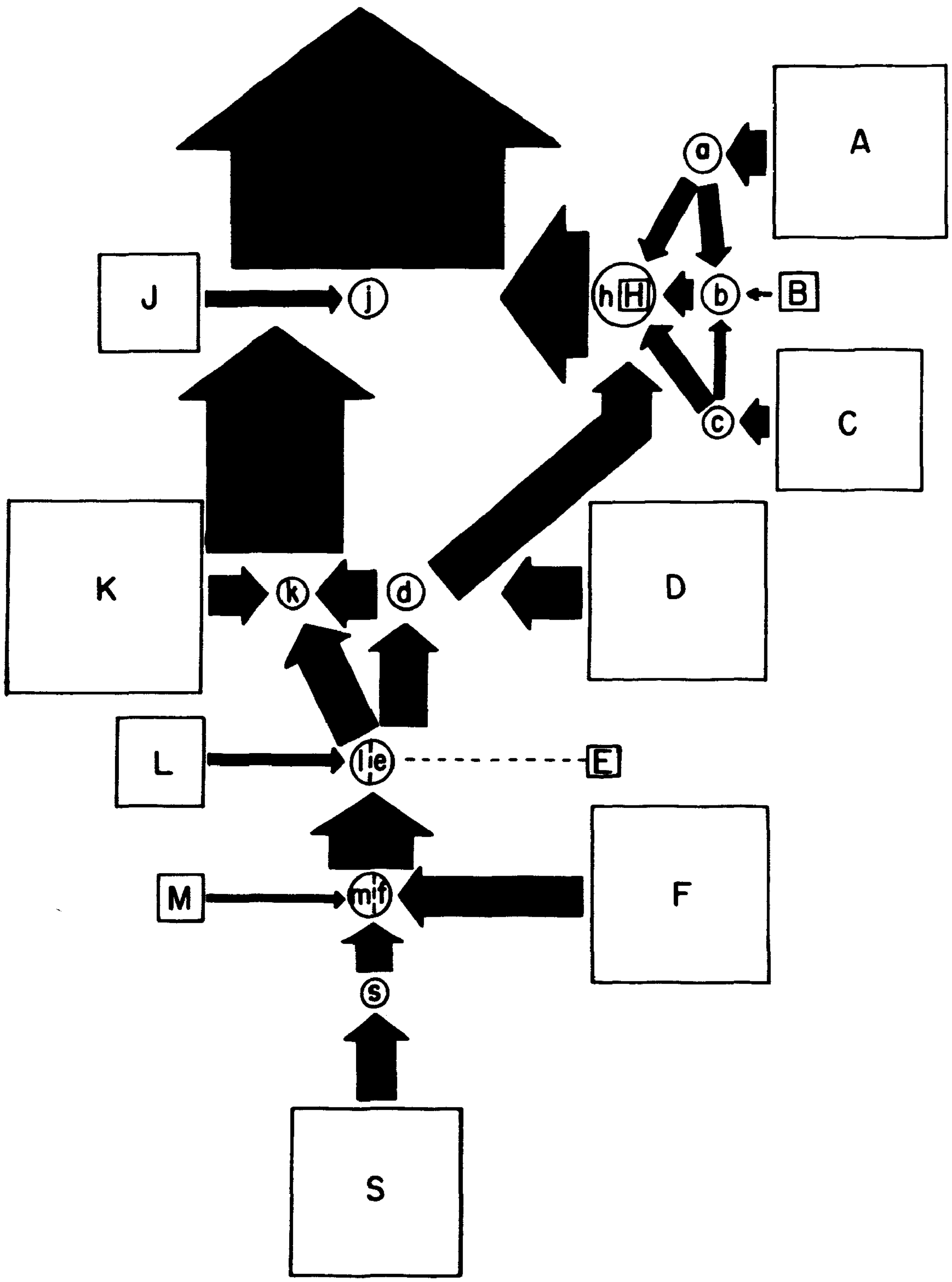


Figure 5. Schematic model of net annual mass water transport in Lake Champlain. Square figures depict the relative areas of the several Districts, or drainage basins. The circles depict the relative areas of the lake Regions, and the arrow widths depict the relative amounts of mean annual net water transport.

to H, and half to K. Regions K and D each receive half of the discharge from EL.

The basic format for this model is given below and displayed for each District in Table 2.

$$\Sigma I_r + A_{i\delta i} \times 10^6 + P_{ri} - E_{ri} + \Sigma_{ri}$$

where i = a designated District (D) or Region (r)

A_i = Area of District i in km^2

Σ_i = Constant of 31.5569 X District discharge as m^3/m^2 of land area.

P_{ri} = Precipitation directly onto a Region as $m^3/Km^2 \times 10^6$

E_{ri} = Evaporation from a Region as $m^3/Km^2 \times 10^6$

I_{ri} = Water input to a Region from an adjacent Region

The solution for this water transport model is set out in Table 3. According to this run, the net water balance for Lake Champlain is 8,712.5 X 10^6 m^3/year. This is equal to 9,750 cfs, about 7% below the normal discharge figures. The model does include significant variables (District discharges, regional precipitation, and evaporation) that could be handled easily with computer manipulation as better data become available. It should be noted that the water balance within each Region can be modeled as subroutines.

The last two columns in Table 3 are of special interest as they relate to the transport of nutrients in the lake. The residence time (Tw) is the time (years) the water theoretically remains in the basin before being removed. The longer the residence time, the longer the nutrients have the opportunity to become a part of the ecosystem of the Region. These values are annual means, and during Spring melt-off, the value has less meaning. The last column, ρw (flushing rate) is an index of the rate at which water is being replaced in the Region basin, the inverse of residence time. In effect, the flow-through rate tells us, using Region A as an example, that the water coming into Region A per year would fill the basin more than six times.

Those Regions with high flushing rates (Regions J, S, A) would serve mainly to transport the nutrients elsewhere and full expression of eutrophication would be translocated and delayed. Those Regions with high residence times (Regions EL, B, H) are areas where the water input is relatively low compared with the water volume of the Region, and where a build-up of nutrients might be expected.

HUMAN RESOURCES IN THE BASIN

The number of people living in the basin, how they live and how they are distributed in the basin, will have a distinct impact on the condition of the lake. The population is not static and mention will be made of long- and short-term changes.

TABLE 2. MATHEMATICAL FORMULATION OF THE MASS TRANSPORT WATER BUDGET MODEL

District	Equation
A	$A_A\delta_A \times 10^6 + P_a - E_a = D_a$
C	$A_C\delta_C \times 10^6 + P_c - E_c = D_c$
B	$(A_B\delta_B \times 10^6 + P_b - E_b) + pD_a + pD_c = D_b$
S	$A_S\delta_S \times 10^6 + P_s - E_s = D_s$
FM	$(A_F\delta_F \times 10^6 + P_f - E_f) + (A_M d_M \times 10^6 + P_m - E_m) + D_s = D_{fm}$
EL	$(A_E\delta_E \times 10^6 + P_e - E_e) + (A_L d_L \times 10^6 + P_l - E_l + D_{fm} = D_{el}$
D	$(A_D\delta_D \times 10^6 + P_d - E_d) + pD_{el} + D_d$
K	$(A_K\delta_K \times 10^6 + P_k - E_k) + pD_{el} + pD_d + D_k$
H	$(A_H\delta_H \times 10^6 + P_h - E_h) + pD_a + D_b + pD_c + pD_d = D_h$
J	$(A_J\delta_J \times 10^6 + P_j - E_j) + D_k + D_k = D_j$ (outlet)

Where:

A is District area (km^2)

δ is discharge coefficient (m^3/sec. X 31.5569)*

P_r is precipitation onto a Region

E_r is evaporation from a Region

D_r is excess water, or outflow from a Region

$A_D\delta_D$ is water input from land drainage (District)

* δ_i = K from Table 1 X 0.0109332, the conversion from cfs/sq. mi. to (Appendix A) $m^3/sec/km^2$ X 31.5569, the integer of the number of seconds/year.

TABLE 3. WATER MASS TRANSPORT CALCULATIONS FOR THE SUBDIVISIONS OF THE LAKE CHAMPLAIN DRAINAGE. VALUES IN CUBIC METERS X 10^6/YR UNLESS OTHERWISE INDICATED.

District/Location	Values X 10^6 = m^3/year					Qy (as m^3/sec)	tw (years)	ρw Exchanges/ year
	δ_i	P_r	E_r	I_r	Qy			
A (Missisquoi)	0.44852	71.8	58.1	1343.10	1343.10	42.56	0.164	6.098
C (Malletts - Lamoille)	0.48303	44.8	40.6	985.86	985.86	31.24	0.709	1.410
B (St. Albans)	0.37952	110.9	100.7	82.75	1000.77	31.71	1.730	0.578
S (South End)	0.41402	54.9	43.2	1284.09	1284.09	40.69	0.121	8.254
F (Otter Creek)	0.44852	45.8	36.7	1325.45	1967.50	62.35	0.607	1.647
M (Port Henry)	0.41402	45.8	36.5	109.53	751.575	23.82	1.589	0.629
FM	-	-	-	1434.98	2719.08	86.16	0.878	1.140
E (Charlotte, Vt.)	0.37952	56.7	53.6	12.20	1371.74	43.47	2.585	0.387
L (Bouquet R.)	0.39677	55.9	53.6	297.72	1657.26	52.52	2.140	0.467
EL	-	-	-	309.92	3028.99	95.99	2.341	0.427
D (Burlington - Winooski)	0.48303	99.7	105.7	1477.48	2991.98	93.86	1.003	0.991
K (Ausable - Plattsburgh)	0.37952	64.8	63.0	1348.50	4358.98	137.66	1.160	0.862
H (Grand Isle)	0.37952	217.5	204.1	46.74	3954.45	124.84	1.139	0.878
J (Chazy - Rouses pt.)	0.39677	91.9	86.3	414.07	8727.50	276.09	0.108	9.278

* The mean outflow of the lake according to this model is 9,767 cfs, about 7.0% less than a mean of 10,500 cfs given for the outlet discharge.

The historical record of human habitation in the Champlain basin shows trends that indicate that outside forces are very influential; the basin cannot remain provincial. The transition patterns of transportation from railroad and steamboat to interstate highways and aircraft; the dynamics of metropolitan growth in the urban perimeters of Montreal, Boston, New York City, and Albany; and the changing economic and employment patterns; all contribute to changes in basin population. Some towns in the basin have lost population, and others have gained (Fischer, 1976). Some short-term population changes that can become traumatic are related to recreation. During the summers there is a general increase in the population in the basin for water-related endeavors, with increased boating and occupation of summer dwellings along the lake shores. There is also the increased use of water during the summer months for watering lawns and gardens and swimming pools, and this modifies the waters flowing into the lake. During the winter months, following the introduction of snow, the mountain areas receive an influx of skiers and their followers. Some ski resorts may entertain more people in one day than residents in the entire town. The Winter Olympics in Lake Placid in 1980 is expected to draw 35,000 to 60,000 persons per day.

The total population in the basin has been increasing on an average of 1.3% per year during the past 10 years. The populations for the individual districts of the basin were estimated by adding the populations in all towns wholly within a District and then estimating the percentage of those towns along the outer margins (Table 4). The total basin population of 438,255 is within 2% of that given by Fischer (1976) in the Champlain Planning Guide (This estimate was computed independently [Appendix B] before the Planning Guide was released).

Three hydrographic Districts have population densities of more than 100/square mile. About a fourth of the population lives in cities with populations of 10,000 or more (three of these cities are in District D). Cowansville, Quebec is the only Canadian City represented in this category. An additional 40,000 inhabit villages of from 3,000 to 10,000 in population. These figures indicate that about a third of the basin population lives in developed communities, and about two-thirds live in small rural communities, most situated on water-courses or on farms.

In the Champlain Basin Planning Guide, Fischer (1976) points out that east of the lake there has been a trend in ruralization of the population, that even though the larger communities are also growing in numbers, the percentage of rural inhabitants is increasing at a greater rate (This is in contrast to national trends). Below are tabulated the percentages of the 1970 populations of the Towns bordering the lake as to urban and rural (From Table IV-6 in the Planning Guide):

State	Urban	Rural
Vermont	32.1	67.9
New York	85.6	14.4
Quebec	38.8	61.2

TABLE 4. POPULATION ESTIMATES FOR EACH DISTRICT OF THE LAKE CHAMPLAIN DRAINAGE BASIN, INCLUDING THE PORTION IN CANADA*.

District	Population	Percent		Number/sq. mile
A	56,678	12.99		50.86
B	13,279	3.03		179.91
C	32,853	7.50		41.87
D	131,674	30.05		113.33
E	733	0.17		79.16
F	57,472	13.11		50.72
H	3,574	0.82		105.43
J	19,861	4.53		49.96
K	77,094	17.59		56.27
L	4,155	0.95		14.45
M	6,645	1.52		71.09
S**	34,237	7.81		28.85
Totals	438,255	100.00	Average	57.09

* Data based on the 1970 Census Bureau Reports, and 1971 census data for Canada. Estimates were made by adding the populations of all the Towns completely within a District, and estimating the percentage of the population of border towns.

** Not including the three towns along the north shore of Lake George.

A pertinent comment in the Planning Guide is that, though there is a shift of the population into the rural scene, this move is not all the way to the farm, but the trend is the suburbanization of the small villages in commuting distance to the larger communities. In terms of nutrient loading to the lake, this trend can be read to mean that the point source loading will tend to cluster in denser packets in the future, putting pressure on the assimilative capacity of the waters receiving the wastewater.

We see from the above table that of the population on the western side of the lake, only about 14% of the population is rural. The specific strategy to control nutrients from New York will have to be different from the strategy developed for the eastern side of the lake.

LAND USE

The pattern of generalized land use in the U. S. sector of the Champlain basin is given in Table 5 with the information from Table V-6 of the Planning Guide (Fischer, 1976). About 70% of the land is under shrub and forest, 9% as waters and wetlands, and about 4% covered by urbanization. The percentage of built-up areas is much higher in Vermont than in New York (despite the fact that 86% of New York population is urban). Agriculture, which includes orchards, cropland and pasture (19%) is a far more common use of land in Vermont than in New York. A fourth of the land in Vermont is agricultural, and most of this is cropland. According to another set of statistics (Planning Guide, Table V-7), between the years 1980 and 2020, cropland and pasture in the basin are projected to decrease 11.5% (from 22% to 10.5%), non-farm forest lands to increase 10.2%, and urbanization to increase from 1.9 to 2.6%.

TABLE 5. GENERALIZED USE OF THE LAND OF THE CHAMPLAIN BASIN, 1970 IN NEW YORK AND VERMONT. DATA FROM FISCHER, 1976.

	PERCENT OF TOTAL LAND IN BASIN		
Land use	N. Y.	Vermont	Totals
Forests and shrubs	78.2	60.9	67.7
Water and wetlands	9.3	8.7	8.9
Public and semipublic	1.1	0.9	1.0
Agriculture*	9.8	24.5	18.8
Build-up (urban)	1.6	5.0	3.6
Totals	100.0	100.0	100.0

* Agriculture includes orchards, croplands and pasture.

Agriculture

The role of agriculture in lake eutrophication is a complex one, and will not be examined in any detail here, but because of use the industry makes of phosphorus, some comments are in order. The character of the Vermont population has changed over the years. There once were more cows in Vermont than people. The agricultural trends have been that (1) the population of cows has decreased 27% in the past 20 years with the 1970 population standing at 193,956 bovines; and (2) the number of herds has decreased 60%, though the herd size has increased (Little, 1971). This trend should increase point source loading with increased concentration of cows, and reduce diffuse loading. The Missisquoi District leads the State in cow population, and Addison County (District F) ranks second (Tremblay, 1967). In 1970, the farm animals contributed slightly more than 3-4 million tons of wet manure. Wet manure is about 75-79% water; and a ton of wet manure contains 2-3 lbs. of P_2O_5, or 0.052% phosphorus. Thus, the annual wet manure crop in Vermont amounts to 1,571 tons, or 1.425×10^6 kg phosphorus per year. Although this figure represents the entire State, most of the dairys of the State are found in the Champlain basin. This is almost double the entire Lake Champlain loading. Considering the load emanating from the two dairy Districts (A and F), the phosphorus originating from manure contributes a sizable portion of the total estimated loading (not including cleaning operations). Over the years the dairy industry would tend to increase the phosphorus export from the land as non-point loading because of long-term accumulations. The manure problem could become acute in small watersheds because of the trend of the bovine sources to be concentrated into smaller geographical units.

In addition to the manure, more than 3.0×10^6 kg of fertilizer phosphorus are applied to the croplands in Vermont annually (Little, 1971), more than twice the manure production.

SECTION 4

GENERAL LIMNOLOGICAL OVERVIEW OF LAKE CHAMPLAIN

THE LAKE AS A UNIT

Lake Champlain is one of the largest lakes in the United States (1,130 km^2 surface area). It does not consist of one morphometric basin, but is divided by peninsulas, islands, and railroad and highway causeways into a number of distinct water basins. Physical, chemical, and biological data indicate that the lake can be divided into five general water masses. These areas include: the "south lake" (Whitehall, N.Y. to Crown Point, N.Y.), the "main lake" (Crown Point, N.Y. following the main channel to Rouses Point, N.Y.), Mallets Bay (Vermont), the "northeast arm" (Sandbar Bridge, Milton, Vt. to Alburg, Vt.), and Missisquoi Bay (Vermont and Quebec, Canada).

Because there are a number of distinct water masses in Lake Champlain, it is not possible to discuss any specific characteristics of the whole water body. Therefore, throughout this report, each of these indicated areas will be discussed individually as to their physical, chemical, and biological characteristics. There are, however, a few general comments that are applicable to the majority of Lake Champlain and which set the background for the specific water mass descriptions.

Wind induced wave action and water column turbulence play an important role in determining the limnological conditions of Lake Champlain. The lake basin has a north-south orientation and the prevailing winds are generally strong and from the south.

Thus, large open regions of the main lake and the northeast arm are mixed to considerable depths and exposed embayment areas such as Missisquoi, Cumberland, Monty, King's, and outer St. Albans bay are mixed constantly or only stratify for short periods. Areas of the lake that are protected from the prevailing winds, such as Shelburne, Willsboro, and Malletts bays, tend to thermally stratify for extended periods (Potash & Henson, 1966: Potash, Sundberg & Henson, 1969; and Gruendling, 1976a).

There is evidence that Lake Champlain has strong internal and surface seiche activity and strong surface and subsurface currents. These phenomena play important roles in current generation, vertical mixing, the flushing action (retention time) of basins, and water movement between the various water masses. These in turn influence the distribution and retention times of nutrients throughout the lake (Myer, Larson, Cole and Hulburt, 1976).

The maximum and minimum water temperatures and the vertical temperature regimes in Lake Champlain vary considerable geographically. The main lake from Rouses Point, N.Y. to Port Douglas, N.Y. has colder surface and bottom temperatures than the southern portion of the main lake, Malletts Bay, the northeast arm, Missisquoi Bay and the south lake (Henson & Potash, 1966; Gruendling, 1976a).

Data from numerous sources indicate that there are significantly different chemical characteristics in the various drainage basins and water masses of Lake Champlain. Potash, Henson, & Sundberg (1969) have identified five major water masses according to cation concentrations. Studies on the distribution of major plant nutrients indicate that there are significant geographical differences in concentrations of total, particulate, and dissolved phosphate; total and nitrate nitrogen; and silicate (Gruendling & Malanchuk, 1974; U.S.E.P.A., 1974).

Total cation concentrations decrease from the south lake to the outlet at Rouses Point, N.Y. This gradient is unlike most lakes which pick up cations as the water moves through the basin (Henson & Potash, 1966). Dilution from New York rivers, which contribute water low in cations, and ground water augmentation are two possible explanations for this phenomenon (Henson & Potash, 1976; Hunt, 1971).

The waters in most areas of Lake Champlain are well suppled with dissolved oxygen. The surface waters are generally near saturation and the oxygen saturation levels in the bottom waters rarely fall below 65 per cent. Malletts Bay is the major exception to this pattern. It has severe dissolved oxygen depletion in the hypolimnion during the summer and early fall (Potash & Henson, 1966; Potash, Sundberg, & Henson, 1969).

Studies of phytoplankton populations classify Lake Champlain as a diatom lake with a few species of bluegreen algae becoming dominant in late summer and fall (Muenscher, 1930; Gruendling, 1976a). An evaluation of the seasonal dynamics of phytoplankton in the various water masses indicate basic qualitative, quantitative, and temporal differences between embayments and the deep water stations and differences among the main lake, the northeast arm, Mallets Bay, and the south lake (Gruendling, 1976a). There is also some evidence that there are significant differences in the abundance of the filamentous green alga Cladaphora glomerata growing on the rocky shoreline areas. It appears to be abundant in Shelburne Bay, but with only trace amounts in Malletts Bay and the northeast arm area (Mercer, 1972). The New York shore and the extreme north and south shores of Vermont have not been examined for Cladophora however.

The zooplankton populations in Lake Champlain have not been completely surveyed and analysed, but it appears that the species composition is similar throughout most of the lake, except in the south lake. However, there are temporal and quantitative differences in zooplankton among the various water masses. The total copepod component generally outnumbers the cladoceran component throughout the year in all regions investigated. The cyclopoid copepods comprise the major portions of the copepod community (Legge, 1969; Sage, 1969; Gruendling & Luguri, 1974; Pagel, 1975). A taxonomic discrepancy presently exists for the oligo-eutrophic indicator Eubosmina coregonii and the eutrophic indicator Bosmina longirostris in the lake. Some studies record the presence of only Eubosmina while others only Bosmina. Recent studies by Kantor (per. comm.) seem to indicate the presence of both species.

The benthic invertebrate fauna of Lake Champlain must be scrutinized very carefully, for it may not only reflect differences in trophic conditions of the water masses, but also differences in sediments, water depth, aquatic plant growth, and organic waste materials. The sediment type varies greatly throughout the embayment areas and becomes more uniform in the deep profundal areas of the lake. Each bay region has significantly different benthic populations, which also differ from the deep water areas. They are generally dominated by populations of Chironomidae and Mollusca. In the profundal regions, the Oligochaeta are dominant, comprising from sixty to ninety per cent of the benthic invertebrate community (Pagel, 1969; Pantas, 1966; Wade, 1976). The south lake has been receiving considerable amounts of effluent from pulp and paper manufacturing which has significantly influenced the benthic populations in this region (Pagel, 1975). In general, the benthic fauna of Lake Champlain is unique when compared with the Great Lakes.

CHARACTERISTICS OF REGIONS OF THE LAKE

Missisquoi Bay

Missisquoi Bay, Vermont and Quebec, is located in the extreme northeast portion of Lake Champlain and receives little influence from other water masses in the lake. It is situated within drainage basin (A) of this report and has major inputs from the Missisquoi, Rock, and Pike Rivers (Henson & Potash, 1976). Table 6 summarizes the morphometric features of Missisquoi Bay.

The current patterns of the bay are still under investigation. There is evidence that a significant amount of the water flows south through the Alburg Passage into the main lake; however, some of the water also flows into the northeast arm near Maquam Bay (Myer, Larson, Cole & Hulburt, 1976; Henson & Potash, 1974a).

There is no permanent summer thermal stratification in Missisquoi Bay due to its shallow depth and high wind activity. There are indications that the wind velocities and duration are substantially higher in the region than those measured at Burlington, Vermont. The bay may stratify on a temporary basis during warm, calm periods (Potash, Sundberg & Henson, 1969; Henson & Potash, 1974a; Vermont Water Resources Dept., 1976).

Table 7 summarizes the physical and chemical parameters for Missisquoi Bay. The dissolved oxygen pattern appears to be affected locally by the incoming rivers. There is oxygen deficient water entering from the Pike River (approx. 20% oxygen deficit) and the Missisquoi River (approx. 10% oxygen deficit), while there is oxygen saturated water entering from the Rock River. The general condition in the bay is for some oxygen deficit (approx. 5-20%) throughout the year (Henson & Potash, 1974a; Vermont Water Resources Dept., 1976).

The relative total cation concentrations are some of the lowest values

TABLE 6. BASIC MORPHOMETRIC FEATURES OF THE MAJOR WATER MASSES OF LAKE CHAMPLAIN, VERMONT, NEW YORK, AND QUEBEC.

Water Mass	Surface Area (km^2)	Volume ($X\ 10^6 m^3$)	Maximum Depth (m)	Mean Depth (m)	Approximate Retention Time (years)
Missisquoi Bay	77.5	220.4	4.0	2.8	0.3
Northeast Arm	268.5	3,450.0	49.0	12.8	0.96
Malletts Bay	54.2	699.3	32.0	12.9	0.6
South Lake	56.9	155.5	14.0	2.7	0.12
Main Lake	682.5	21,000.0	122.0	30.8	2.5 - 3.0

TABLE 7. SUMMARY OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF MISSISQUOI BAY, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Secchi Disc (m)	0.7-2.3	1.6	eutrophic	28, 74
Conductivity (micromho)	78-124	94.3	-	62, 74
pH (standard units)	7.1-8.1	7.6	-	74
Total Alkalinity (mg/l)	21.0-31.0	26.7	-	62
Total Phosphate-P (mg/l)	.016-.19	.050	eutrophic	74
Particulate Phosphate-P (mg/l)	-	-	-	
Dissolved Phosphate-P (mg/l)	.007-.023	.015	eutrophic	74
NO_2 & NO_3 - N (mg/l) (summer)	.20-.63	.32	eutrophic	74
NO_2 & NO_3 - N (mg/l) (winter)	-	-	-	
NH_3-N (mg/l)	.004-.63	.026	eutrophic	74
K^+ (mg/l)		1.03	-	62
Na^+ (mg/l)		3.24	-	62
Mg^{++} (mg/l)		2.68	-	62
Ca^{++} (mg/l)		11.34	-	62
Oxygen Saturation - Surface (%)	82-107	93	-	74
Oxygen Saturation - Bottom (%)	82-96	92	mesotrophic	74

* All values are from the surface waters except where indicated. The numbered references are the data sources used, and correspond to those listed in the bibliography.

found in Lake Champlain. They are similar to concentrations found in Malletts Bay and are approximately 25-30% lower than the main lake. In comparison with cation concentrations in the Great Lakes, Missisquoi Bay has calcium and magnesium values similar to Lake Superior and potassium and sodium concentrations similar to Lake Michigan (Potash, Sundberg & Henson, 1969).

The phosphorus and nitrogen concentrations are some of the highest in Lake Champlain, except for the south lake (Vermont Water Resources Dept., 1976). Total phosphate, dissolved phosphate, and total inorganic nitrogen values compare favorably with the values found in western Lake Erie and should be considered at a eutrophic level. The high phosphorus and nitrogen values coupled with the low cation and alkalinity concentrations suggest that Missisquoi Bay is probably receiving significant loading from man-made sources.

The secchi disc readings range from 0.75-2.3 meters, indicating that Missisquoi Bay is a rather turbid body of water. Low readings are due to both phytoplankton and sediment particulate matter in the water column (Henson & Potash, 1974a; Vermont Water Resources Dept., 1976).

Table 8 summarized the biological parameters for Missisquoi Bay. There are very little published data available on phytoplankton populations, primary productivity, and zooplankton populations for the region. The only phytoplankton data available on Missisquoi Bay were collected in 1966-67. From these data, it is apparent that the algal community throughout the year is quite different from other regions of the lake. Diatoms are almost always the dominant group with Melosira italica, Asterionella formosa, Diatoma sp. and Stephanodiscus sp. being the most important species. Occasionally, Dinobryon bavaricum and D. divergens are abundant. The most striking difference between Missisquoi Bay and other regions of the lake is the lack of significant populations of bluegreen algae. Aphanothece sp. and Anabaena flos-aqua occasionally reach moderate population densities. In general, the phytoplankton community is mesotrophic (Philip Cook, personal communication). Only two chlorophyll values are available. They indicate a moderate amount of phytoplankton biomass present in the summer (Vermont Water Resources Dept., 1976).

The oligochaete and other benthic populations were sampled in 1966, 1974, and 1975. Wide year to year variations in benthic organism numbers have been found, however there are generally equal percentages of Sphaeridae, Gastropoda, Oligochaeta, and Chironomidae present. Among the oligochaetes, Peloscolex ferox, immature capilliform specimens, Aulodrilus americanus, and Potamothrix vejdovskyi are the most abundant. These populations are characteristic of shallow mesotrophic to eutrophic areas in the Great Lakes and other regions (Pagel, 1969; Wade, 1976).

Presently, the trophic status of Missisquoi Bay can be classified as late mesotrophic to eutrophic based on phosphorus and nitrogen concentrations and benthic invertebrate populations. More data are needed on the plankton and aquatic plant components to verify this assessment however. It appears that the shallow depth with subsequent mixing and the short retention time of the bay do not allow for the development of certain eutrophic characteristics. For example, dissolved oxygen concentrations do not reflect the amount of plant nutrients available in the region.

TABLE 8. SUMMARY OF THE BIOLOGICAL CHARACTERISTICS OF MISSISQUOI BAY, LAKE CHAMPLAIN.

Parameter	Range	Mean	Trophic Status	Reference*
Phytoplankton Biomass (mg/l)	-	-	-	-
Chlorophyll A (μg/l)	**7.0-14.0	**10.0	eutrophic	74
P.A.A.P. Final Biomass (mg/l)	-	-	-	-
P.A.A.P. Limiting Factor	-			
Dominant Phytoplankton				
(Diatoms)				
Melosira italica				
Asterionella formosa				
Diatoma sp.				
Stephanodiscus sp.				
(Bluegreens)				
Aphanothece sp.				
Anabaena flos-aqua				
(Golden-Browns)				
Dinobryon bavaricum				
Dinobryon divergens				
Dominant Zooplankton				
Dominant Benthic Invertebrates				
(Oligochaeta)				
Peloscolex ferox			meso-eutrophic	51, 77
Aulodrilus americana				
Immature capilliforms				
(Chironomidae)				
Chaoboris punctipennis				

* The numbered references are the data sources used and correspond to those listed in the bibliography.
** Only 2 values.

Northeast Arm - Main Portion

The northeast arm of Lake Champlain is located within drainage basin (B) and a portion of (H) of this report, between Sandbar Bridge, Milton, Vermont and Swanton, Vermont. The area is isolated from other sections of the lake by railroad and road fills and by large islands. Thus there are only four narrow connections available for water exchange; a culvert to Malletts Bay, a small passage to Missisquoi Bay, the Alburg Passage to the main lake, and a highway and railroad bridge opening through the Gut to the main lake. There are no major tributaries entering the region, although a few small streams contribute significant phosphorus loading. The morphometric features are summarized in Table 6 (Potash, Sundberg, & Henson, 1969; Henson & Potash, 1976).

In the following discussion, the data collected by the U. S. Environmental Protection Agency during 1972 will be used sparingly. It was felt that the sampling station was not representative of the northeast arm area since it was located in quite shallow water and close to St. Albans Bay, which probably significantly influenced the chemical constituents (U.S.E.P.A., 1974). Also, since the characteristics of St. Albans Bay are substantially different from the rest of the northeast arm, a separate section discussing its features is included.

The deeper portions of the northeast arm are thermally stratified during the summer with an average epilimnion thickness of about 12.0 meters and a maximum of 20.0 meters. Maximum surface and hypolimnial temperatures are significantly higher than in other areas of the lake (Henson & Potash, 1966; Potash, Sundberg & Henson, 1969; Gruendling, 1976a).

Table 9 summarizes the physical and chemical characteristics of the northeast arm. The surface waters are well oxygenated throughout the year. However, bottom waters show considerable oxygen deficit during the summer stratification period. Minimum values in the hypolimnion generally range from 45-48% saturation. Moderate algal productivity, relatively small hypolimnial volume, and warmer bottom temperatures, probably account for this oxygen deficit (Henson & Potash, 1966; Potash, Sundberg & Henson, 1969).

Major cation concentrations in the northeast arm are very similar to Malletts Bay and Missisquoi Bay and only slightly less than the main lake. Potassium concentrations are an exception, exhibiting the highest concentrations found in the lake. Cation values are similar to oligotrophic Lake Superior and oligo-mesotrophic Lake Huron. Total alkalinity is also substantially lower than the main lake (Henson, Potash & Sundberg, 1966; Potash, Sundberg & Henson, 1969).

The particulate phosphorus values average slightly higher than most stations on Lake Champlain, except for a few enriched embayment areas and the south lake. These values, however, are in the mesotrophic range. Total nitrate-nitrogen values ranged from 40-80% lower than values observed in other portions of the lake. This trend continues during the winter when phytoplankton are low and can not be solely attributed to phytoplankton uptake during the rest of the year. Values for inorganic nitrogen are lower throughout most of the northeast arm than the Great Lakes and must be considered in the oligotrophic to mesotrophic range (Gruendling & Malanchuk, 1974).

The secchi disc values are the highest found anywhere in Lake Champlain. The mean values for three stations within the region during the summer and fall are indicative of early mesotrophic situations. The phytoplankton data support this contention (Gruendling, 1976b).

Table 10 summarizes the biological parameters for the northeast arm. Studies on the seasonal and geographical distribution of phytoplankton populations indicate some qualitative and quantitative differences between the northeast arm and other areas. Algal populations are generally lower throughout the growing season in the northeast region. This is supported by relatively lower chlorophyll A and phytoplankton biomass values, both of which are in the oligo-mesotrophic range. Qualitative differences are reflected in the relative dominance of phytoplankton species. Fragilaria crotonenses, F. capucina, and Synedra ulna are the most abundant diatoms. Melosira islandica, a diatom that reaches relatively high numbers in other areas of the lake, is a minor constituent in the northeast arm. Among the bluegreen algae, the three major Anabaena species are found in lower numbers than elsewhere. The floristic composition and the population numbers of phytoplankton in the region are indicative of mesotrophic conditions (Gruendling, 1976a; Gruendling, 1976b). The P.A.A.P. algal bioassays conducted in the northeast arm demonstrate that phosphorus is the limiting factor to algal growth. Final control yields of Selenastrum are indicative of mesotrophic areas (U.S.E.P.A., 1974; Gruendling, 1976b).

The composition of the zooplankton fauna of the northeast arm region is very similar to other areas of the lake. The copepods dominate the community throughout most of the year, comprising 53-85% of the total microcrustacea. Cyclops bicuspidatus thomasi is generally the predominant species except during the fall when the three species of Diaptomus sp. become dominant. The cladoceran fauna is dominated by Daphnia galeata mendotae (comprising approximately 41-85% of the cladoceran community) and the Bosmina-Eubosmina complex which comprises from 10-57% throughout the year. The total copepod numbers (maximum - $1.18 \times 10^6/m^2$; mean - $0.63 \times 10^6/m^2$) are slightly lower than other deep portions of the lake but higher than most bay regions. The total cladoceran numbers (maximum - $0.71 \times 10^6/m^2$; mean = $0.28 \times 10^6/m^2$) are slightly higher than other areas of Lake Champlain.

The general chemical and biological characteristics of the deeper portions of the northeast arm indicate early mesotrophic conditions. Although there are little data available, the shallow bay areas (Maquam Bay, Keeler Bay, Lapam Bay, Cary Bay, and the Gut) tend to have late mesotrophic to eutrophic conditions. St. Albans Bay is classified as eutrophic.

Northeast Arm - St. Albans Bay

St. Albans Bay has been selected for separate treatment in this report due to the occurrence of limnological conditions that are extremely different from

TABLE 9. SUMMARY OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF NORTHEAST ARM, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Secchi Disc (m)	4.5-6.5	5.5	mesotrophic	21
Conductivity (micromho)	**130-132	**131	-	14
pH (standard units)	7.5-8.2	7.8	-	14
Total Alkalinity (mg/l)	-	30.8	-	31
Total Phosphate-P (mg/l)	†	-	-	14
Particulate Phosphate-P (mg/l)	.006-.02	.011	mesotrophic	24
Dissolved Phosphate-P (mg/l)	†	-	-	14
NO_2 & NO_3-N (mg/l) (summer)	-	.014	oligo-mesotrophic	24
NO_2 & NO_3-N (mg/l) (winter)	-	.033	oligo-mesotrophic	24
NH_3-N (mg/l)	†	-	-	14
K^+ (mg/l)		**1.2	-	62
Na^+ (mg/l)		**3.0	-	62
Mg^{++} (mg/l)		**2.9	-	62
Ca^{++} (mg/l)		**13.2	-	62
Oxygen Saturation-Surface (%)	108-89	-	-	14, 62
Oxygen Saturation-Bottom (%)	100-45	-	meso-eutrophic	14, 62

* All values are from the surface waters except where indicated. The numbered references are the data sources used, and correspond to those listed in the bibliography.

** Median value.

† Samples taken from a station near St. Albans Bay which is more eutrophic than Northeast Arm in general (see text for explanation).

TABLE 10. SUMMARY OF THE BIOLOGICAL CHARACTERISTICS OF NORTHEAST ARM, LAKE CHAMPLAIN.

Parameter	Range	Mean	Trophic Status	Reference*
Phytoplankton Biomass (mg/l)	.15-.66	.50	oligo-mesotrophic	21
Chlorophyll A (μg/l)	1.5-6.5	3.5	oligo-mesotrophic	21
P.A.A.P. Final Biomass (mg/l)	-	-	-	
P.A.A.P. Limiting Factor - Phosphorus				14, 19
Dominant Phytoplankton	max. cells x 10^5/l			20, 21
Fragilaria crotonensis	4.83			
Synedra ulna	.55		mesotrophic	
Anabaena circinalis	3.69			
Anabaena flos-aqua	1.24			
Dominant Zooplankton				23
(Copepods)				
Cyclops bicuspidatus thomasi				
Mesocyclops edax				
Diaptomus oregonensis				
Diaptomus minutus				
Diaptomus sicilis				
(Cladocerans)				
Daphnia galeata mendotae				
Eubosmina coregoni-Bosmina longirostris				
Dominant Benthic Invertebrates				

* The numbered references are the data sources used and correspond to those listed in the bibliography.

other areas of the northeast arm. St. Albans Bay is divided into two general areas; the inner bay with a maximum depth of approximately 6.0 meters and the outer bay with a maximum depth of 10.0 meters. There appears to be a gradient of chemical conditions, especially the concentrations of phosphorus and nitrogen, from the inner bay to the outer bay area. This is primarily a result of the heavy nutrient loading from the City of St. Albans, Vermont sewage treatment facility entering via Stevens Brook. Stevens Brook has the highest total phosphorus concentration of any tributary entering Lake Champlain (Henson & Potash, 1976).

Due to the shallowness of the bay region, the water column seldom stratifies for any length of time. Throughout the majority of the season the bay is isothermal (Gruendling, 1976a; Vermont Water Resources Dept., 1976).

Table 11 summarizes the physical and chemical characteristics of inner St. Albans Bay. The dissolved oxygen concentrations in the bay seldom show any oxygen deficit. During the summer and early fall, surface water dissolved oxygen values are generally supersaturated, while the bottom waters are only slightly less than saturated. The lack of a significant oxygen deficit in the bottom water is probably due to the well mixed conditions and active photosynthesis throughout the water column. Trends in oxygen values since 1966 demonstrate increasing oxygen saturation values in the surface water, thus indicating increasing productivity (Henson & Potash, 1974b; Vermont Water Resources Dept., 1976).

The dissolved and total phosphate concentrations are high. The values are the highest recorded for the lake, except for the south lake and Missisquoi Bay, and are two-three times the average values for other areas of the northeast arm. They fall well within the eutrophic range (Vermont Water Resources Dept., 1976). Phosphorus has been determined to be the chief limiting factor to algal growth in St. Albans Bay (U.S.E.P.A., 1974; Gruendling, 1976b).

Corlis and Hunt (1973) have compared the phosphorus content of the sediments in St. Albans Bay with that of an adjacent area, Lapan Bay. The concentrations of phosphorus ranged from 513-1576 p.p.m. (mean = 983) in St. Albans Bay, while in the relatively unpolluted Lapan Bay the values ranged from 298-760 p.p.m. (mean = 535). The maximum concentrations in St. Albans Bay were found near the mouth of Stevens Brook and in the deeper parts of the bay and are associated with high organic content sediments. It is believed that continued buildup of phopshorus in the sediments may make future restoration of the bay difficult (Corliss & Hunt, 1973).

The Secchi disc transparencies are the lowest recorded summer values for Lake Champlain, except for the south lake. The present values are indicative of eutrophic conditions. Secchi disc values have recently declined, with the summer range in 1966 being 2.0 - 4.0 meters and the summer mean during 1974 being 1.25 - 2.25 meters. The majority of this reduced transparency is believed to be due to increases in phytoplankton growth (Henson & Potash, 1974b; Vermont Water Resources Dept., 1976).

Although algal blooms and aquatic weed growth have been considered serious problems for inner St. Albans Bay in recent years, there are little detailed quantitative data available on the subject. Table 12 is a summary of the biological characteristics of the area. Studies on phytoplankton in the outer St. Albans Bay, an area that is less nutrient rich than the inner bay, indicate a mesotrophic-eutrophic flora with algal biomass and chlorophyll A values also suggesting the same trophic classification (Gruendling, 1976a; Gruendling, 1976b). There are indications that the inner bay has significantly higher algal populations however (Vermont Water Resources, Dept., pers. comm.).

In order to control some of the algal blooms in inner St. Albans Bay, 50,000 pounds of copper sulphate have been applied over the past nine years (Burlham, 1974). This has apparently lead to the increase in rooted aquatic weed growth, which, in turn, is believed to have affected fish populations of the area (Anderson, 1974). The Vermont Water Resources Department considers the extensive growth of the rooted aquatic plants to be the largest eutrophication problem of the inner bay area. The european milfoil, Myriophyllum spicatum, in addition to other plants, form dense beds around the perimeter of the bay and interfere extensively with recreational activities (Vermont Water Resources Dept., pers. comm.).

The zooplankton fauna and seasonal dynamics in outer St. Albans Bay is very similar to those observed in other sections of the northeast arm. The copepods comprise 38-94% of the total fauna throughout the year, while the cladocerans comprise from 6-62%. Cyclops bicuspidatus thomasi is the most abundant copepod followed by Diaptomus oregonensis and Diaptomus minutus. The Bosmina-Eubosmina complex and Daphnia galeata mendotae generally comprise nearly all of the cladoceran biomass. The total numbers of copepods (maximum $= 0.39 \times 10^6/m^2$; mean $= 0.15 \times 10^6/m^2$) and cladocerans (maximum $= 0.19 \times 10^6/m^2$; mean $0.12 \times 10^6/m^2$) are lower than other parts of the northeast arm but similar to some of the other bay regions of the lake.

The general distribution and population trends of benthic invertebrates reflect both the effects of increased eutrophication and the treatments with copper sulphate. In the regions where copper sulphate treatments have been the heaviest, there has been a reduction in gastropods and a six-fold increase in "copper-tolerant" chironomids. The oligochaete population numbers throughout the bay are lower than expected for the highly organic sediments, possibly a copper sulphate influence. However, the dominant types of oligochaetes have changed from mesotrophic forms (Peloscolex ferox) which were dominant in 1966 to strongly eutrophic species (Limnodrilus hoffmeisteri and others) in 1974 (Pagel, 1969; Wade, 1976a).

In summary, all indicators point to St. Albans Bay being a eutrophic body of water. Trends in the past ten years also indicate that the problem is accelerating. It is generally believed that the major cause of the accelerating eutrophication is the significant phosphorus loading from the sewage facility in St. Albans, Vermont.

Malletts Bay

Malletts Bay, Vermont is an area of Lake Champlain that is almost completely isolated from the main lake and the northeast arm by railroad and

TABLE 11. SUMMARY OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF INNER ST. ALBANS BAY, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Secchi Disc (m)	2.0-3.0	2.4	eutrophic	74
Conductivity (micromho)	100-165	136	-	74
pH (standard units)	7.5-9.3	8.1	-	74
Total Alkalinity (mg/l)	35-43	39.1	-	74
Total Phosphate-P (mg/l)	.022-.066	.037	eutrophic	74
Particulate Phosphate-P (mg/l)	-	-	-	
Dissolved Phosphate-P (mg/l)	.008-.036	.015	eutrophic	74
NO_2 & NO_3-N (mg/l) (summer)	-	-	-	
NO_2 & NO_3-N (mg/l) (winter)				
NH_3-N (mg/l)	.004-.06	.023	-	74
K^+ (mg/l)	-	-	-	
Na^+ (mg/l)	-	-	-	
Mg^{++} (mg/l)	-	-	-	
Ca^{++} (mg/l)	-	-	-	
Oxygen Saturation-Surface (%)	90-110	-	-	74
Oxygen Saturation-Bottom (%)	80-103	-	mesotrophic	74

* All values are from the surface waters except where indicated. The numbered references are the data sources used, and correspond to those listed in the bibliography.

TABLE 12. SUMMARY OF THE BIOLOGICAL CHARACTERISTICS OF INNER ST. ALBANS BAY, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Phytoplankton Biomass (mg/l)	**.18-2.1	**1.0	meso-eutrophic	21
Chlorophyll A (μg/l)	**4.1-12.6	**6.7	meso-eutrophic	21
P.A.A.P. Final Biomass (mg/l)	-	-	-	
P.A.A.P. Limiting Factor - phosphorus				19, 74
Dominant Phytoplankton -	max. cells x 10^5/l			
** (Diatoms)				20, 21
Fragiliana crotonensis	** 5.64			
Melosira islandica	.97		meso-eutrophic	
(Bluegreens)				
Anabaena flos-aqua	30.39			
Anabaena circinalis	23.35			
Dominant Zooplankton				23
** (Copepods)				
Cyclops bicuspidatus thomasi				
Mesocyclops edax				
Diaptomus oregonensis				
Diaptomus minutus				
(Cladocerans)				
Eubosmina coregoni-Bosmina longirostris				
Daphnia galeata mendotae				
Dominant Benthic Invertebrates				
(Oligochaeta)				77
Limnodrilus hoffmeisteri			eutrophic	
Ilyodrilus templetoni			eutrophic	
Tubifex tubifex			mesotrophic	

* The numbered references are the data sources used and correspond to those listed in the bibliography.
** Measurements taken in Outer St. Albans Bay only.

highway fills. As a result, conditions in the bay are often quite different than they are in the open portions of the lake. There is evidence that seiche activity in these open portions have some influence on Malletts Bay in terms of mass water movement through the openings in the causeway barriers (Myer, Larson, Cole & Hulbert, 1976). Studies are presently being completed to quantify these phenomona (Myer, pers. comm.).

The Malletts Bay area actually consists of two areas; a small shallow inner bay and a larger, deeper outer bay. Most of the research has been conducted on the outer bay and the discussion that follows concentrates on this area.

Malletts Bay is located in drainage basin (C) of this report. The Lamoille River, the major tributary of the drainage basin, has significant influences upon the limnological characteristics of the bay. This river contributes the second largest discharge of tributaries entering Lake Champlain, it ranks sixth in terms of phopshorus loading, and discharges large amounts of BOD to the Malletts Bay area (Gregg, 1974; Henson & Potash, 1976). Table 6 summarized the morphometric features of Malletts Bay.

Malletts Bay generally exhibits strong thermal stratification from early July through early October. Maximum surface temperatures range from 22.0 - 24.0° C in the summer, while hypolimnial temperatures range from 9.0 - 10.0° C. The major reason for such a long period of stratification is the lack of strong winds and other mechanisms for vertical water movement due to the protected nature of the basin (Potash & Henson, 1966; Potash, Sundberg & Henson, 1969; Gregg, 1970; Gruendling, 1976a).

Table 13 summarizes the physical and chemical characteristics of Outer Malletts Bay. As a result of the strong thermal stratification, the in-lake productivity, and the organic matter entering via the Lamoille River, the hypolimnion of the outer bay exhibits severe oxygen depletion during the summer and early fall. The bay has had oxygen depletion each year since 1964 with minimum values reaching as low as 3.0% saturation (0.1-0.2 mg/l oxygen). An illustration of the localized nature of the severe oxygen depletion in Malletts Bay is that summer bottom water values in the main lake just west of the railroad fill are not below 75% saturation and values in the northeast arm north of the causeway are not below 50% saturation. Oxygen values close to saturation reoccur following turnover in the fall. There are also indications that oxygen values during ice cover dropped below 50% saturation at 25.0 meters and below 15% (1.0 mg/l oxygen) near the bottom. No severe oxygen depletion in the hypolimnion has been demonstrated for inner Malletts Bay (Potash & Henson, 1966; Potash, Sundberg & Henson, 1968; Potash, Sundberg & Henson, 1969; Gregg, 1970).

Epilimnetic oxygen values are generally above 90% saturation throughout the year. The only significant oxygen deficits in the epilimnion occur during fall turnover and at times when unusually high winds induce a vertical displacement of the epilimnion-metalimnion boundary. Under these displacement conditions, epilimnial water is exposed to the reduced organic sediments and a significant drop in the dissolved oxygen occurs (Potash & Henson, 1966; Potash, Sundberg & Henson, 1968; Potash, Sundberg & Henson, 1969).

Cation concentrations in Malletts Bay tend to be lower than most other areas of the lake. This is possibly due to the short retention time of the basin. Calcium and magnesium values compare favorably with Lake Superior values and potassium and sodium concentrations are similar to Lakes Huron and Michigan (Henson, Potash & Sundberg & Henson, 1969).

Phosphorus and nitrogen values appear to support the trends of low nutrient levels as demonstrated by the cation concentrations. Total, particulate, and dissolved phosphorus concentrations are low, even though there is high phosphorus input entering from the Lamoille River. This possibly reflects the short retention time of the water mass and/or loss of phosphorus to the sediments. Phosphorus levels are lower than levels for other areas of Lake Champlain. Values are similar to phosphorus concentrations in Lake Michigan and the eastern basin of Lake Erie and are considered to be in the early mesotrophic range. Mean winter values for nitrate nitrogen are slightly lower than other areas of the lake, except the northeast arm. Mean summer values in the surface waters are higher than other areas, indicating a lack of biological uptake during this period. The range of nitrate nitrogen concentrations are similar to the open waters of Lake Ontario and are considered to be at mesotrophic levels (Gruendling & Malanchuk, 1974; U.S.E.P.A., 1974).

The Secchi disc readings are among the highest for Lake Champlain, except for the deeper portions of the northeast arm. The range of values and mean summer and fall values are within the mesotrophic range (U.S.E.P.A., 1974, Gruendling, 1976b).

Table 14 summarizes the biological characteristics of outer Malletts Bay. The phytoplankton data present somewhat of a confusing picture as to the trophic status of Malletts Bay. The calculated phytoplankton biomass values from May-October 1970 and 1974 are low and are similar to Lake Huron, thus indicating an oligotrophic condition. Chlorophyll A concentrations for the summer and fall period are some of the highest determined for the lake and fall within the mid-mesotrophic range. The dominant phytoplankton species are somewhat different than other areas of Lake Champlain. The most striking difference is the lack of appreciable numbers of bluegreen algae. The area is dominated by diatoms (Fragilaria crotonensis, Synedra ulna, Tabellaria fenestrata) at all times of the year and has basically a mesotrophic flora. The benthic green alga, Cladophora glomerata, which is so abundant in eutrophic situations such as Lake Erie, is extremely sparce on the rocky shores of Malletts Bay (Gruendling, 1976a; Gruendling, 1976b; U.S.E.P.A., 1974; Mercer, 1972).

The composition of the zooplankton fauna is not significantly different than other areas of the lake. During the winter and spring, the copepods comprise about 95% of the crustacean zooplankton, of which a major portion are the cyclopoid copepods (Cyclops bicuspidatus thomasi dominant). During the summer and early fall, there are significant increases in the cladoceran populations; primarily the Bosmina-Eubosomina complex, Daphnia galeata mendotae, and Daphnia retrocurva. However, the copepods still comprise a majority of the zooplankton community in the summer. Both the maximum (0.63×10^6 organisms/m^2) and the mean ($.014 \times 10^6$ organisms/m^2) numbers of total copepods in Malletts Bay are slightly less than other areas of the lake except some of

TABLE 13. SUMMARY OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF OUTER MALLETTS BAY, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Secchi Disc (m)	3.7-6.5	4.4	mesotrophic	21
Conductivity (micromho)	100-123	106	-	14
pH (standard units)	6.4-7.4	7.0	-	14
Total Alkalinity (mg/l)	-	27.6	-	62
Total Phosphate-P (mg/l)	.007-.021	.012	oligo-mesotrophic	14
Particulate Phosphate-P (mg/l)	.006-.013	.010	mesotrophic	24
Dissolved Phosphate-P (mg/l)	.005-.013	.009	mesotrophic	14
NO_2 & NO_3-N (mg/l) (summer)	-	.095	mesotrophic	24
NO_2 & NO_3-N (mg/l) (winter)	-	.149	mesotrophic	24
NH_3-N (mg/l)	.030-.070	.047	mesotrophic	14
K^+ (mg/l)		.092	-	62
Na^+ (mg/l)		2.86	-	62
Mg^{++} (mg/l)		2.53	-	62
Ca^{++} (mg/l)		12.30	-	62
Oxygen Saturation-Surface (%)	86-100	-	-	60, 61
Oxygen Saturation-Bottom (%)	3-90	-	eutrophic	60, 61

* All values are from the surface waters except where indicated. The numbered references are the data sources used, and correspond to those listed in this bibliography.

TABLE 14. SUMMARY OF THE BIOLOGICAL CHARACTERISTICS OF OUTER MALLETTS BAY, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Phytoplankton Biomass (mg/l)	.24-1.33	.69	oligotrophic	21
Chlorophyll A (μg/l)	3.4-11.4	6.2	mesotrophic	21
P.A.A.P. Final Biomass (mg/l)	-	-	-	
P.A.A.P. Limiting Factor - Phosphorus				14, 19
Dominant Phytoplankton	max. cells x 10^5/l			
(Diatoms)				20, 21
Fragilaria crotonensis	32.56		oligo-mesotrophic	
Tabellaria fenestrata	2.30			
Synedra ulna	1.41			
(Bluegreens)				
Anabaena circinalis	1.89			
Dominant Zooplankton				18, 23
(Copepods)				
Cyclops bicuspidatus thomasi				
Diaptomus minutus				
Diaptomus sicilis				
Mesocyclops edax				
(Cladocerans)				
Daphnia galeata mendotae				
Daphnia retrocurva				
Eubosmina coregoni-Bosmina longirostris				
Dominant Benthic invertebrates				54, 77
(Oligochaeta)				
Limnodrilus sp.			eutrophic	
Potamothrix vejdovskyi			eutrophic	
(Diptera)				
Chironumus anthracinus			meso-eutrophic	
(Isopoda)				
Ascellus intermedius			mesotrophic	

* The numbered references are the data sources used and correspond to those listed in the bibliography.

the shallow bay regions. Cladoceran populations (maximum = $0.24 \times 10^6/m^2$; mean = $0.14 \times 10^6/m^2$) are also lower than most areas of the lake (Sage, 1969; Gruendling & Luguri, 1974).

The benthic invertebrate populations in Malletts Bay are typical of deep water lakes of the glaciated region of North America. It appears as though the populations reflect the dissolved oxygen conditions occurring in the lower waters. The inner bay (no significant oxygen deficit) is dominated by a number of mesotrophic chironomid species with some oligochaete species also being important. Approximately 97% of the oligochaete component consists of immature capilliform specimens. The outer bay (severe oxygen depletion) is dominated by the oligochaetes, Limnodrilus sp. and Potamothrix vejdovskyi, both of which are abundant in eutrophic situations. The seasonal population dynamics of the isopod Asellus intermedius and the chironomid Chironomus anthracinus also reflect the changes in the dissolved oxygen conditions in the hypolimnion. Both species increase in number at deep stations only after completion of fall turnover. These population increases are a result of migration from well oxygenated shallow water areas (Pantas, 1966; Wade, 1976a).

The general trophic status of Malletts Bay is a paradoxical situation. Characteristics such as severe oxygen depletion of the hypolimnion and the benthic invertebrate populations indicate that eutrophic conditions are present. On the other hand, the transparency of the water, most of the chemical data, and the phytoplankton data, indicate that the area is probably in an early mesotrophic state. The oxygen characteristics are probably due to the high BOD loading from the Lamoille River and not solely due to nutrient loading. The invertebrate populations subsequently respond to the oxygen conditions. Considering these data, Malletts Bay should be classified as early mesotrophic (Gregg, 1970).

South Lake

South Lake Champlain, Vermont and New York, is that portion of the lake from the Crown Point Bridge south to Whitehall, N.Y.. It is located within drainage basin (S) of this report and is comprised of drainage areas (G) in Vermont and (N) in New York. It receives major inputs from the Barge Canal-Poultney River System, Putnam Creek, East Creek, Mill Creek, Ticonderoga Creek, and the International Paper Company outfall north of Ticonderoga, N.Y. It ranks fifth in the amount of phosphorus loading and has an exceptionally high theoretical phosphorus concentration (Henson & Potash, 1976). Table 6 summarizes the morphometric features of the region.

Summer thermal stratification is generally not pronounced throughout most of the south basin. The shallow depth, long, narrow surface area to generate turbulence, and the frequent barge traffic probably all contribute to periodic mixing of the water column. In the deeper northern parts of the region, some thermal stratification does occur. The south lake is considered one of the "warm" regions of Lake Champlain, with maximum summer temperatures 2.0-4.0° C higher than the main lake (Henson & Potash, 1966; Henson, Potash & Sundberg, 1966; Potash, Sundberg & Henson, 1969).

Table 15 is a summary of the physical and chemical features of the south lake. Dissolved oxygen concentrations in the surface and bottom waters have a wide range of values throughout the region. Oxygen values near or above saturation occur in algal growth areas and low values in localized areas receiving organic pollution. In general, there is no significant oxygen depletion in the lower waters for any appreciable length of time. However, generalizations about the limnological characteristics of the south lake are difficult to make since the overall conditions are complicated by major inputs from past and present pulp and paper operations. Areas in the vicinity of Ticonderoga Bay and the "effluent diffuser" of the International Paper Company have limnological conditions quite different from other south lake areas (Potash, Sundberg & Henson, 1969; Pagel, 1969; U.S.E.P.A., 1974; Pagel, 1975).

Median values for the concentration of major cations are significantly higher (50-60%) than other areas of the lake, although when compared to the Great Lakes, the values are similar to the low nutrient lakes of Huron and Michigan. Total alkalinity values are also significantly higher in the south lake. It has been noted that there are great fluctuations in concentrations of ions, 50% or more, between sampling periods in the region. These periodic variations may be due to increased short-term runoff in a lake basin of very small volume (Henson, Potash & Sundberg, 1966; Potash, Sundberg, Henson, 1969).

Nitrogen and phosphorus are abundant throughout the south lake region, with values averaging higher than any other areas of Lake Champlain. Values for total and dissolved phosphorus and inorganic nitrogen compare favorably with those for the western basin of Lake Erie and fall well within the eutrophic range. The nutrient rich water of the south lake has the potential of significantly influencing the water mass in the main lake north of Crown Point, N.Y. Extension of high nutrient water into this area of the lake may result in accelerating eutrophication problems. There have already been reports of extensive algal blooms just north of Crown Point Bridge and in the Port Henry, N.Y. area (Beak Associates, 1972; U.S.E.P.A., 1974; Pagel, 1975).

The secchi disc values for the south lake are the lowest found in Lake Champlain (0.7-1.3 meters) and fall within the eutrophic range. However, the turbidity found in this region is caused primarily by suspended clay particles and only occasionally due to substantial algal growth (U.S.E.P.A., 1974).

Table 16 is a summary of the biological features of the south lake. There have been no detailed seasonal studies made of phytoplankton populations. Preliminary reports, however, indicate that there have been blooms of Aphanizomenon sp. and Melosira sp. in the region. A limited number of chlorophyll A measurements and P.A.A.P. control yields indicate that the phytoplankton biomass is not extremely high and it can be categorized as mesotrophic to eutrophic. It appears that, because of high nutrients and elevated summer temperatures, the potential for extensive algal blooms (especially bluegreen algal blooms) exists in the south lake. However, due to the extremely high turbidity, phytoplankton productivity is suppressed (Beak Associates, 1972; Wood, 1972; U.S.E.P.A., 1974).

TABLE 15. SUMMARY OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOUTH LAKE, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Secchi Disc (m)	.07-1.3	0.7	eutrophic	14
Conductivity (micromho)	90-245	188	-	14
pH (standard units)	6.8-8.3	-	-	52
Total Alkalinity (mg/l)	-	**67.4	-	62
Total Phosphate-P (mg/l)	.012-.188	.050	eutrophic	14
	.04-.34	.11	eutrophic	52
Particulate Phosphate-P (mg/l)	-	-	-	
Dissolved Phosphate-P (mg/l)	.006-.071	.020	eutrophic	14
	.005-.14	.045	eutrophic	52
NO_2 & NO_3-N (mg/l) (summer)	.01-.44	.158	mesotrophic	14
NO_2 & NO_3-N (mg/l) (winter)	-	-	-	
NH_3-N (mg/l)	.01-.22	.098	mesotrophic	14
K^+ (mg/l)	-	**1.2	-	62
Na^+ (mg/l)	-	**5.1	-	62
Mg^{++} (mg/l)	-	**5.8	-	62
Ca^{++} (mg/l)	-	**24.4	-	62
Oxygen Saturation-Surface (%)	36-98	-		52
Oxygen Saturation-Bottom (%)	20-100	-	meso-eutrophic	52

* All values are from the surface waters except where indicated. The numbered references are the data sources used, and correspond to those listed in the bibliography.
** Median value.

TABLE 16. SUMMARY OF THE BIOLOGICAL CHARACTERISTICS OF SOUTH LAKE, LAKE CHAMPLAIN.

Parameter	Range	Mean	Trophic Status	Reference*
Phytoplankton Biomass (mg/l)	-	-	-	
Chlorophyll A (μg/l)	1.5-30.2	10.1	meso-eutrophic	14
P.A.A.P. Final Biomass (mg/l)	0.2-8.0	1.9	eutrophic	8, 14
P.A.A.P. Limiting Factor - phosphorus				8, 14
Dominant Phytoplankton				
(Diatoms)				8, 14
Melosira granulata			eutrophic	
(Bluegreens)				8, 14
Aphanizomenon sp.			eutrophic	
(Flagellates)				80
***Ochromonas acuta*			-	
Dominant Zooplankton				
(Copepods)				52
Macrocyclops albidus			-	
Mesocyclops edax				
Cyclops vernalis				
(Cladocerans)				
Sida crystallina				
Daphnia retrocurva				
Dominant Benthic Invertebrates				52, 77
(Diptera)				
Chironomus tentans				
Cryptochironomus fluvus				
Chaoborus punctipennis				
Coelotanypus concinnus				
(Oligochaeta)				
Limnodrilus hoffmeisteri				
Peloscolex ferox			meso-eutrophic	
Potamothrix vejdovskyi				

* The numbered references are the data sources used and correspond to those listed in the bibliography.

** Examined only in October, 1972.

The zooplankton populations in the south lake are quite different from other areas of the lake. Most of the organisms are characteristic of shallow water environments. There are no quantitative data presently available on the zooplankton communities in the south lake (Pagel, 1975).

The benthic invertebrate community is generally dominated by chironomids and oligochaetes. The oligochaetes, in particular, increase in abundance in areas of high organic pollution. In assessing the benthic populations in the south lake, one is faced with the problem of separating the conditions resulting from eutrophication and those caused by effluents from pulp and paper operations. Although the majority of the benthic invertebrate populations are mesotrophic-eutrophic indicators, there are a number of species present that are indicative of earlier trophic states (Pagel, 1969, Wade, 1976).

The effects of the pulp and paper effluents on the benthic fauna have been intensively studied. Before the new International Paper Company mill in Ticonderoga, N.Y. began operations in December, 1970, samples taken at the effluent diffuser area contained abundant mayflies (*Hexagenia limbata*) and significant populations of Amphipoda and Sphaeriidae. Since mill operations began, the bottom fauna has been significantly altered in the diffuser line area. Of over fifty benthic species formerly known to inhabit this area, only eighteen were collected in 1975. Changes in the community structure from 1972 to 1975 have been the loss of most Chironomidae, Sphaeridae, and Ephemeroptera and a drastic increase in Tubificidae. A pollution tolerant oligochaete, *Limnodrilus hoffmeisteri*, had increased to tremendous numbers by 1974. The numbers of oligochaetes in this region are from 10-60 times greater than in other portions of the south lake. The new International Paper Company mill contributes substantial amounts of phosphorus, suspended solids, and BOD to the south lake (Pagel, 1975).

A potential eutrophication related problem that has received little attention in the south lake is the extensive growth of the water chestnut (*Trapa natans*) and the yellow floating heart (*Nymphyoides peltatum*). Both aquatic plants have been introduced into the United States and in some eutrophic situations have caused significant degradation of water quality. These two populations have been increasing in the south lake in recent years and they present a potential problem for the future (Gruendling & Bogucki, 1975).

The nutrient characteristics of the south lake are definitely indicative of eutrophic situations. Primary productivity would be considerably higher if it were not for the extremely high turbidity of the water. Limnological characteristics of localized areas are significantly influenced by industrial pollution, which tend to compound the eutrophication related problems.

Main Lake

The main lake is considered that area of Lake Champlain from Crown Point, N.Y. to Rouses Point, N.Y., excluding the northeast arm, Malletts Bay, and Missisquoi Bay. It can be subdivided into three regions that have slightly different limnological characteristics: south basin - Crown Point, N.Y. to Split Rock Point (drainage basins M and F); central basin - Split Rock Point to Cumberland Head, N. Y. (drainage basins, D, E, L, K, and part of H); and north basin - Cumberland Head, N. Y. to Rouses Point, N.Y. (drainage basins J and part of H). There are eighteen major tributaries with drainage basins of ten square miles or more entering the region. Table 6 summarizes the morphometric features of the main lake. In general, the south and north basins are shallower and have significantly smaller volumes than the central basin (Hunt & Boardman, 1968; Hunt, Boardman & Stein, 1971; Potash, Sundberg & Henson, 1969; Henson & Potash, 1976).

As was mentioned in the general overview, the thermal regimes in the main lake are highly variable and are dependent upon depth and the orientation of the water mass in relation to the prevailing winds. The deeper portions of the main lake are a typical temperate dimictic lake. Stratification begins in early June and continues into October or November. Maximum surface temperatures are generally about 23.0° C and hypoliminal temperatures during the summer average close to 6.0° C (Potash, Sundberg & Henson, 1969; Henson & Potash, 1976; Gruendling, 1976a).

Table 17 is a summary of the physical and chemical characteristics of the main lake. Stratified areas of the main lake generally have epilimnial oxygen saturation levels near or above saturation, while hypolimnial values rarely fall below 65% saturation. The minimum bottom water oxygen saturation values generally range between 70 - 80%. Recent evidence from the very deep stations demonstrate minimum oxygen levels in the metalimnion during the summer rather than in the hypolimnion. There is also evidence of a gradual trend toward higher supersaturated values in the epilimnion, thus suggesting a trend toward accelerating rates of primary production (Potash, Sundberg & Henson, 1969; Henson & Potash, 1976).

Cation concentrations in the main lake are generally higher than other areas, except the south lake. Values for cations and total alkalinity are relatively similar throughout the main lake with only slightly higher values observed in the southern basin and slightly lower values found in the northern basin. Sodium and potassium concentrations are similar to Lake Michigan, while calcium and magnesium concentrations most closely resemble values for Lake Superior (Potash, Sundberg & Henson, 1969: Henson & Potash, 1976).

Phosphorus and nitrogen concentrations for the deep portions of the main lake are the lowest recorded for Lake Champlain, except for Malletts Bay and the northeast arm (only nitrogen values lower). These levels are similar to values for the early mesotrophic Great Lakes. The shallow areas of the main lake, however, have higher phosphorus and nitrogen values. Cumberland Bay, Burlington Bay (east of the breakwater) and inner Shelburne Bay have significantly higher levels of these nutrients than the deep stations. Table 18 compares characteristics of the embayment areas with the main lake. Phosphorus and nitrogen concentrations in these bay areas are characteristic of late mesotrophic to early eutrophic situations. The high nutrient values in Cumberland Bay result from the major input entering from the Saranac River and the City of Plattsburgh, N. Y. Sewage Treatment Facility. High values in inner Burlington and Shelburne Bays are probably due to input from sewage treatment facilities (Burlington, South Burlington, and Shelburne Fire District) and small tributaries (Potash Brook) (Gruendling & Malanchuk, 1974; U.S.E.P.A., 1974; Barnett, Poulias & Biggane, 1975; Henson & Potash, 1976).

Secchi disc transparencies for the deep stations are relatively high and are within the mesotrophic range. There is a trend toward lower Secchi disc values in the south basin with a gradial increase in transparency northward toward the outlet at Rouses Point, N.Y. The areas of Cumberland Bay, inner Burlington Bay, and inner Shelburne Bay have Secchi disc readings substantially lower than other areas of the central and northern basin of the main lake. These values are in the late mesotrophic to early eutrophic range (U.S.E.P.A., 1974; Gruendling, 1976b).

Table 19 summarizes the biological characteristics of the main lake. The total biomass of phytoplankton populations in the main lake, as determined by chlorophyll A, dry weight, and total cell count, are the lowest values recorded for Lake Champlain, except for a few stations in the northeast arm. These values generally indicate oligotrophic to mesotrophic conditions. Melosira islandica is dominant in the spring, Fragilaria crotonensis, F. capucina, Anabaena planktonica, and A. circinalis are abundant in the summer and fall, and the flagellates (Cryptomonas ovata, C. erosa, and Rhodomonas lacustris are periodically abundant throughout the year. The qualitative and quantitative aspects of the phytoplankton community are indicative of mesotrophic situations. Although the qualitative components of the phytoplankton in the embayment areas are similar to the deep stations, the quantitative aspects are quite different. Cumberland Bay, inner Burlington Bay, and inner Shelburne Bay have significantly higher chlorophyll A, dry weight, and cell numbers of phytoplankton than the deep areas (see Table VI-13) (Gruendling, 1976; Gruendling, 1976a).

A number of shoreline areas in Shelburne Bay have high amounts of Cladophora glomerata growing on the rock surfaces. This is another indication of developing eutrophic conditions in the region (Mercer, 1972).

The P.A.A.P. algal bioassays conducted throughout the main lake, both in deep areas and at bay stations, indicate that phosphorus is the limiting factor to algal growth (Gruendling, 1976b; U.S.E.P.A., 1974).

The zooplankton community in the main lake is typical for deep cold-water lakes of North America. The total copepod component (Calanoida and Cyclopoida) generally outnumbers the Cladocera, except during short periods in mid-summer and early fall, when species of Daphnia, Chydorus, and Bosmina-Eubosmina become abundant. Numerically, the cyclopoid copepods are the major component throughout the year with Cyclops bicuspidatus thomasi being the most abundant species. The calanoid populations of Diaptomus sicilis, D. minutus, and D. oregonensis reach maximum abundance in August and September. The species composition of the main lake is not identical to any one of the Great Lakes, but it closely resembles the zooplankton community of northern Lake Michigan. The total copepod community is larger in the deep open portions of the main basin than in other areas of the lake. Maximum copepod numbers are 3.6×10^6 organisms/m^2, while the average during the summer and fall period is 1.1×10^6 organisms/m^2. Cladoceran population numbers are similar to deep portions of the northeast arm (maximum = $0.59 \times 10^6/m^2$; mean = $0.26 \times 10^6/m^2$) and generally higher than the bay region in the lake (Leggi, 1969; Gruendling & Luguri, 1974).

TABLE 17. SUMMARY OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF MAIN LAKE, LAKE CHAMPLAIN*.

Parameter	Range	Mean	Trophic Status	Reference
Secchi Disc (m)	3.0-6.7	4.4	mesotrophic	21
Conductivity (micromho)	100-160	137	-	14
pH (standard units)	5.8-8.3	7.5	-	14
Total Alkalinity (mg/l)		**41.4	-	62
Total Phosphate-P (mg/l)	.009-.040	.018	mesotrophic	14
Particulate Phosphate-P (mg/l)	.006-.019	.011	mesotrophic	24
Dissolved Phosphate-P (mg/l)	.005-.017	.009	mesotrophic	14
NO_2 & NO_3-N (mg/l) (summer)	-	.066	mesotrophic	24
NO_2 & NO_3-N (mg/l) (winter)	-	.164	mesotrophic	24
NH_3-N (mg/l)	.010-.090	.043	-	14
K^+ (mg/l)		**1.13	-	62
Na^+ (mg/l)		**3.92	-	62
Mg^{++} (mg/l)		**3.59	-	62
Ca^{++} (mg/l)		**15.81	-	62
Oxygen Saturation-Surface (%)	83-120	-	-	14, 30
Oxygen Saturation-Bottom (%)	64-91		mesotrophic	14, 30

* All values are from the surface waters except where indicated. The numbered references are the data sources used, and correspond to those listed in the bibliography.

** Median value.

TABLE 18. SUMMARY OF SELECTED PARAMETERS INDICATIVE OF TROPHIC CONDITIONS IN THE EMBAYMENT AREAS AND THE MAIN PORTIONS OF LAKE CHAMPLAIN*.

	Total Phosphorus (mg/l)	Secchi Disc (m)	Chlorophyll A (μg/l)	Maximum No. Bluegreens (X 10^6 cells/l)	Maximum No. Diatoms (X 10^6 cells/l)
Cumberland Bay	.025	2.9	5.45	1.40	0.90
Burlington Bay	.022	3.9	5.80	1.17	0.88
Shelburne Bay	.020	3.8	-	1.15	1.40
Main Lake (4 stations)	.018	4.4	3.74	0.90	0.35

* Total phosphorus data are mean values taken from U.S.E.P.A. (1974) and Vermont Water Resources Dept. (1976). Remaining data are monthly means calculated from data collected from May-Oct., 1970 and 1974 by Gruendling (1976a) and Gruendling (1976b).

TABLE 19. SUMMARY OF THE BIOLOGICAL CHARACTERISTICS OF MAIN LAKE, LAKE CHAMPLAIN.

Parameter	Range	Mean	Trophic Status	Reference*
Phytoplankton Biomass (mg/l)	.23-1.6	.56	oligo-mesotrophic	21
Chlorophyll A (μg/l)	2.0-5.8	3.8	oligo-mesotrophic	21
P.A.A.P. Final Biomass (mg/l)	-	-	-	
P.A.A.P. Limiting Factor - phosphorus				14, 19
Dominant Phytoplankton - max. cells x 10^5/l				
(Diatoms)				20, 21
Melosira islandica		3.55		
Fragilaria crotonensis		3.19		
(Bluegreens)			mesotrophic	
Anabaena planktonica		6.45		
Anabaena circinalis		5.93		
Dominant Zooplankton				
(Copepods)				23, 39
Cyclops bicuspidatus				
Diaptomus sicilis				
Diaptomus minutus				
(Cladocerans)				
Eubomina Coregoni-Bosmina longirostris				
Daphnia retrocurva				
Chydorus sphaericus				
Dominant Benthic Invertebrates				
(Oligochaeta)				
Stylodrilus heringianus			oligotrophic	
Peloscolex variegatus			oligotrophic	77
Limnodrilus hoffmeisteri			eutrophic	
Limnodrilus claparedianus			eutrophic	

* The numbered references are the data sources used and correspond to those listed in the bibliography.

The two most abundant groups of benthic invertebrates in the profundal zone are the Oligochaeta (59-90% of the total fauna) and the Sphaeriidae. There are very low numbers of Chironomidae, Amphipoda, and Hirudinea. The deep benthic fauna of Lake Champlain are unique when compared with the Great Lakes. The Great Lakes have substantial numbers of chironomids and the amphipod, Pontoporeia affinis; both of which are insignificant in the main lake. There are also considerable less organisms per square meter in Lake Champlain than in most large lakes. For example, the average number of total benthic organisms/m^2 in the main lake is 663 as compared to an average of approximately 6000 organisms/m^2 in Cayuga Lake, N. Y. (Wade, 1976a).

Among the oligochaetes, Stylodrilus heringianus is the most abundant. This species is generally abundant in oligotrophic areas such as Lake Superior and Lake Michigan. The oligotrophic indicator Peloscolex variegatus is also quite abundant in some of the profundal areas. There appears to be a general decrease of Stylodrilus heringianus and an increase in Limnodrilus species at the northern stations of the main lake. The overall trend appears to be an increase in species characteristic of more eutrophic situations at the northern stations (Wade, 1976).

Only a limited number of the embayment areas of the main lake have been investigated for benthic invertebrates. For those areas that have been studied, the general trend is toward more chironomids and less oligochaetes than the profundal zone. In some areas there is also a trend toward more eutrophic species of oligochaetes. There is a succession from the mesotrophic species Peloscolex ferox and Stylodrilus heringianus outside the breakwater in Burlington Bay to the eutrophic indicator Limnodrilus hoffmeisteri in the inner bay. In Shelburne Bay, there is also a trend toward more eutrophic species from the outer bay to the inner bay. The inner bay is dominated by the eutrophic indicator Limnodrilus sp. (Wade, 1976a).

The main portion of Lake Champlain is comprised of a number of water masses which have different trophic characteristics. The deeper portions of the southern, main, and northern basins are generally mesotrophic, although some areas have conditions approaching oligotrophy. Those bay areas (Willsboro, Whallon, Corlear, Treadwell, Monty Bays) which do not receive significant nutrient inputs have conditions similar to the deep portions of the region. Other bay areas (Bullwagga, Northwest, Cumberland, Shelburne, Burlington Bays) tend to be more eutrophic.

SECTION 5

RECENT TRENDS OF ACCELERATED EUTROPHICATION

Studies depicting any signs of accelerating eutrophication in Lake Champlain are limited. In some cases, there have been casual visual observations of water quality deterioration in various embayment areas such as St. Albans Bay, Shelburne Bay, Cumberland Bay, and Burlington Bay, but there is little quantitative evidence available to support these observations. Some quantitative data for these regions and the south lake have been discussed previously in this report.

Some recent investigations demonstrate that Lake Champlain is showing signs of increased eutrophication. An analysis of the diatom stratigraphy has shown recent increases in the characteristic mesotrophic-eutrophic species of diatoms *Fragilaria capucina*, *F. crotonensis*, *Asterionella formosa*, *Melosira islandica* in the main lake. The general shift from oligotrophic species to more eutrophic species apparently began shortly after 1900 and more recent sediments contain larger numbers of these indicators (Sherman, 1972).

Detailed analyses have been made of the phytoplankton in Lake Champlain, comparing populations present in the early 1970's with populations recorded by Muenscher (1930). Although quantitative comparisons with the 1929 data were difficult to make due to the manner in which th data were collected and expressed, there are indications that significant changes in phytoplankton populations have taken place. Bluegreen algal populations are becoming more abundant and the characteristic eutrophic species of *Anabaena flos-aqua*, *A. circinalis*, *A. planktonica*, and *Aphanizomenon flos-aqua* are becoming more important. Also, populations of the oligotrophic species of *Dinobryon*, which were very abundant in 1929, are presently very sparse and not very widely distributed (Gruendling, 1976a).

The only comprehensive physical and chemical data supporting increased eutrophication trends in Lake Champlain come from a reference station in the main lake, west of Burlington, Vermont. This station is located in a deep open area of the lake (approximately 100 meters in depth) and was sampled at regular intervals from 1965 through 1974. Four general trends in chemical and physical characteristics of the water mass are apparent. The ten-year trend has been for slight increases in the conductivity and cation concentrations in the surface waters. However, the conductivity values appear to have stabilized over the last few years and the cation concentrations have decreased slightly during the past three years. These changes are difficult to evaluate and may only be natural variations due to changes in precipitation. The ten-year trend in Secchi disc readings show a decline in transparency during the summer and fall. Values during 1965 ranged from 4.5-6.0

meters, while the 1974 values ranged from 2.5-4.5 meters. There has also been a recent trend toward increasing dissolved oxygen values in the surface waters above the 100% saturation level and some trend toward decreasing hypolimnetic oxygen concentrations. Both the Secchi disc and dissolved oxygen values suggest increased algal growth over the ten-year period. This trend can not be substantiated, however, since no data were collected on phytoplankton populations (Henson & Potash, 1976).

SECTION 6

PHOSPHORUS LOADINGS, TRANSPORT, AND BUDGETS IN LAKE CHAMPLAIN

BACKGROUND INFORMATION

Theoretical Considerations

It is axiomatic in the science of limnology that in any lake system (lake and drainage basin) there exist a certain amount of materials entering the lake to establish a dynamic ecosystem. This ecosystem will consist of primary producers, herbivores, and predators. The dynamics of the system is such that equilibrium is established according to the energy and materials entering and leaving the system. With the statement that the system tends to develop a balance, we have the format of a controlled system that can be understood.

In our attempt to understand the Lake Champlain ecosystem, we must make some assumptions, use inadequate data, and over simplify. We take as a premise that the lake is (1) phosphorus limited (documented by E.P.A., 1974; Gruendling, 1976a), (2) that increasing amounts of phosphorus to the system is causing a disbalance to the system, expressed in documented symptoms of excessive algae growth, large amounts of aquatic weeds, decreased oxygen concentrations in certain bottom waters, and a number of additional ramifications; and (3) that if the phosphorus input is reduced, the lake would respond by an alleviation of the symptoms, and there would be general improvement for public benefit.

The mission here is to identify and quantify the role of phosphorus in the Champlain ecosystem, and to develop information for the formulation of policy of nutrient control necessary for future lake improvement.

Estimation of Background Phosphorus in the Lake

Before a full assessment can be made on the cultural influence of phosphorus input, it would be desirable to have some reasonable estimate of the general background phosphorus entering the lake if there were no human inhabitation of the basin. There are obvious limitations in attempting this, but we should be able to provide some order of magnitude that would be useful in interpretation. Vollenweider (1968) abandoned this approach, as natural as it is, because man's complex intervention in nature increasingly tends to obscure the boundary between natural and modified soil export. This reason for abandoning the approach is less valid in parts of North America than in Europe, where civilization has been in existence for more than a thousand years. The Champlain Valley has been open for settlement for less than 400 years.

In examining the phosphorus from soils, Vollenweider (1968) estimated oligotrophic soils to yield less than 0.02 g/P/yr, and more than 0.05 g/P/yr per square meter from polytrophic soils. The conservative value of 0.02 g applied to the Champlain basin would yield an annual loading of nearly 400,000 kg/yr. This estimate, based on data from "contaminated" soils is believed to be too high for natural loadings.

A team from Cornell University (Porter, 1975) attempted to measure the non-human background loading by measuring the concentrations of phosphorus (biogeochemical total dissolved phosphorus) in streams draining small watersheds that contained no homes or farms, and from wells distant from barns, houses etc. The mean value ranged from 12 and 24 μg/l, with the grand mean of 107 samples being 15 μg/l, and with a standard deviation of 0.9 μg/l.

Applying this mean value to the Champlain Valley, which is equal to 66 x 10^{-4} g/m^2 of land annually, we derive an estimate for background loading of 128,770 kg/yr or 0.1154 g/m^2/yr of lake surface (Table 20). Since the increasing amounts of phosphorus in precipitation were not considered in the Cornell data, this estimate determined for the lake should be considered maximal.

ESTIMATES OF TOTAL PHOSPHORUS LOADING BUDGETS

There are several methods by which the phosphorus loadings and budgets can be estimated, and these will be reviewed, applied, and compared in this section. Only two studies conducted thus far have attempted to measure the phosphorus loading into the lake. The Working Paper #154 (E.P.A., 1974), based on a 13-month sampling program, was the first. The materials input study of Henson and Potash (1976) reported on five years of sampling from 37 tributaries, but made no attempt to relate the results with the trophic levels of the lake. These two reports will be reviewed here before further analyses.

The EPA Report of 1974

An evaluation of the total Champlain phosphorus loading was made by (1) measuring monthly for 13 months the phosphorus concentrations near the mouths of 21 key tributaries to the lake, applying these data to the normalized flow of the streams, and calculating the loading; (2) analysing the populations being served in each stream by waste treatment facilities, and calculating the point-source loadings in each stream. By using a cut-off point of 25 miles from the lake where point sources were of reduced significance, they were able to estimate the relative amounts of point-source and non point-source phosphorus being introduced into the lake; (3) the point sources discharging directly into the lake were analysed and compiled; and (4) the unsampled smaller streams and diffuse drainage into the lake were estimated by using data from some of the sampled streams that were without point sources, and applying this rate to the unsampled areas. Contributions to the lake from the atmosphere were adapted from the literature.

The results of this study are summarized in Table 21 and show an annual loading of 598.14 metric tonnes of phosphorus, 90% derived from the tributaries, and about 50% of this leaving through the outlet.

TABLE 20. COMPARISON OF ESTIMATED PHOSPHORUS INPUT VALUES AS DERIVED BY SEVERAL METHODS FROM THE DISTRICTS.

District	Kg/yr of total phosphorus			
	I Background	II Population	III Measured	IV Vollenweider
A	19,420	90,680	86,920	92,950
B	1,090	21,250	22,560	26,860
C	14,720	52,560	41,130	21,800
D	21,800	210,680	137,480	98,350
E	140	1,170	810	-
F	19,750	91,960	133,740	-
H	500	5,720	4,330	49,530
J	6,130	31,780	52,690	248,440
K	20,200	123,350	127,930	119,380
L	4,430	6,650	20,090	-
M	1,500	10,630	18,470	-
S	19,090	54,780	63,620	85,570
EL	-	-	-	151,760
FM	-	-	-	9,160
Total	128,770	701,210	709,770	903,800

I Assuming background leaching amounts to 15 μg/l.
II Assuming a 1.6 kg/P per capita per year.
III From Henson and Potash, 1976.
IV Vollenweider, 1976.

TABLE 21. E.P.A.* ESTIMATES OF TOTAL PHOSPHORUS LOADING INTO LAKE CHAMPLAIN.

	kg/yr**	gms/m²/yr***	%
I. INPUTS			
1. Sampled tributaries	484,810	0.429	81.0
2. Minor tributaries and diffuse drainage	57,460	0.058	9.6
3. Municipal (8) STP directly into the lake	34,440	0.030	5.8
4. Industries directly into the lake	10,930	0.010	1.8
5. Precipitation into the lake	10,500	0.009	1.8
total input . . .	598,140	0.529	100.0
II. PHOSPHORUS LOST			
1. Through outlet	296,070	0.262	49.5
III. RETENTION	302,070	0.267	50.5

* E.P.A., 1974, Working Paper No. 154; (Table 13, pg. 44).
** Original was expressed in pounds/yr.
*** Over entire area of Lake Champlain.

The Henson-Potash Report (1976)

The strategy behind this investigation was to sample for total and reactive phosphates (and other parameters) for a five-year period (1970-1975) at stations located near the mouths of nearly 40 tributaries of the lake. The central tendency value used was the median, and this was applied for determining the loading for each stream. Stream discharge estimates were made by examining the mean annual discharge data for the stations in the Champlain Valley from the Water Supply Papers of the U. S. Geological Survey, and with cfs/sq. mile as the unit. From the plotted isopleths, a discharge index per unit area was derived for each of the Districts in the drainage basin. The weighted mean concentration for the District was used to estimate the diffuse input for each District. These diffuse inputs, which include the smaller unsampled streams in a District, were usually small when compared with each tributary considered as a point source.

It might be noted that the values for total phosphorus utilized in the present document are not identical to those presented in the original paper (Henson & Potash, 1976). Standard reagents were prepared throughout the 1970-1974 sampling season, and blanks were run for each series of analyses. New standards were recently made up to take care of the wide range of dilutions that were required, and this has slightly modified the scope of the standard curve. Applying this curve has downgraded some of the published values, expecially the very high values. The results of phosphorus loading into the lake according to this survey are offered in Table 20 with the raw data placed in Appendix D. With this account, 30.9% of the phosphorus is derived from New York, 10.4% from the South Lake, 38% from Vermont south of Malletts Bay, and 20.7% from the northeast sector. District F (Otter Creek) contributes 19% of the total input of 709,770 kg/yr, from the drainage basin.

Comparison of the Two Reports

The EPA total loading estimate of 598,140 kg/yr (Table 21) is somewhat low compared with the HP estimate of 709,770 kg/yr (Table 20). Some of this difference can be attributed to the fact that the HP study included a number of smaller tributaries with high phosphorus concentrations not sampled in the EPA study. The HP study extended for five years allowing for a better chance of collecting more of the higher values. EPA assessed the smaller non-point watersheds at a rate of 106 pounds P/sq. mi., while our data with the same streams were 72% higher. When the two sets of data from the same streams sampled during the overlapping year are compared, the magnitude of concentrations overlap (i.e., our lower values are within the range of the higher values of EPA) so the HP values tend to be higher, but there is no consistency in how much higher. For the present mission these differences are of little significance. The relative amounts are more important in the development of a nutrient control program. We will adopt here the data from the HP report, not because it is more accurate, but because there are more relative data available in it.

Loading Estimate by Basin Population

One frequently used method for estimating the amount of phosphorus entering a lake is to count the number of people living in the watershed and multiply by a factor determined by the mass of phosphorus generated by an average individual per unit time. The EPA (1974) used a factor of 3.5 pounds (1.587 kg) per capita per year. For treated waste this value was reduced to 2.5 pounds (1.1340 kg). These values were obtained from Bartsch (1972). Vollenweider (1968) estimated the per capita genesis of phosphorus to be between 1.5 and 1.7 kg/yr. Patalas (1972), Patalas and Salki (1973), and Stewart et al. (1974) each used 1.7 kg/C/yr because of the heavy agricultural influence.

The populations in the individual Districts (Table 4) were multiplied by a middle factor of 1.6 kg to derive a set of estimated phosphorus loading from each District (Table 20). The contribution by this method is 701.2 tonnes/yr.

Estimates by the Patalas Formula

Patalas (1972) and Patalas and Salki (1973) used an equation developed from Vollenweider's discussion (1968) on estimating phosphorus loading. This equation:

$$L_p = E_s \times \left[\frac{A_d}{A_o} + \frac{E_c \cdot C}{A_o} \right]$$

presents the loading in terms of grams of phosphorus per square meter of lake surface, and applies the factor E_s (the soil export), and the population contribution ($E_c C/A_o$). A_d is the area of the drainage basin, and A_o is the area of the lake. According to this model, the total loading is the summation of the edaphic plus the human factors.

Theoretically, the above model withstands logical analysis, but in practice, it tends to inflate the loading. Applying this model to the Champlain basin, we obtained loading values 2-3 times larger than any other estimate. The second factor in the equation, the human component, is the mass of phosphorus per person entering the lake, divided by the lake area. At the present time, the measure of the amount per capita entering a lake is a matter of subjective judgement. The above authors used a value of 1.7 kg/C/yr because of the high human influence, and used low to middle values for the soil export component. When we compared the loadings from this equation using the second factor alone, it was almost identical to the estimates based on population, as discussed above. In other words, the second factor in this equation presents a reasonable estimate of loading based on population. The first factor, the edaphic factor is already included in the second factor. When we consider that the water the population uses has the edaphic phosphorus in it, that P is looped in a recycling process and should be removed from the equation.

Estimates by the 1976 Vollenweider Model

In the latest publication, Vollenweider (1976) presents his equation 11, which is:

$$[L_c] = [P]_c^{sp} \times \bar{z} \left(\frac{1 + \sqrt{t_w}}{t_w} \right)$$

where the critical loading $[L_c]$ is equal to the specific concentration of phosphorus in the lake during spring overturn, multiplied by the mean depth ($\bar{z}$), and by a relation of the retention time (t_w). This is a non-linear model, and intends to show that the critical loading is a function of mean depth and retention time.

In this eutrophication model, $[P]_c^{sp}$ is given a value of 10 µg/l at the time of Spring overturn to separate oligotrophic from more enriched waters (mesotrophic). If we were to substitute into the equation the observed values of total phosphorus in the lake, we could then calculate for L rather than the specific, or critical loading.

The solution to this equation, solving for loading, and converting the values from $g/m^2/yr$ to read in terms of kg/yr, are tabulated in Table 20 yielding 904 tonnes/yr, a higher estimate than the others. A better set of data from the Regions of the lake during early Spring would probably refine this estimate. The Vollenweider equation requires precise values of phosphorus concentration levels.

EVALUATIONS OF THE DIFFERENT LOADING ESTIMATES

The results of these three methods for estimating the loading into Lake Champlain are compared in Table 20. For the lake as a whole, the estimates ranged between 701.2 to 903.8 tonnes/year, and averaged 771.60 tonnes. The range was within 17% of the mean. On the basis of this analysis, the HP Report is representative, and falls between the other values.

The three assessments presented in Table 20 were made according to three different approaches. The first evaluation is based completely on the population in the basin, and assumes that all of the phosphorus generated by that population will enter the lake. The second evaluation was based on a five-year measurement of the loading from a fairly large number of tributaries, and the third is based on an empirically derived mathematical model associating the most probable load with the actual concentration of phosphorus found in the lake. The first estimate used a fairly conservative value of 1.6 kg/capita. Using the value of 1.7 kg/c would raise the loading value to 745.03 tonnes. The Vollenweider equation demands precise values of the phosphorus concentrations at the time of spring overturn, and we do not have this information. According to the HP assessment, the actual per capita ratio is 1.620 kg/C/yr. Since the measured values presented in the HP Report are of intermediate value, and there is good regional representation, these values will be used in the further discussion.

OTHER SOURCES OF PHOSPHORUS

Atmospheric Input

The amount of phosphorus entering the lake surface from the atmosphere, either as dissolved in the precipitation, or as bulk fallout, is variable in space and time, and based on minimal data in the literature. In a discussion of this subject, Vollenweider (1968) summarizes that in Europe, atmospheric P amounts to between 0.02 and 0.05 $g/m^2/yr$. Wetzel (1976) says that the total amount from this source may amount to as much as 0.1 $g/m^2/yr$. Loehr (1974) reviewed the world literature on this subject and found that the yield ranged from 0.005 to 0.1 $g/m^2/yr$.

A recent study of atmospheric inputs in the upper Great Lakes gave a range of 0.01 to 0.04 g/m^2. The average value for southern Lake Huron was around 0.025 g/m^2. Stewart et al. 1974, using melted snow in central New York State as a basis for estimating annual loading found concentrations to range between 0.008 and 0.034 mg/l, the higher values being found near Buffalo, N. Y., and the average was 0.019 mg/l. Peuchert (1976) determined an average of 0.08 in East Germany. Aulenbach (1972) derived a figure of 23.85 kilograms per year for Lake George, equal to 0.009 g/m^2. For the purpose of this document, we have used an average of 0.018 $g/m^2/yr$.

Bird Populations

There is a certain amount of phosphorus exchange by way of the gull populations over the lake, but no data are really available that are applicable. Sanderson (1960) claims that domestic ducks contribute 0.4 kg/P/yr, while Paloumpis and Starrett (1960) estimate that wild ducks contribute about 0.53 g/m^2 to a lake in Illinois, but this could be a high value for a large lake. Peuchert (1976) suggested that the bird's net input to the ecosystem on the order of 3 - 24 kg/ha/yr (.03 - 2.4 g/m^2). It is possible that the P exchange is balanced; that what is removed from the lake as food about equals what is dropped in the lake later. Islands are known to accumulate guano, so the bird's role may be one of redistribution of the phosphorus, rather than input.

Municipal Waste Treatment Plants

There are seven municipal waste treatment plants that contribute an estimated 38,850 kg/P/yr directly into the lake, (EPA,1974) and another near Plattsburg is presently under construction. There is but a single industrial plant discharging directly into the lake (See Appendix E).

Discharges from Boats and Marinas

The potential problem from this source is not as great today as it was a few years ago before withholding tanks were required for boats on the lake. There are still some boats that move into the lake with overboard disposal systems. There may be local problems at marinas where boat owners wash down the vessels with detergents.

ORTHOPHOSPHATE LOADING DATA

A body of data does exist for loadings of reactive, or soluble phosphorus (Henson and Potash, 1976). All of the 37 tributaries sampled were transporting reactive phosphates to the lake, though a number of streams had concentrations from time to time below detectable limits. The median values ranged between 0.007 and 0.493 mg/l, with eight tributaties having median values exceeding 0.05 mg/l.

Examining the sets of data where total and reactive P were measured for the same sample, we find that the relative amounts of reactive P was small, ranging from 1.7% for Salmon River to 20.5% for Mill River. Since the first Vollenweider model (1968) utilized the reactive phosphate, these data have been analysed for the Districts to derive loading values for the reactive phosphorus (Table 22). These data were obtained by finding the average percent of the total that was reactive for each District (column 3) and multiplying this by the annual load of total phosphorus. This analysis suggests that about 10% of the phosphorus entering the lake is in the reactive form.

RESULTING ASSESSMENT OF THE PHOSPHORUS BUDGETS

We will now assemble the information available to derive a realistic picture of the distribution of phosphorus to and within the lake. Table 23 is an accounting of the phosphorus budgets. Almost 90% of the phosphorus entering the lake enters from the larger tributaries. About 20% of the 747.5 tonnes entering the lake leaves through the outlet at Rouses Point. There are some other losses of P, and these are mentioned in the table, but at present we do not have enough data for evaluation. The amount of phosphorus being retained in the lake concurs with values given in the literature (Patalas, 1972; Stewart & Markello, 1974).

Table 24 will become a working table, for it provides the data of Regional loadings that will be used with some of the models later. The point sources in column 4 are the municipal and industrial waste treatment plants. Districts D and F each contribute more than 18% of the total loading to the lake.

APPLICATION OF MODELS TO THE PHOSPHORUS DATA

The 1968 Vollenweider Model

In this model, the impact of phosphorus loads into a lake is a function of mean depth alone, and requires data for the loading of "total phosphorus (biochemically active)", and this is interpreted to mean the reactive phosphorus. According to this most of the regions are in the oligotrophic range, mainly because of the major influence of large mean depths. Region A is just at the dangerous level, but Missisquoi Bay does not exhibit the symptoms of trophy nearly as much as does Malletts Bay (Region C), which is below the permissible level. Region F receiving the heavy load from Otter Creek is near the dangerous level, and Region D (Burlington) is just below the permissible. In subsequent evaluations of the loading problems, Vollenweider has indicated that

TABLE 22. ESTIMATED LOADINGS OF REACTIVE (DISSOLVED) PHOSPHORUS TO LAKE CHAMPLAIN FROM THE DISTRICTS.

District	kg/yr Total P input from drainage	Avg. prop. as reactive	Loading of reactive P-kg/yr	gms/m^2	$\bar{z}$	Trophic* status
A	86,920	.0672	5,410	.0754	2.8	M/E
B	22,560	.1438	3,240	0.024	12.9	0
C	41,130	.1316	5,410	0.759	12.9	0+
D	110,460	.1544	17,000	0.1455	25.8	0/M
E	810	.1015	80	0.001	55.6	0
F	133,740	.1036	13,860	0.2846	24.5	M+
H	4,280	.1306	560	0.0021	16.6	0
J	50,240	.0958	4,810	0.042	8.2	0
K	127,930	.0797	10,200	0.130	64.5	0
L	20,090	.0454	910	0.014	55.6	0
M	15,640	.0652	1,020	0.021	24.5	0
S	63,620	.1015	6,460	0.011	2.7	0
Total	677,420	.1015	9,450	0.060	22.8	0

* Vollenweider's 1968 model. 0 = oligotrophic; m = mesotrophic; e = eutrophic.

TABLE 23. SUMMARIZED PHOSPHORUS BUDGETS OF LAKE CHAMPLAIN.

	kg/yr	%
I. INPUTS		
1. From measured tributaries	649,120	86.8*
2. From unmeasured drainage basin	28,310	3.8*
3. From WTP directly to lake	38,850	5.2
4. Atmospheric input	20,340	2.7
5. Industrial input	10,930	1.5
	747,570	100.0
II. PHOSPHORUS LOST:		
1. Through outlet	147,860	
2. Through fishing	?	
3. Sedimentation	?	
4. Biologic incorporation	?	
	147,860	19.8%
III. PHOSPHORUS RETAINED	599,690	80.2%

* Includes 128,763 kg/yr as "background" loading (Table 20), which makes up 17.2% of total input.

TABLE 24. VALUES FOR TOTAL PHOSPHORUS LOADINGS INTO THE HYDROGRAPHIC REGIONS OF LAKE CHAMPLAIN, FROM SURFACE RUN-OFF FROM THE DRAINAGE BASIN, FROM THE ATMOSPHERE, AND FROM POINT SOURCES THAT INCLUDE INDUSTRIAL OR MUNICIPAL DISCHARGE DIRECTLY INTO THE LAKE (FROM EPA REPORT NO. 154).

Region	Land drainage kg/yr	Precipitation kg/yr	Point sources kg/yr	Total kg/yr	%	gms/m²*	Theoretic* mg/l	Actual* mg/l
A	86,920	1,390	-	88,310	11.8	1.14	0.401	0.050
B	22,560	2,420	-	24,980	3.3	0.19	0.040	0.034
C	41,130	980	-	42,110	5.6	0.78	0.060	0.012
D	110,460	2,110	27,020	139,590	18.8	1.19	0.046	0.024
E	810	1,150	-	1,960	0.3	0.03	0.001	0.021
F	133,740	880	-	134,620	18.0	2.76	0.113	0.018
H	4,280	4,890	540	9,710	1.3	0.04	0.002	0.021
J	50,240	2,070	2,450	54,760	7.3	0.48	0.058	0.017
K	127,930	1,410	-	129,430	17.3	1.65	0.026	0.013
L	20,090	1,150	-	21,240	2.8	0.33	0.006	0.021
M	15,640	880	8,830	25,350	3.4	0.52	0.021	0.018
S	63,620	1,020	10,930	75,570	10.1	1.33	0.486	0.050
Totals:	677,420	20,350	49,770	747,540		0.66	0.029	

* Column 6 converts the total loading to grams phosphorus per square meter of lake surface in the Region, and the "theoretical concentration" is the concentration of the water in the Region if the total load were added to the volume of water in the region. Actual concentrations is based on sampling, data from several sources.

in lakes where the flushing rate is influential on the trophic impact, this first model is not very realistic. This notion applies to Lake Champlain.

The Mass Transport Model

The mass transport scheme was adopted earlier to evaluate the water budgets of the lake, and to trace the major water movements through the lake. The same scheme is applied now to the phosphorus budgets of the lake. In a comparable fashion, the phosphorus enters the headwater Regions A, C, and S. The actual phosphorus concentration in that Region (Table 24) and the flow leaving the Region (D_r of Table 2) were used to obtain a value for the phosphorus in the Region. The solution of this model is outlined in Table 25 and using this scheme, the phosphorus retention time is calculated for each Region, a value needed for later analyses. The model is displayed in Figure 6.

The 1976 Vollenweider Model

As was discussed earlier, this equation was developed after a considerable study of both the theoretical aspects of the subject, and by testing it on a vast array of empirical data from a large number of lakes throughout the world. The equation is here presented again:

$$L_c = [P]_c^{sp} \times \bar{z} \frac{1 + \sqrt{tw}}{t_w}$$

where L_c is the critical loading of a lake in g/m²/yr. The critical loading is that level where the lake can be oligotrophic, or defined as moderately eutrophic, or dangerously eutrophic. The value $[P]_c^{sp}$ is the critical concentration of total phosphorus at the time of spring overturn, and is expressed in units of µg/l or mg/m³. A value of 10 for the critical concentration is used to separate oligotrophy from mesotrophy. A value of 20 would be eutrophic, but when the critical concentration attains a value of 30, experience has shown these lakes to be "highly" eutrophic. The factor $\bar{z}$ is the mean depth (meters), and t_w is the retention time in years.

If lake standards of trophy are adopted, then the values of 10, 20, 30 etc. can be assigned to the critical concentration factor $[P]_c^{sp}$, and then the equation can be modified to read:

$$L_s = (10)\ q_s\ (1 + \sqrt{z/q_s})$$

where q_s is the hydraulic load = $\bar{z}/t_w$.

The critical loading has been determined using these relationships and these are presented in Table 26. The actual loading for each Region is given in the second column, and therefore the actual load, and the critical loading for any lake standard can be compared.

With this analysis, Regions A, B, F, and M, and S are experiencing

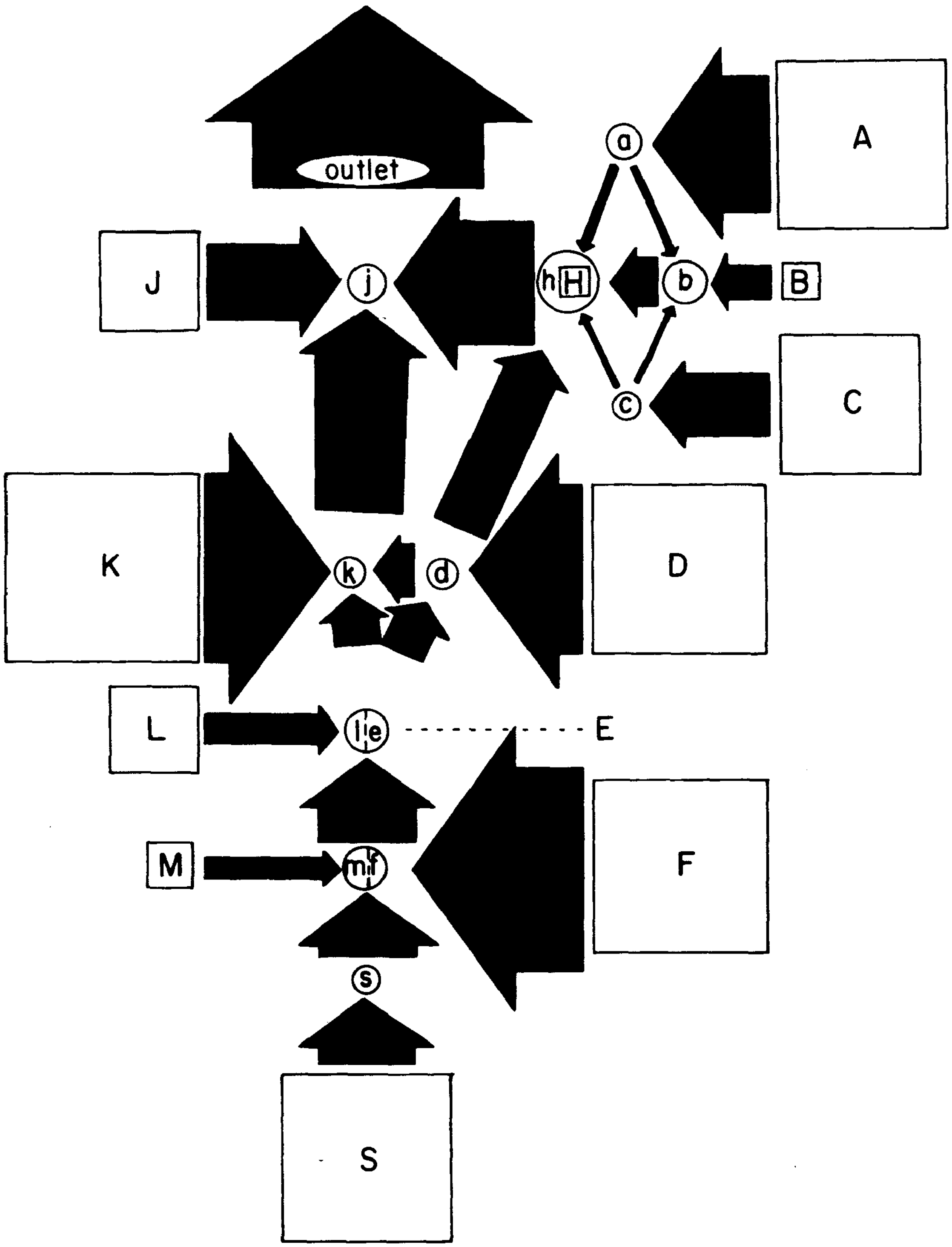


Figure 6. Schematic model of the net annual mass transport of phosphate-phosphorus in Lake Champlain. The width of the arrows depict the relative amounts of PO_4-P being transported annually.

TABLE 25. SOLUTION OF THE MODEL INDICATING INPUT AND MASS TRANSPORT OF TOTAL PHOSPHORUS INTO AND THROUGH THE REGIONS OF LAKE CHAMPLAIN*.

Region	District input	Gained by mass transport	Total input tonnes	Outflow	Amount retained	% retained	Mass of P in region
A	88.310	-	88.310	83.272	5.038	5.7	13.668
C	42.110	-	42.110	42.110	30.280	71.9	8.392
B	24.980	44.594	69.574	34.026	35.548	51.1	58.852
S	75.570	-	75.570	64.204	11.366	15.0	7.779
FM	159.970	64.204	224.174	48.943	175.231	78.2	42.983
EL	23.200	48.943	75.143	63.609	8.534	11.8	148.928
D	139.590	31.804	171.394	71.088	100.309	58.5	72.460
K	129.340	67.348	196.688	56.472	140.216	71.3	65.722
H	9.710	120.079	129.789	82.728	47.061	36.3	94.552
J	54.760	139.200	193.960	147.858	46.102	23.8	15.963
Lake Champlain	747.540	-	-	147.858	599.683	80.2	529.298

Total phosphorus in the cycle: Input: 747.55 t (52.5%); In lake: 529.30 t (37.2%); Outlet: 147.86 t (10.4%) = 1,424.71 t (100.0%).

* Values are in metric tonnes, total phosphorus per year. Input data in Column 1, total loading in the Districts is from Table 22.

TABLE 26. SUMMARY OF SPECIFIC CRITICAL LOADINGS* OF TOTAL PHOSPHORUS (L_c) FOR REGIONS OF LAKE CHAMPLAIN FOR SELECTED GIVEN VALUES OF THE CRITICAL CONCENTRATION OF TOTAL PHOSPHORUS $[P]_c^{sp}$ AT TIMES OF SPRING CIRCULATION (μg/l).

Region	Actual Areal loading g/m²/yr	Actual [P] μg/l	Areal loading in g/m²/yr needed to achieve indicated $[P]_c^{sp}$ values P_{10}	P_{20}	P_{30}	P_{40}
A	1.140	47.5	0.240	0.360	0.480	0.719
B	0.518	30.0	0.172	0.258	0.345	0.518
C	0.777	23.2	0.335	0.502	0.670	1.005
D	1.462	28.5	0.508	0.763	1.017	1.526
E	0.414	7.4	0.914	1.371	1.828	2.742
F	3.424	47.7	0.530	0.795	1.060	1.590
H	0.477	15.8	0.300	0.451	0.601	0.901
J	1.688	16.7	1.009	1.513	2.018	3.026
K	2.509	21.7	1.153	1.729	2.305	3.458
L	0.716	11.2	0.640	0.960	1.280	1.920
M	1.180	33.8	0.282	0.423	0.564	0.846
S	1.328	44.2	0.301	0.451	0.602	0.902
EL	0.615		0.601	0.901	1.202	1.803
FM	2.302		0.541	0.811	1.081	1.622
Lake	0.661	31.5	0.209	0.314	0.418	0.628

* After equation 11 of Vollenweider (1976).

extremely high levels of loading, and this applies to the lake as a whole. Only Regions H, J, and L would be considered to be in the mesotrophic zone. In Table 27 are outlined the necessary reductions of phosphorus from each Region in order to obtain a selected degree of trophic state. For example, Region A has a loading in excess of $P_c = 30$. The loading of 88.31 tonnes of phosphorus would have to be reduced 36.9%, or by 32.6 tonnes before the Missisquoi Bay would be just at the (P)30 level.

TABLE 27. NECESSARY REDUCTIONS OF PHOSPHORUS LOADING TO LAKE CHAMPLAIN AND ITS REGIONS WITH GOALS OF OBTAINING OLIGOTROPHY (P) 10, BELOW EUTROPHY (P) 20, OR BELOW DANGEROUS EUTROPHY (P) 30.

Region	Present loading Tonnes/year	$[P]_c^{sp}$ = 10	15	20	30
		Percent Reduction of Present Loading			
A	88.32	78.9	68.4	57.9	36.9
B	69.57	66.8	50.2	33.4	0.1
C	42.11	56.9	35.4	13.8	*
D	171.40	65.3	47.8	30.4	-
E	26.43	-	-	-	-
F	166.72	84.5	76.8	69.0	53.7
H	129.80	37.2	5.5	-	-
J	194.00	40.2	10.4	-	-
K	196.69	54.0	31.1	8.1	-
L	45.71	10.7	-	-	-
M	57.45	76.1	64.1	52.2	28.3
S	75.57	77.3	66.0	54.7	32.1
EL	72.14	**	-	-	-
FM	224.17	76.5	64.8	53.1	29.5
LAKE	747.55	68.4	52.5	36.8	5.0

* Dashes indicate present loading is below the standard.
** On borderline and within rounding error.

SECTION 7

SOURCES OF PHOSPHORUS IN THE DISTRICTS

GENERAL COMMENTS

District Individuality

There is much diversity in the source and means of introduction of phosphorus into the waterways that lead to the lake. There are differences in the sources of phosphorus loading from one subwatershed to another within a District, and there are also major differences in the manner that loading occurs between the Districts.

The following comparison of the Missisquoi District (A) with District D (Burlington-Winooski) is given as an example: District A is international and predominantly rural and agricultural. The phosphorus loading is scattered over a large area containing only two communities with populations of more than 2,000. There are more than 30 communities with populations of less than 1,000, and the total input from these sources amounts to about 18% of the total phosphorus entering the lake from District A.

District D is predominantly urban and suburban, and the prime agricultural land is sandwiched between the expanding urbanization of the lake-shore and the recreationally utilized high elevation terrain. As a result, about 80% of the loading is generated from point sources.

The same contrasts are to be found on the New York side of the lake where the phosphorus contributions from point sources are much higher from the urbanized District K (Plattsburg) than from the agricultural District J (Chazy).

It must be recognized that the problems of phosphorus loadings are not the same for all parts of the Champlain drainage basin, and that the ratio of point source to non-point source loading varies considerably. Any nutrient control policy should be addressed to generalized phosphorus reduction: as in the elimination of phosphorus in detergents, as well as nutrient elimination in selected waste treatment plants.

Loading Categories

In the following discussion a very brief description of the District is first presented followed by an itemization of the assessment of the loadings of total phosphate-phosphorus into the Region of the lake from all sources, including that entering the Region via mass transport from adjacent Regions.

This is the best evaluation of what is entering the lake that is available.

Following, there is a discussion of the inventory of point-source loading in the District as presented in full in Appendix E. Not all of the phosphorus that is introduced to the waterways in a District are actually transported into the lake. The relative amount of this transport loss is not known at the present time.

The analyses of the point source loading, presented in Appendix E and summarized in Table 28 are based on the following community categories: (a) communities with individualized means of waste disposal (e.g. septic tanks, leach fields etc.), (b) communities that are on a sewerage system, but without any treatment, (c) the communities that are served by primary treatment, and (d) that population served by secondary treatment. As outlined in the introduction to Appendix E, the base loading used is 1.6 kg of phosphate phosphorus per capita per year, and this base value is reduced by a certain amount according to treatment type and river distance from the lake.

DISTRICT EVALUATIONS

District A (Missisquoi)

The Missisquoi District (Fig. 7) has an area of 2,963 km^2 and has a population of 56,678. It is drained by the Missisquoi, Pike, and Rock Rivers in addition to a number of smaller streams. About two-thirds of the population are rural, or live in communities of less than 300 population. There are six urban areas with a population of more than 1,000. Swanton, Vermont, and Bedford, Quebec are the largest population centers, each with a population of slightly more than 2,600.

The distribution of phosphorus to the lake from the Missisquoi District is:

Missisquoi River	64,710 kg	73.3%
Pike River	14,280	16.2%
Rock River	6,390	7.2%
Charcoal Creek	310	0.3%
Diffuse (unmeasured)	1,230	1.4%
Precipitation	1,390	1.6%
Totals	88,310	100.0%

The total loading of phosphorus into the Missisquoi Bay is at the (P)47.5 level much above acceptable levels (Table 26). The present loading would have to be reduced by 36.9%, or by 32.6 metric tonnes to bring the loading down to the (P)30 level, and by 68% to reduce the loading to the (P)15 level (Table 27).

An inventory of the point source loadings to the waterways in District A is presented in Table 1 of Appendix E, and summarized in Table 28. The total point source loading amounts to 15,880 kg/yr; 39% of this total is derived from five secondary treatment facilities, and 34% from communities without

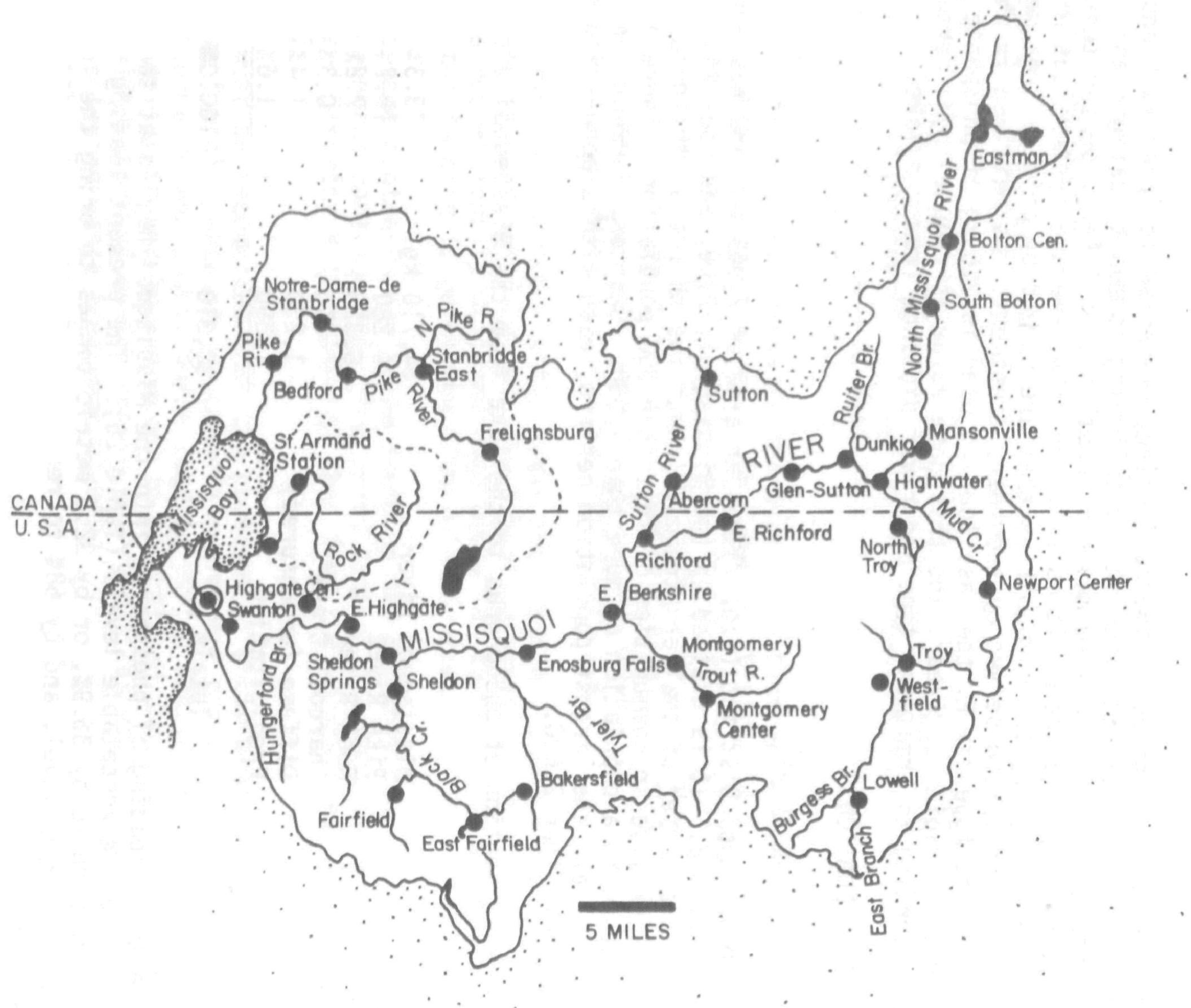


Figure 7. Drainage map of District A (Missisquoi) locating major streams and villages.

TABLE 28. SUMMARY OF THE POINT SOURCE LOADING OF TOTAL PHOSPHORUS AS PRESENTED IN THE TABLES OF APPENDIX E.

District	No. of points	Annual loading, in Kg., by class of disposal. a	b	c	d	Totals	% of total load from the district*
A	38	2,230	5,350	2,071	6,230	15,880	18.3
B	1	-	-	-	11,520	11,520	51.1
C	24	1,360	6,610	270	3,280	11,520	28.0
D	32	490	1,560	29,090	81,110	112,250	81.6
F	30	880	1,730	24,140	4,520	31,270	23.4
H	1	-	-	1,720	-	1,720	35.7
J	12	640	2,900	-	5,040	8,580	16.3
K	35	360	12,640	20,740	41,230	74,970	58.6
L	9	360	970	-	-	1,330	6.6
M	5	-	1,340	7,150	860	9,350	38.2
S	33	3,430	14,260	5,320	11,020	34,030	45.6
Totals:	221	9,750	47,360	90,500	164,810	312,420	
%		3.1	15.2	29.0	52.7	100	

* Column 1 plus column 3 of Table 24.

any waste treatment. The total point source loading is about 18% of the total loading into the lake, and this is consistent with the rural nature of the drainage basin.

District A is non-point source controlled since only 18% of the loading is derived from point sources. Point source control would, however, be effective in easing the extremely high loading presently being experienced. A detergent phosphate ban in the State of Vermont would eliminate approximately 5,500 kg/P/yr, and reduce the areal loading from the present 1.140 g/m^2 to 1.069 g/m^2 (Tables 26,29). Subsequent tertiary treatment from the two secondary plants on the Vermont side of the border would remove 90%, or 4,500 kg/yr. With the dual nutrient control measure, the total phosphorus reduction would amount to 10,000 kg, or 11.5% of the land drainage input. This would reduce the areal loading to 1.009 g/m^2 (Table 26) and reduce the trophic standard from (P)47.5 to (P)42.0. Additional reductions would have to be obtained from non-point source control.

District B (St. Albans-Northeast Region)

This small District is a special case because most of the loading enters the small and protected St. Albans Bay (Fig. 8). The morphometric values given in Table 1 relate to the entire area between Malletts Bay and the Missisquoi delta, and halfway between the islands and the main Vermont shoreline. The eutrophic conditions are much more severe in St. Albans Bay than indicated in the following discussion. Any alleviation of phosphorus loading would have its initial influence on the bay, and later in the open waters east of the islands, with the reservation that the phosphorus accumulation in the bottom sediments in the bay (Corliss and Hunt, 1973) would delay recovery.

The loadings into the Region are as follows:

*Stevens Brook	16,760 kg	24.1%
*Mill River	970	1.4%
Stone Bridge Brk.	1,120	1.6%
Trout Brook	350	0.5%
Diffuse	3,360	4.8%
Precipitation	2,420	3.5%
Transport from A	41,640	59.8%
Transport from C	2,960	4.3%
Totals	69,580 kg	100.0%

The asterisk indicates the loading directly into St. Albans Bay. Because of the morphometry, we can divide the Region into (1) St. Albans Bay receiving 17,740 kg/yr (25.8%) and the outer region extending from Sand Bar to Maquam Bay, with a much greater volume of water, receiving 75% of the load; mainly by mass transport from adjacent regions.

Recommended phosphorus reductions to the [P]20 level amount to 33.4%, or 23,240 kg. For the north end of the outer region in the vicinity of Maquam Bay, a reduction of about 12% of the load would proportionaly reduce the load

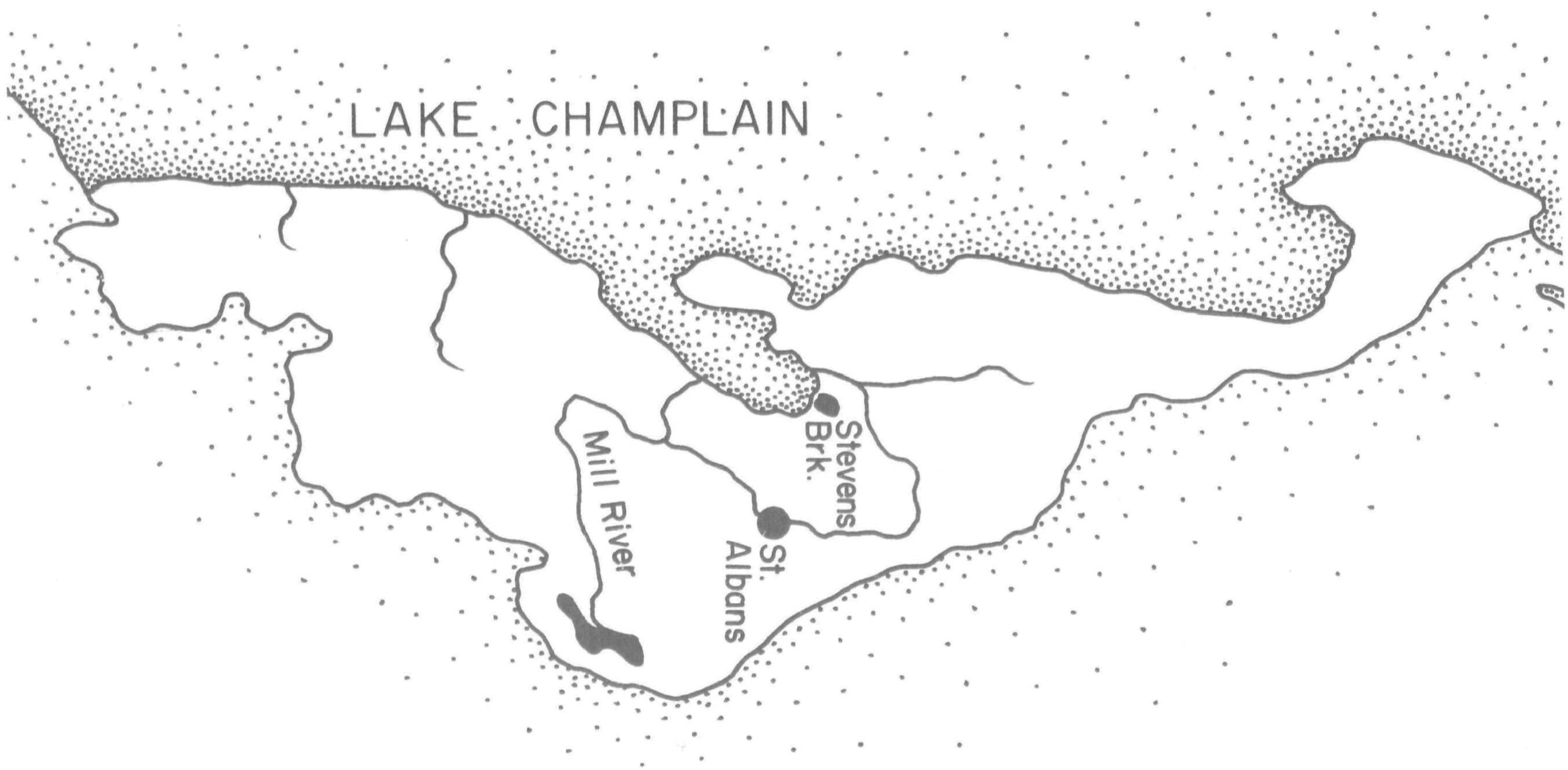


Figure 8. Drainage map of District B (St. Albans).

coming in from Region A, a reduction of approximately 5,000 kg. Control in the Missisquoi District would alleviate some of the problems in the northern regions of the islands and Maquam Bay. In the same manner some nutrient reduction in Malletts Bay would alleviate problems in the southern sector of Region B around Sand Bar.

The total population in District B is 13,280, and the largest point source is the St. Albans treatment plant contributing about 64,150 kg/yr, or 92% of the total. Much of this is lost in the wetland between the plant and the sampling station on Stevens Brook, where the input has been calculated to be 16,760 kg, or about a fourth of what is released from the treatment plant. Because of the unusual situation existing in the Stevens Brook area, calculations of possible phosphorus reductions are based on the output from Stevens Brook at the sampling station. A detergent phosphate ban would reduce this loading by 6,700 kg or 9.6% of the total loading to the lake, and in effect reduce the areal loading to 0.484 g/m^2 (Tables 26, 29). A 90% reduction of the remaining 10,060 kg by tertiary treatment would be 9,050 kg. Thus, by the dual control measures, 15,760 kg of phosphorus would be removed annually, or 22.6%, reducing the areal loading to 0.401 g/m^2, bringing the critical loading level below the [P]30 level (Table 26).

District C (Lamoille-Mallets Bay)

The Lamoille River drains 95% of District C (Figure 9). This river originates east of the Green Mountains and flows 84.9 miles to Malletts Bay. At Malletts Bay the channel divides into two arms, leaving a wetland island in the middle. The Lamoille delta houses a Federal and State wildlife refuge.

The total population in the District is estimated to be 32,853 (Table 4), with approximately 22,923 living in the Lamoille drainage. The remaining 9,930 persons live in the small region of Colchester and Milton along the lake north of Milton.

The total phosphorus loading into Region C is distributed as follows:

Lamoille River	37,810 kg	89.8%
Malletts Creek	1,540	3.6
Indian Brook	570	1.4
Allen Brook	510	1.2
Pond Brook	300	0.7
Diffuse	390	0.9
Precipitation	990	2.4
Totals:	42,110	100.0%

This amount of loading into Malletts Bay is presently below the [P]30 level (Table 26) but to reduce the loading to attain the [P]20 standard would require the reduction of 13.8%, or 5,810 kg. A total of 23,960 kg would have to be removed to attain the oligotrophic standard of [P]10.

The point source loading into District C (Table 2 of Appendix E, and Table 28) amounts to 11,520 kg/yr, or 28% of the total loading entering Malletts

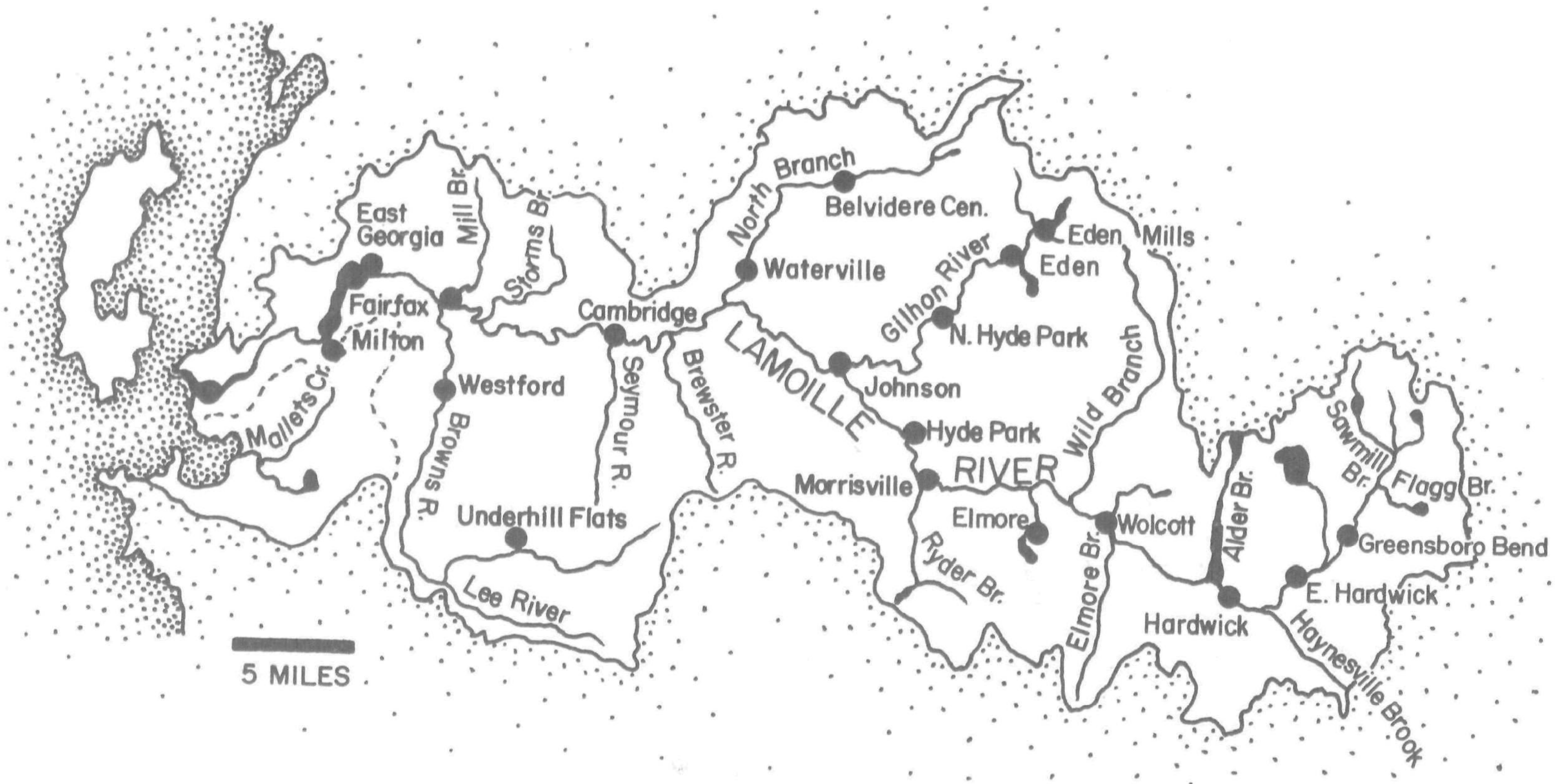


Figure 9. Drainage map of District C (Lamoille) locating major streams and villages.

Bay. More than half of this loading is derived from communities in category b, on a system without treatment. There must be a reduction of 13.8% (5,810 kg) to attain the [P]20 trophic condition, or a 68% reduction to reach the mesotrophic [P]15 level.

The elimination of phosphates in the detergents would remove 40% of the phosphorus loading from the point sources in categories b, c, and d, or 4,100 kg. This by itself is a reduction of 9.7% of the total loading to Malletts Bay, and would improve the trophic status of Malletts Bay from [P]23.2 (Table 26) to [P]21.1. Tertiary reduction of the remaining loading from the present primary and secondary facilities would remove an additional 1,900 kg. With this dual control, which would remove 6,000 kg/yr, the loading to the bay would be reduced by 14%, bringing the areal loading of 0.777 g/m^2 (Table 26) to 0.666, and bringing the loading below the critical [P]20 level. Construction of additional waste control facilities for those communities in category b should bring Malletts Bay to the moderately mesotrophic standard.

District D (Burlington-Winooski)

This District of 1,162 Sq. miles is drained predominantly by the Winooski River, but also by Potash Brook, Munroe Brook, and the LaPlatte River (Fig. 10). It includes the cities of Burlington, South Burlington, Winooski, Essex Junction, Montpelier, and Barre. It has more point sources of phosphorus loading per square mile than any other District. The population within the District is estimated to be 131,674, or 30% of the entire population in the Champlain basin. The population density is 113/sq. mi., ranking second in density to St. Albans (B).

The complete inventory of phosphorus to the Region is as follows:

Winooski River	99,730 kg/yr	58.2%
LaPlatte River	8,700	5.1
Munroe Brook	630	0.4
Potash Brook	740	0.4
Diffuse	660	0.4
Precipitation	2,110	1.2
Treatment plants	27,020	15.8
Mass transport	31,804	18.5
Totals:	171,390	100.0%

Because of the very large volume of water in Region D, and the fairly long retention time of 1.02 years (Table 3), this loading falls short of the critical [P]30 loading, but yet only 4.4% below this "dangerous" level. In other words, the loading is only 7,500 kg/yr short of reaching the critical level. With the projected population growth in the Burlington area (Fischer, 1976), this critical input may already have been matched.

To attain the [P]20 standard would require that the phosphorus loading be reduced 30.4%, or by 52,110 kg/yr.; and to reach the [P]10 standard of oligotrophy would require a reduction of 65.3%, or 111,930 kg/yr. With all of the

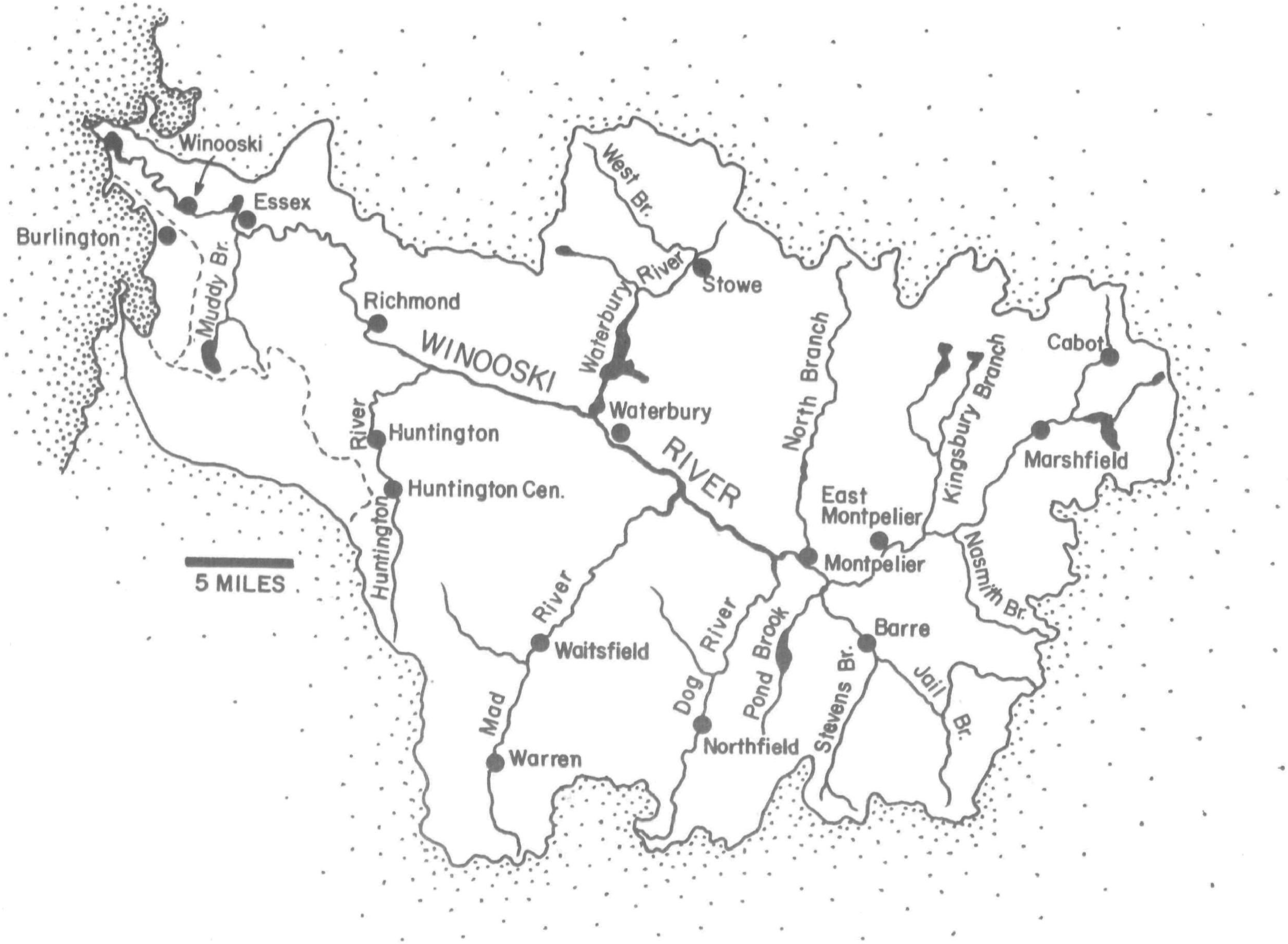


Figure 10. Drainage map of District D (Winooski) locating major streams and villages.

point sources in the District, this could be accomplished, since two-thirds of the input is derived from surface drainage, 16% from sewage treatment plants discharging directly into the lake, and 19% transported in from the more southern part of the lake.

The point source loadings within this District are given in Table 3 of Appendix E, and summarized in Table 28. The total introduction of effective phosphorus amounts to 112,240 kg, or 65% of the total input for Region D (80% of the tributary loading).

It should not be difficult to reduce the loading by a minimum of 50% to achieve a [P]15 standard. A detergent phosphate ban, reducing the major point source loadings by at least 40% would remove 44,700 kg, or 26.1% of the total loading. This by itself would improve the trophic loading status of the Burlington area of the lake from a [P]28.5 to [P]20.9. When the Vermont schedule for many of the existing waste treatment plants in District D to provide phosphorus elimination becomes effective in the early 1980's, there will be anticipated an observed improvement in the conditions of the lake, by the removal of an additional 59,500 kg.

District E (Charlotte)

This is a small segment of land between the two larger Districts of Vermont and is inhabited by less than 800 people. The land consists mainly of woodlands, orchards, and estates. Holmes Brook is the only real channel draining the District, and it was dry during most of the collecting time so that inadequate data are available to assess loadings. This District is considered completely as non-point source of phosphorus.

District F (Otter Creek)

Otter Creek, flowing for more than 100 miles and the largest river of the basin is the dominant drainage in this District (Fig. 11). Lewis and Little Otter Creeks also share in the drainage. This District contributes about 20% of the entire basin loading of phosphorus, and the distribution of loading is as follows:

Otter Creek	113,730 kg	68.2%
Little Otter Creek	10,810	6.5
Lewis Creek	5,780	3.5
Thorpe Brook	740	0.4
Hospital Clerk	510	0.3
Diffuse	2,170	1.3
Precipitation	880	0.5
Mass Transport	32,102	19.3
Totals	166,720	100.0%

Most of the input is derived from Otter Creek, and transported in from the South end lake. The total loading of phosphorus into this District very much exceeds the Vollenweider [P]30 standard, and it would require a reduction of 53.7% (87.5 tonnes) of phosphorus to approach that standard. It would

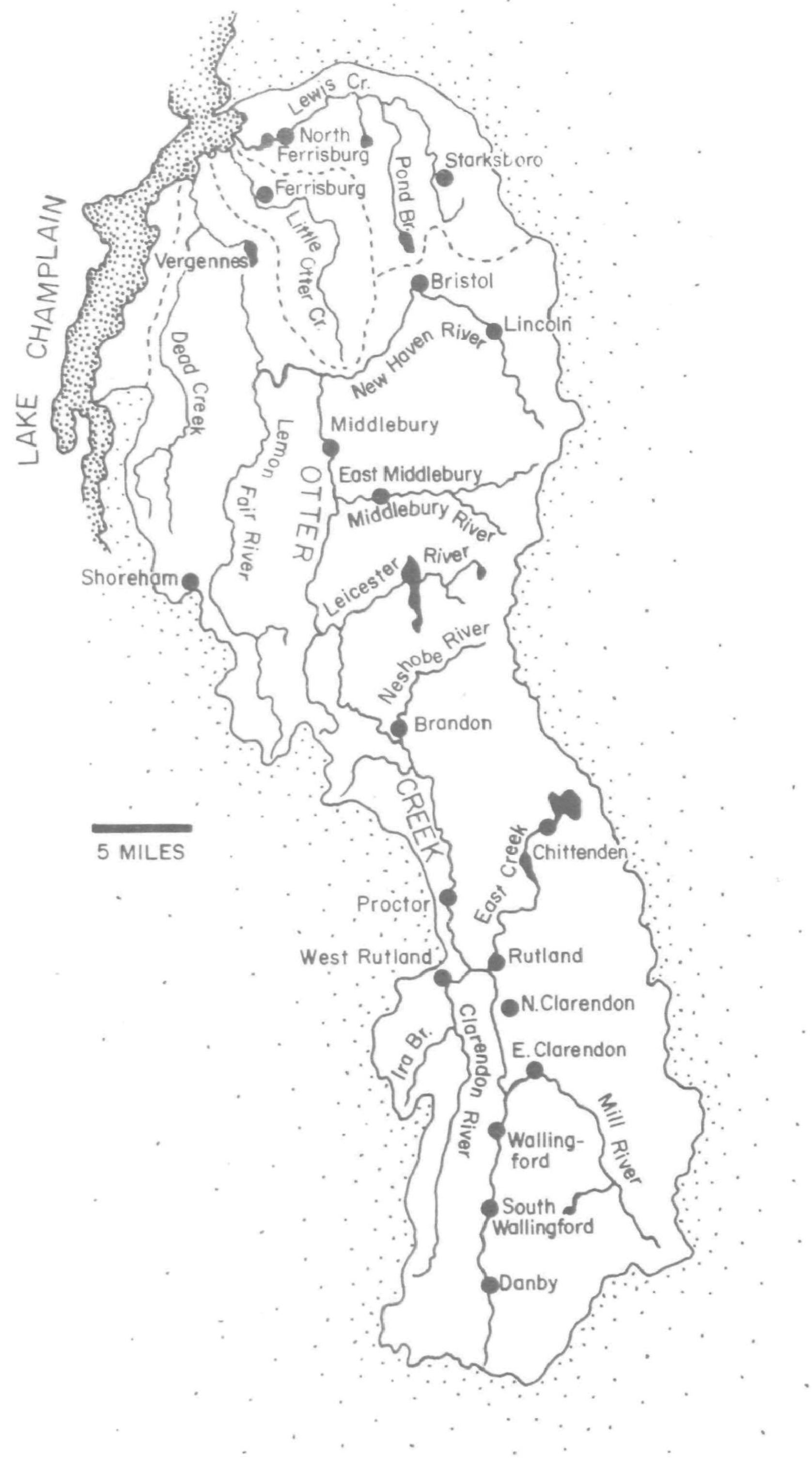


Figure 11. Drainage map of District F (Otter Creek) locating major streams and villages.

require a reduction of 76.8% to obtain the [P]15 level (Table 27).

Any reduction in phosphorus input in Region F will relieve some of the pressure in the Burlington area that receives 18% of its loading from mass transport from the Otter Creek Region.

The inventory of point source loading from the lower 85 miles of Otter Creek is given in Table 4 of Appendix E, and summarized in Table 28. The total point sources amount to 31,270 kg/yr, 23% of the watershed loading into the lake from this District. Primary treatment plants contribute 77% of this loading and 14% from secondary facilities.

A detergent phosphate ban would reduce this loading by 12,200 kg/yr, providing a 7.3% reduction in total loading into this Region of the lake, and a 9% reduction of the loading from District F watershed input. The detergent phosphate ban would reduce the trophic status of Region F waters from a value of [P]47.7 to [P]44.2.

Superimposing tertiary treatment for the present primary and secondary facilities would remove an additional 15,500 kg, and the combined effect would be a removal of 27,700 kg, or 16.7% of the total loading. This would reduce the critical loading level to approximately [P]39.8, a major improvement, though much above the eutrophic level of [P]20.

District S (South End Lake)

The morphometric structure of District S, a very large and complicated drainage basin accomodating a long, narrow, and shallow basin, has been considered as another tributary to the lake (Henson and Potash, 1976). The total District phosphorus input has been calculated to be 75,570 kg/yr (Table 25).

This District can be divided into three sub-basins: (1) The Poultney River drainage (Fig. 12) which forms part of the border between New York and Vermont, (2) the Metawee River Drainage (Fig. 13) that is included in both States, and also includes part of the Hudson-Champlain Canal, and (3), the Lake George and western shore of the South End Lake (Fig. 14). Lake George constitutes a sink for phosphorus entering from the Lake George Basin, and that loading will not be included in this discussion; and towns along the northern part of the lake are excluded.

The South End Lake is in a eutrophic status, and the phosphorus loading to this basin exceeds the [P]30 level (Table 26). Phosphorus loadings must be reduced by 32.1% (24,260 kg) to attain the [P]30 level, 54.7% to reach the [P]20 level (41,340 kg) and 77.3% (58,420 kg) to reduce the loading to the oligotrophic standard.

Table 5 of Appendix E lists point sources for an estimated 34,030 kg of annual load from the three sub-basins, or about 45% of the total loading. About 13,270 kg (39%) of this is derived from Vermont sources. A detergent phosphate ban would reduce this by 5,300 kg/yr, or 7.0% of the total loading, reducing the critical loading value from the present 1.328 g/m^2 to a value of

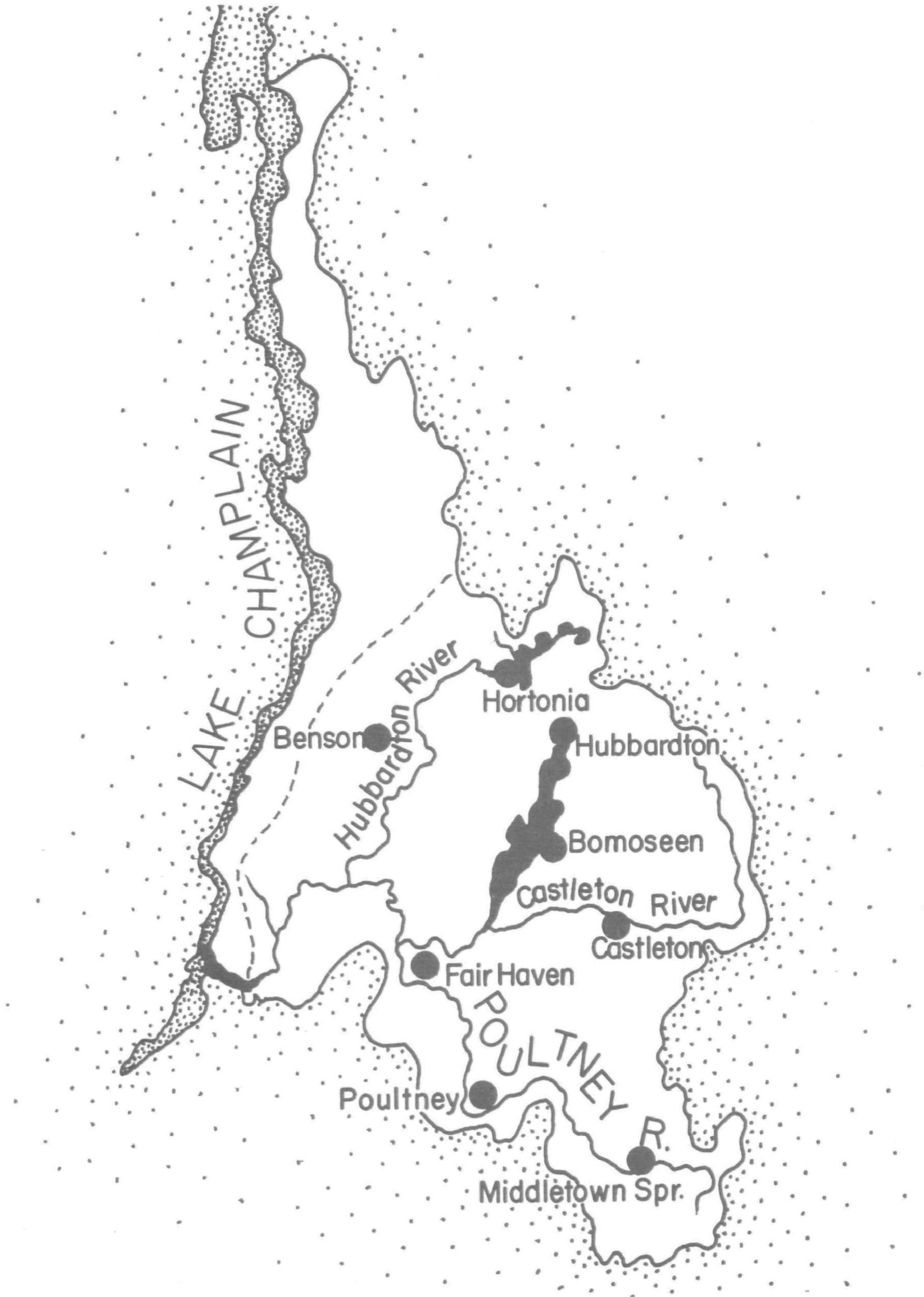
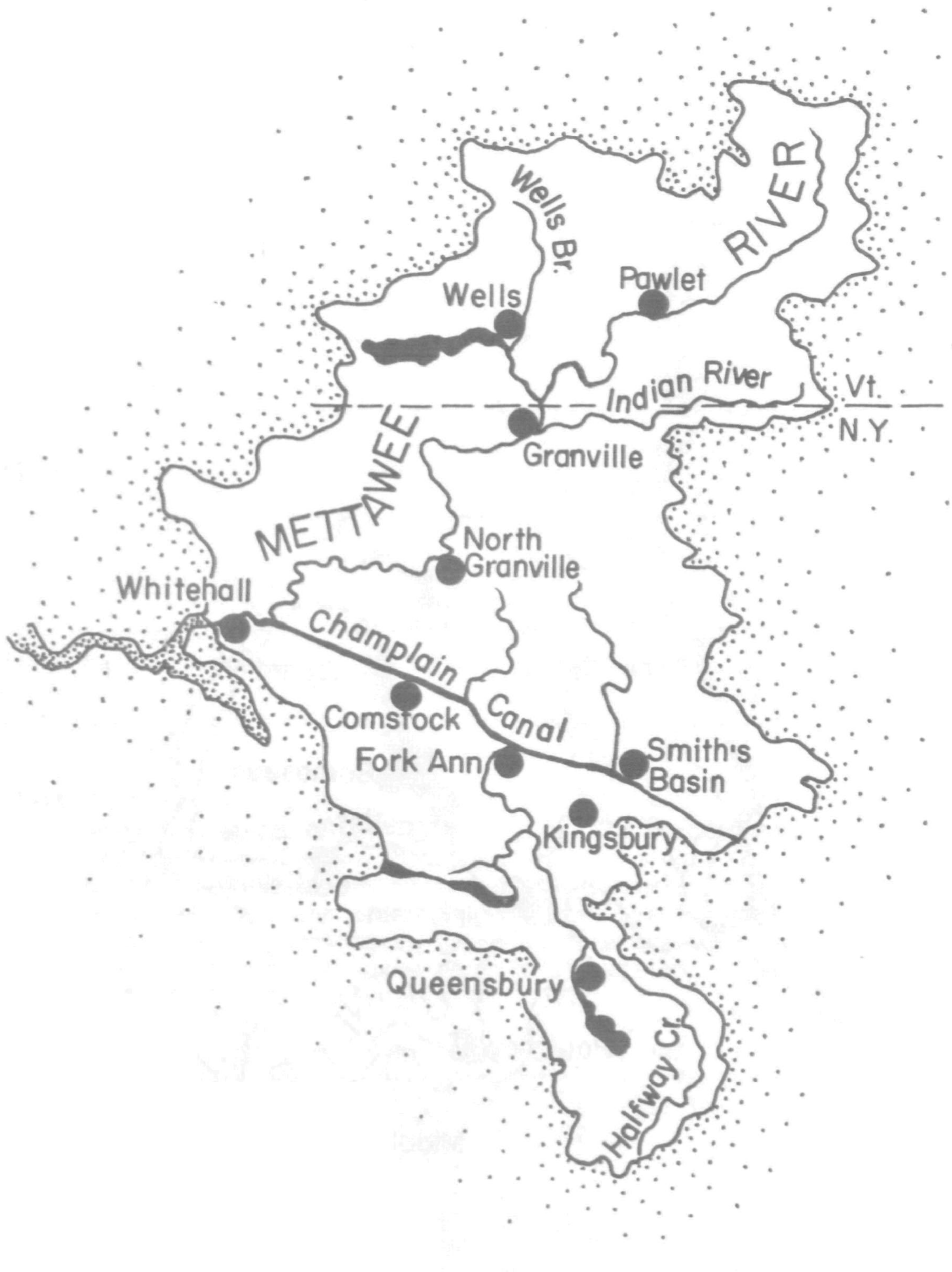


Figure 12. Drainage map of the Poultney River sub-drainage basin of District S.



District 13. Drainage map of Metawee River sub-drainage basin of District S.

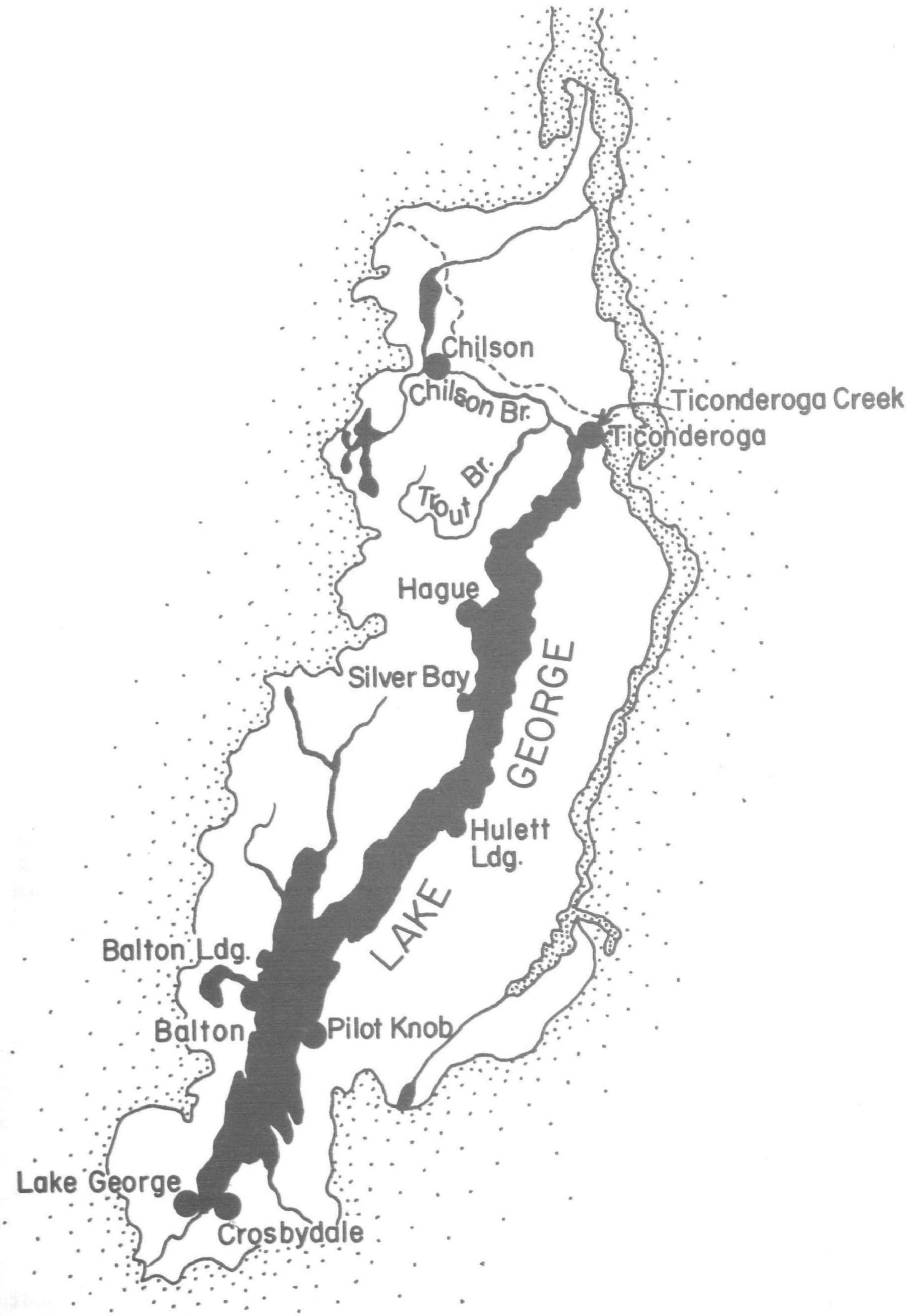


Figure 14. Drainage map of the Lake George sub-drainage basin of District S.

1.234, but still above the [P]30 value. After a detergent ban, the remaining 11,930 kg from category (c) and (d) point sources in New York and Vermont could be reduced by 10,700 kg through tertiary treatment. The combined reduction would amount to 16,000 kg or 21.2% of the total load, reducing the critical loading values from the present 1.328 g/m^2 to 1.047 still above the [P]30 level, but improved.

The above analysis does not consider the potential reduction of the 10,927 kg/yr loading from an industrial plant discharging directly into the South End Lake (EPA, 1974).

District M (Port Henry)

This small District (Figure 15) in the southwest corner of the basin, with a population of 6,645, contributes about 3% of the total phosphorus to the lake. The loading to the Region is distributed as follows:

Hammond Brook	1,210 kg	2.1%
Stacy Brook	730	1.3
Beaver Brook	930	1.6
Mullen Brook	120	0.2
Mill Brook	6,360	11.1
Diffuse	6,280	10.9
WT Plants	8,840	15.4
Precipitation	880	1.5
Mass transport	32,100	55.9
Totals:	57,450 kg	100.0%

According to Table 27, this loading must be reduced by 76% for oligotrophy, and 28.3% (16,260 kg) for the [P]30 level.

The two Moriah Sanitary District primary treatment plants generate about 2,850 kg/yr, so the total point source loading amounts to 9,350 kg. A 90% (tertiary) reduction (7,200 kg) would represent about 12.5% of the loading. Since two-thirds of the loading in Region M is derived from the South End Lake, reduction there would ease the situation near Fort Henry.

District L (Bouquet)

The Bouquet District is drained by the Bouquet River (Figure 16). The distribution of the phosphorus loading into the Region is:

Bouquet River	19,430 kg	42.5%
Diffuse	660	1.5
Precipitation	1,150	2.5
Mass Transport	24,470	53.5
Totals:	45,710 kg	100.0%

The population of slightly in excess of 4,000 is scattered in about a dozen small communities. Elizabethtown, with a population of 607, is one of

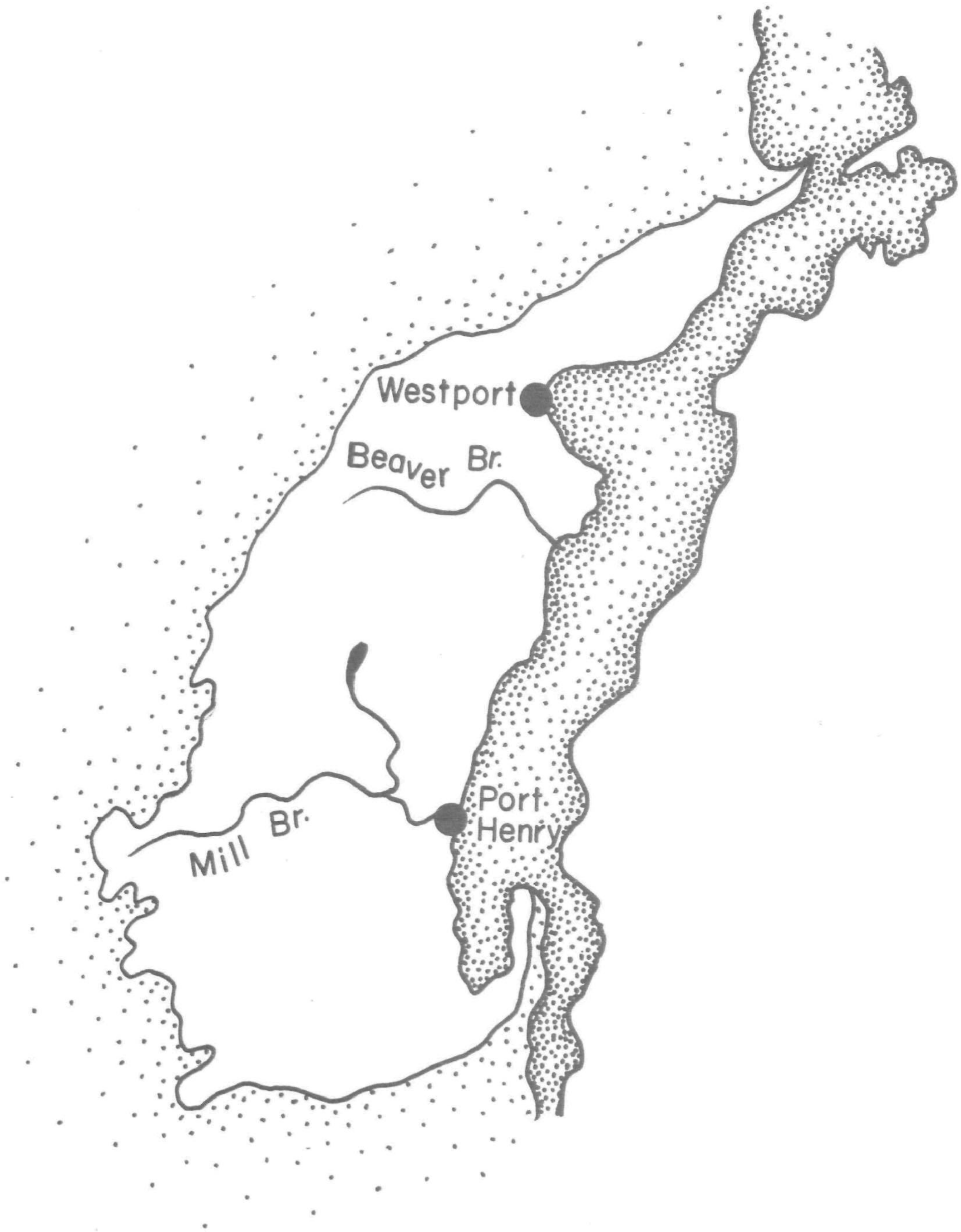


Figure 15. Drainage map of District M (Port Henry).

Figure 16. Drainage map of District L (Bouquet).

the larger villages. If the other eight communities along the Bouquet River had populations of 300, the total contribution of phosphorus, at 1.5 kg/C/yr, would be about 4,500 kg/yr. The potential point source loading is relatively small.

Because of the large volume of water of Region L and the fairly high retention time, the loading into this part of the lake falls below the [P]30 standard, and is about 11% above the [P]10 level. A reduction of 4,890 kg/yr would reduce the loading to the oligotrophic status. Phosphorus control among the nine communities could account for about 4,400 kg, and reduction in District M and S would contribute to a reduction through mass transport input.

<u>District K (Saranac-Ausable)</u>

This is the largest District with an area of 3,548 km^2, comprises 18% of the Champlain drainage (Figure 17). It includes a total population of 77,094, also representing 18% of the basin's total population. The total phosphorus input to this Region is as follows:

Saranac River	68,920 kg	35.0%
Ausable River	33,810	17.2
Little Ausable R.	13,780	7.0
Scomotion Creek	4,200	2.1
Salmon River	3,840	2.0
Silver Stream	630	0.3
Diffuse	2,740	1.4
Precipitation	1,410	0.7
Mass Transport: D	35,550	18.1
Mass Transport: EL	31,810	16.2
Totals:	196,690	100.0%

This loading of nearly 200 tonnes of phosphorus is more than a quarter (26%) of the total loading into the lake. Region K has a very large volume of water; therefore the impact of phosphorus input is not severe except in local and shoreward areas. Because of this morphometric situation the critical loading is below the [P]30 level. There must be a 54% reduction in the phosphorus loading to approach the oligotrophic standard, and the loading would have to be reduced 8.1% to attain the mesotrophic standards. This necessitates a reduction of 15,930 to 106,210 kg/yr to maintain good quality standards in this part of the lake.

About a third of the phosphorus entering Region K is derived from the mass transport from Regions D and EL. Even though phosphorus reduction measures taken in Districts upstream would alleviate some of the "tension" in Region K, much more than half of the phosphorus is derived from its own drainage basin. The phosphorus entering the Region through mass transport has less impact because it is more dilute than the amount discharging into the lake, where sedimentation and biological uptake is more likely to take place.

Figure 17. Drainage map of District K (Ausable-Saranac).

Table 7 in Appendix E, and Table 28 summarize the known major point sources of phosphorus in the District, excluding those that are discharging directly into the lake. The total yield amounts to 75.0 tonnes per year or 38.1% of the total input. A tertiary program for the communities providing 90% removal would account for a reduction of 55,800 kg (28.4%), a significant reduction. Nutrient control in upstream Districts would allow reduction from mass transport input.

District H (Islands)

The main point source in this District is the Town of Alburg (population 1,279), presently on a primary system, with scheduled tertiary in the planning stage. Total load is estimated to be 1,716 kg. Local control of marinas and small communities along the waterfront should help to alleviate problems in the coves and bays. Nutrient reduction elsewhere, *e.g.* Missisquoi Bay, will reduce the amount of phosphorus entering by mass transport, and will help alleviate present and potential problems. A detergent phosphate ban would remove 686 kg of phosphorus, with scheduled tertiary capable and removing an additional 927 kg leaves this source as very minor.

District J (Chazy-Rouses Point)

District J is the northwestern corner of the basin (1,030 km^2) just above the outlet at Rouses Point. It is drained by the Great Chazy and Little Chazy Rivers, and the small Riley Brook (Figure 18). The total population in the District is 19,861, 4% of the Champlain basin. The total loading from the District, as listed below, amounts to 52.7 tonnes, 7% of the Champlain loading. This is equivalent to 2.65 kg per capita, the highest per capita loading from any District in the basin.

The loading is as follows:

Great Chazy River	35,990	18.5%
Little Chazy River	6,320	3.3
Diffuse	7,930	4.1
Precipitation	2,070	1.1
Rouses Pt. WTP	2,450	1.3
Mass transport, H	82,730	42.6
Mass transport, K	56,470	29.1
Totals	193,960	100.0%

Because of the shallow depth and low retention time of Region J, the present loading is below the [P]20 level (Table 26). To attain the [P]10 level would require a reduction of 40.2%, or 77.970 kg.

Table 28 summarizes the inventory of point source loadings given in Table 6 of Appendix E. Secondary plants generate 5,040 kg of the total of 8,590 kg. Tertiary treatment from these secondary plants would remove 4,500 kg., 8.6% of the load draining from the District.

Because Region J serves to transport waters received from all other parts

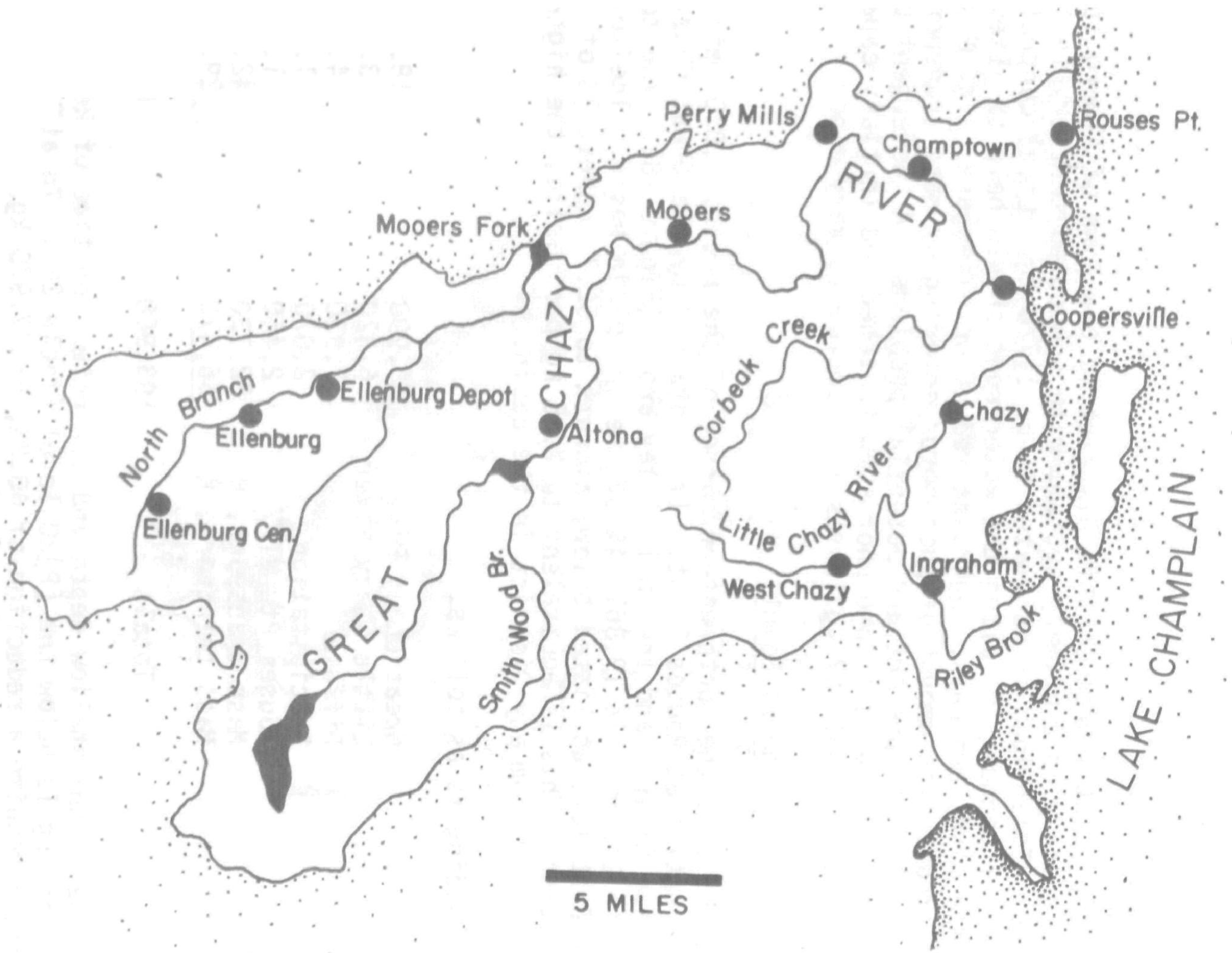


Figure 18. Drainage map of District J (Chazy).

of the lake to the outlet at Rouses Point, and there is a rapid flow-through time, the impact of the heavy loading is minimized. Nearly three-fourths of the loading to the Region is from mass transport. Phosphorus leaving the lake here through the outlet becomes the loading to the Richeleau River, and this, in turn, eventually, contributes to the loading of the Atlantic ocean.

SUMMARY

In this section an assessment has been made of the total amount of phosphorus entering each region of the lake from the adjacent District, and by mass transport from adjacent Regions. An inventory of point source loadings within each District (Appendix E) has been applied to estimate effects of the proposed detergent phosphate ban in Vermont, and to assess the amounts of phosphorus reduction that would take place if present primary and secondary waste treatment plants were to add nutrient removal controls.

These matters are summarized in Table 29. It should be noted that the data given in this table are conservative figures since (1) the reduction through banning detergent phosphates was based on a 40% removal rather than the commonly used value of 50%, and (2) the stated reductions of loading into the lake do not consider the secondary effect of the reduced amounts of phosphorus being transported from Region to Region.

For the whole of Lake Champlain, about 42% of the total loading of 747.6 tonnes is derived from point sources, but this ratio ranges from 6% to 81%. The dual nutrient control program would remove 249 tonnes of phosphorus, or 33% of the total loading. The revised regional loadings given in column 8 of Table 29 should be compared with the information given in Table 26. The revised trophic [P] standard for the whole of Lake Champlain would be reduced from the present [P]31.5 to [P]21.0. Those four Districts (A, F, M, and S) with still excessively high loading values should be given special attention in order to reduce the significant influence of non-point sources.

TABLE 29. SUMMARY OF THE POTENTIAL EFFECT OF NUTRIENT CONTROL POLICIES ON THE REDUCTION OF PHOSPHORUS ON THE REGIONS OF LAKE CHAMPLAIN.

District	Load[a] Tonnes yr	Point[b] Sources tonnes/yr	%	loss by[c] P-ban tonnes/yr	loss by[d] tertiary tonnes/yr	Total P removed tonnes/yr	Revised[d] load g/m^2	Revised [P]
A	86.92	15.88	18.3	5.5	4.5	10.0	1.009	42.0
B	22.56	11.52	51.1	6.7	9.1	15.8	0.401	23.2
C	41.13	11.52	28.0	4.1	1.9	6.0	0.666	19.9
D	137.48	112.25	81.6	44.7	59.5	104.2	0.573	11.2
F	133,74	31.27	23.4	12.2	15.5	27.7	2.855	39.8
H	4.82	1.72	35.7	0.7	0.9	1.6	0.471	15.6
J	59.69	8.58	16.3	-	4.5	4.5	1.649	16.3
K	127.93	74.97	58.6	-	55.8	55.8	1.797	15.6
L	20.09	1.33	6.6	-	0	0	0.716	11.2
M	24.47	9.35	38.2	-	7.2	7.2	1.032	29.6
S	74.55	34.03	45.6	5.3	10.7	16.0	1.047	34.8
Lake	747.55	312.42	41.8	79.2	169.6	248.8	0.440	21.0

a: Annual load derived from District drainage in metric tonnes.
b: Loading from point sources in the District, from Table 28.
c: Assumes 40% phosphorus reduction from sewered populations by the proposed Vermont detergent phosphate ban.
d: Assumes tertiary treatment provided only by those plants which now have primary or secondary treatment.

SECTION 8

SUMMARY OF LAKE-DRAINAGE BASIN INTERACTIONS

MISSISQUOI BAY

The in-lake concentration and theoretical total phosphorus value (0.50 and 0.40 mg/l respectively) for Missisquoi Bay are some of the highest values recorded for Lake Champlain and are within the eutrophic range. However, because of the shallow depth of the bay and the well mixed water column, many eutrophic characteristics do not occur. The impact of the high phosphorus loading is apparently not manifested in significant increases in productivity since only a small amount of the phosphorus that enters the region is retained (5-6%) while the majority of it (94-95%) is flushed out very rapidly. The total water volume of the bay is renewed approximately six times per year with the bulk of the flushing occurring during the spring runoff.

At the present time, more data are needed to determine the fate and impact upon the Missisquoi Bay region of the 5-6% of the incoming phosphorus that is retained within the basin. Part of this loading is indoubtedly going into some production, which may be reflected in the important yellow perch (Perca flavescens) fishery in the bay. Creel census information, for example, indicate that over one million perch are caught each winter by ice fisherman in the area (Countemesh, per. comm.). The Vermont Water Resources Department has determined that the silt load entering from the Missisquoi and Pike Rivers has a significant influence upon the bay. A total input of 10.7×10^3 tons/year results in an average accumulation rate of sediment of 1.0 mm/year. It is not known, however, what percentage of the loading is from natural or man-made sources.

It has not been established whether the total phosphorus loading entering via the Missisquoi River and Pike River actually reaches the surface waters of the bay. Both tributaries pass through an extensive wetland area (Missisquoi National Wildlife Refuge) and some of the phosphorus may be lost to the wetland vegetation and/or sediment. Also, there are no input data available from Venice en Quebec, Quebec. It is suspected that phosphorus loading may be quite high in this region due to the numerous shoreline cottages and high summer population.

The discharge of significant amounts of phosphorus-rich Missisquoi Bay water would have a significant effect on other areas of Lake Champlain. The data on current patterns in the region suggest that the Missisquoi discharge splits at the northern tip of North Hero Island, with part of the load entering the Maquam Bay and North Hero Island region and part moving south through the Alburg Passage into the main lake east of Isle La Motte. Thus, it is anticipated that eutrophication problems may occur in these areas. In recent years, for example, the Vermont Water Resources Department has received an increasing number of complaints about algal blooms in the extreme northern portion of the northeast arm near Maquam Bay.

Recommendations for Missisquoi Bay

Although the input of phosphorus should be reduced, nutrient loading apparently has minimal influence upon the observable trophic characteristics in Missisquoi Bay; however, if the phosphorus loading into the bay were reduced, it is believed that the potential eutrophication problems in other areas of the lake (Maquam Bay, North Hero Island area, and Isle La Motte region) would also be reduced. In order to lower the phosphorus levels in Missisquoi Bay (Region A) to the levels of the immediate adjacent area (Region B), there would have to be a 74% reduction in the total phosphorus loading. The present loading level of 1.139 gms/m^2 would have to be reduced to 0.30 gms/m^2 in order for this to be accomplished. In order to reach P_{10}, P_{20}, or P_{30} levels within Missisquoi Bay, the phosphorus loading into the bay would have to be reduced by 78.9%, 57.9% and 36.9%, respectively.

It is important to have a better understanding of the point and non-point phosphorus sources from the Pike River, Rock River, and the community of Venice en Quebec. This lack of data from these areas is a result, in part, of jurisdictional problems related to the international boundary with Quebec, Canada. For example, the State of Vermont only examines that portion of the Pike River that flows through Vermont and ignores the Canadian sections of the river in their management plans. It is essential that the total drainage basin of Missisquoi Bay, a large portion of which is located in Canada, be included in the United States Environmental Protection Agency's management plans for Lake Champlain. The Vermont Water Resources Department indicates that there has been cooperation between the two nations on water resources issues, however, it appears that a better data exchange is necessary.

In order to more fully quantify the total phosphorus loading impact on Missisquoi Bay, it may be necessary to investigate the amount of phosphorus that may be lost to the wetland from the Missisquoi and Pike Rivers and the fate of phosphorus retained with the basin.

NORTHEAST ARM

The theoretical value (.040 mg/l) and the mean in-lake concentration (.020 mg/l) of total phosphorus in the entire northeast area are quite low because of the large volume of the region and the major loading entering the region occurs in St. Albans Bay, which tends to retain it. A total of 25.0 metric tons/year of phosphorus is entering the northeast arm from drainage basin (B) and 44.6 metric tons/year from regions (A) and (C). Of this total, approximately 24% (16.8 metric tons/year) is entering St. Albans Bay via Stevens Brook. In relation to its volume, the rest of the northeast arm receives relatively little phosphorus input from other drainage basin sources.

The deeper open waters are considered mesotrophic, while the majority of the embayment areas are typical shallow, mildly eutrophic situations. The Vermont Water Resources Department carefully controls development and sewage disposal in the shoreline areas, thus the only threats to these regions are the loadings from Missisquoi Bay and St. Albans Bay. St. Albans Bay presently has extensive eutrophic characteristics which include abundant submergent aquatic weed growth and some bluegreen algal blooms.

Recommendations for the Northeast Arm

The principle recommendation for this region is to reduce the phosphorus loading into St. Albans Bay entering via Stevens Brook. The major point source along Stevens Brook is the City of St. Albans Sewage Treatment Facility, although there may be some non-point loading from farmlands in low laying areas near the brook. Since algal productivity in St. Albans Bay and other regions of the northeast arm is known to be phosphorus limited, a reduction in the phosphorus input is essential to relieve the present and future eutrophication problems. The phosphorus concentration for the entire northeast arm is presently very close to the P_{30} level. In order to reach P_{10} or P_{20} levels, the loading into the entire region would have to be reduced by 59.9% and 13.8%, respectively. However, because of the specific hydrologic situation of St. Albans Bay, and extremely poor estimates of retention time of the water in the Bay, we can offer no quantitative values for suggested phosphorus reduction other than striving for a 100% reduction in culturally derived input.

The sediments within St. Albans Bay contain extremely high concentrations of phosphorus (mean = 983 p.p.m.). It is important that the transport exchange between the sediments and the water column under different phosphorus concentrations by understood. The probability is small that there will be a significant increase in phosphorus flux from the sediments to the water column upon reduction of the phosphorus loading. Oxygen depletion near the bottom has not been recorded, thus conditions for the release of soluble phosphorus are poor. If there were a prolonged period of calm weather in the summer, the bay may stratify for short periods, and a significant oxygen depletion would be expected. Under such circumstances, a short-term phosphorus release from the sediments may be realized.

Approximately 51% of the phosphorus input into the northeast arm is retained with the basin. A major portion of this phosphorus load is apparently retained in St. Albans Bay, by being incorporated into the submergent aquatic vegetation and the sediments. However, it is important that the fate of this input within the northeast arm be determined to completely understand the impact of the total region.

Reduction in the phosphorus loading from Missisquoi Bay would aid in reducing the potential eutrophication problems of the northeast arm, especially in the northern portions of the area.

MALLETTS BAY

Malletts Bay presents an interesting conflict among the low in-lake phosphorus concentration (mean = .012 mg/l), the relatively high calculated theoretical phosphorus level (.060 mg/l), and the high retention of phosphorus in the region. Approximately 42 metric tons/year of phosphorus enters Malletts Bay, with approximately 92% of this loading (37.8 metric tons/year) entering through the La Moille River. However, even though the calculated retention of phosphorus is very high (about 72%), it is not reflected in the surface water concentrations, which are the lowest found in Lake Champlain. As a result, most of the surface water characteristics for Mallets Bay are oligo-mesotrophic.

At present, there is little understanding of the fate of phosphorus once it enters the bay. Since the La Moille River flows through an extensive marsh area (Sandbar Wildlife Management Area), some of the phosphorus may be lost to the aquatic vegetation and/or the sediments of the wetland. Or perhaps the phosphorus is being lost to the sediments of the deeper portions of the basin and not recycled to the water column. This pathway for phosphorus is somewhat difficult to accept since the hypolimnial waters in Malletts Bay suffer from almost complete oxygen depletion during the stratified period. As a result, conditions in the lower waters and at the sediment/water interface are conducive to formation of soluble phosphorus as indicated by rapid increases in soluble reactive phosphorus concentrations in the lower waters during stratification.

Recommendations for Malletts Bay

There is a need to understand the fate of the phosphorus entering via the La Moille River in order to assess the future potential impact of loading upon the bay region. According to the present figures, the phosphorus loading is below the P_{30} level. In order to accomplish P_{10} or P_{20} levels, the loading into the bay would have to be reduced by 56.9% and 13.8%, respectively.

It is important to understand the mechanisms responsible for the severe hypolimnial oxygen deficit in the summer. This should include a determination of the total BOD loading from the La Moille River and its transport and fate within the bay. It may also be necessary to investigate the total contribution of BOD to the hypolimnion of the aquatic weed beds in the shallow areas of the bay.

Once the fate of the phosphorus and BOD loading in Malletts Bay is determined, then a management strategy involving these two parameters can be initiated.

SOUTH LAKE

The total phosphorus input into the south lake is approximately 75.6 metric tons/year while about 64.2 metric tons/year leave the area. The major point source is the International Paper Company at Ticonderoga, New York, which contributes approximately 10.9 metric tons/year* (about 14.4% of the

* May be a low estimate (U.S.E.P.A., 1974).

total phosphorus loading). Even though there are high inputs into the region and the in-lake and calculated theoretical phosphorus values are extremely high (.050 and .486 mg/l, respectively), the development of severe eutrophication problems in the south lake are not expected. This is mainly due to the high natural turbidity of the waters which limits the development of extensive algal blooms and submergent aquatic weed beds. The only exception may be the potential for the floating aquatic weeds, Trapa natans and Nymphoides peltatum to expand significantly in the nutrient rich waters. In addition to turbidity, the lack of thermal stratification and the rapid flow through of water in the south lake also limit the development of some eutrophic characteristics.

Since the south lake has such a rapid flushing rate (approximately 8.25 times/year) and the phosphorus retention coefficient is low (about 15%), there could be a significant loading influence upon the southern basin of the main lake north of Crown Point, New York. The extent of any influence is not well understood however. There is the possibility that when the flow rates through the south lake slow down in the broad main lake, absorptive phosphorus is carried to the sediments with the settling clay particles. It appears that this process may be occurring in regions (F & M), as indicated by the low in-lake phosphorus value (mean = .018 mg/l) and the very high retention coefficient (78%) between Crown Point, New York and Split Rock Point.

The BOD loading from pulp and paper manufacturing is apparently becoming an increasingly significant problem in the south lake. The impact is mainly upon benthic invertebrate populations, which in turn, will eventually affect fish populations. The present major contributor of high BOD loading in the region is the International Paper Company plant in Ticonderoga, New York.

Recommendations for South Lake

At the present time, it appears that any reduction in the phosphorus loading would have little effect upon reducing eutrophication in the south lake. However, it should be confirmed whether the high phosphorus loading from the south lake has a significant impact upon portions of the main lake. It is logical to assume that the 64 metric tons/year of phosphorus entering the south basin of the main lake will eventually have some impact. This is expecially true since it is known that the majority of the phosphorus is retained within the region. Therefore all efforts should be made to keep phosphorus loading levels from the south lake as low as possible. In order to reduce phosphorus loading in the south lake to P_{10}, P_{20}, or P_{30} levels, it must be reduced by 77.3%, 54.7%, and 32.1%, respectively.

The long term effects of the present BOD loading from point sources should be investigated. Some evidence indicates that the problem is expanding. This should be continuously monitered in order to possibly readjust current loading levels.

MAIN LAKE (SOUTHERN, MAIN, AND NORTHERN BASINS)

The southern basin of the main lake (Districts F & M) receives 160 metric tons/year phosphorus loading from the drainage basin (the largest contribution being from Otter Creek) and 64 metric tons/year via mass transport from the south lake. Approximately 78% of the input (175 metric tons/year) is retained within the southern basin, resulting in the highest retention coefficient for the lake. The theoretical total phosphorus concentration (.094 mg/l) is quite high when compared to the in-lake value (mean = .018 mg/l), suggesting a significant loss of phosphorus from the water column. As mentioned in the previous section, it is proposed that much of the phosphorus is moving to the sediment in this region.

The peripheral regions of the main basin are receiving most of the impact from phosphorus loading in the main lake. Deep open water areas and some embayments have oligo-mesotrophic conditions, while those bay and shoreline areas near population centers are showing signs of increased eutrophication.

The volume of the main basin appears to be large enough to accommodate the present loading, although 60-70% of the incoming phosphorus is being retained. A potential eutrophication problem still exists however, and it must be established how much of the entering phosphorus is being biologically assimilated by the system and how much is being lost to the sediments. There is some evidence that productivity, even in the deep open areas of the main basin, is accelerating.

Major inputs of phosphorus from sewage treatment facilities and local tributaries into Shelburne Bay, Burlington Bay, and Cumberland Bay are having significant local impact. Cumberland Bay, although it receives high phosphorus loading from two sewage facilities, is probably not affected as greatly, because mass water movement to the open lake prevents retention of phosphorus in the region. Burlington Bay is more confined than Cumberland Bay, but has significant northerly and southerly mass water flow which reduces somewhat the retention of phosphorus. However, phosphorus impact has been evident along the east shore of the lake, especially along the south shore of Colchester Point, Vermont, where there have been reports of high Cladophora sp. and aquatic weed growth. Shelburne Bay is the most confined of these bay areas and is showing signs of rapidly accelerating eutrophication. The extreme inner bay is especially affected by phosphorus loading, exhibiting dense weed beds, bluegreen algal blooms, and growth of Cladophora sp. on the shoreline.

The northern basin of the main lake receives water from all other areas of the lake. The phosphorus retention in the region is quite low (approximately 24%) and it is probably a result of the shallow nature of the area and the strong currents flowing toward the outlet. There are extensive weed beds throughout the area especially at major input sites such as the mouth of the Great Chazy River in Kings Bay, east of Isle La Motte, and from Point Au Fer north to Rouses Point, New York. At present, there is no quantitative evidence as to an expansion of these weed bed areas.

Recommendations for the Main Lake

Reduction of phosphorus loading from sewage treatment facilities and local tributaries into Cumberland Bay, Burlington Bay, and Shelburne Bay will help alleviate growing eutrophication problems in these regions. Also, since the entire main lake, including the embayment areas, is phosphorus limited, reduced loading would help alleviate increasing productivity in the deeper portions of the lake. It is recommended that phosphorus loading be reduced by the following percentages in the various drainage areas, in order to accomplish P_{10}, P_{20}, or P_{30} levels:

Drainage Area	P_{10}	P_{20}	P_{30}
D	65.3	30.4	below
E	below	below	below
F	84.5	69.0	53.7
H	37.2	below	below
J	40.2	below	below
K	54.0	8.1	below
L	10.7	below	below
M	76.1	52.2	28.3

It is necessary to understand the fate of phosphorus in the main basin of the lake in order to determine the significance of the high retention of phosphorus in the region.

It is necessary to understand the fate of phosphorus entering the southern basin of the main lake from the south lake, so that the impact of south lake water on this region can be determined. There is also a need for an assessment of the amount of phosphorus being retained by the wetlands in the Otter Creek area.

Throughout the main and northern basins of the lake, there are a large number of private and some municipal water intake sites. Since it is important to retain high water quality in these areas, a careful monitoring of water conditions should be maintained in the region.

SECTION 9

CURRENT RESEARCH AND MANAGEMENT PROGRAMS RELATED TO EUTROPHICATION OF LAKE CHAMPLAIN

VERMONT ENVIRONMENTAL CONSERVATION AGENCY, MONTPELIER, VERMONT*

1. Vermont is presently completing an 18 month study on St. Albans Bay and Shelburne Bay (including the LaPlatte River system). Basic objectives were to determine point and non-point loading sources into the bays and to characterize the limnological conditions of the receiving waters. Completion date is December, 1976.

2. A National Water Quality Surveillence System station on Missisquoi Bay is monitored once monthly and is maintained and operated by the Vermont Department Water Resources (Carl Pagel).

3. Water quality monitoring stations are maintained on six major Vermont tributaries to Lake Champlain; Poultney R., Otter Creek, Lamoille R., LaPlatte R., Winooski R., and Missisquoi R. Each station is sampled six times/year (Carl Pagel).

4. The following monographic studies on the benthic invertebrates of Lake Champlain are in various stages of completion:

   (a) Profundal benthos of Lake Champlain (C. Pagel)
   (b) Sphaeriidae (Mollusca) of Lake Champlain (C. Pagel & J. Pagel)
   (c) Chironomiidae of Lake Champlain (C. Pagel)
   (d) Oligochaetes of Lake Champlain (C. Wade)

5. A number of water quality surveillence stations are maintained in the south lake region. Four stations are sampled four times/year for chemical and biological characteristics (Doug Burnham).

6. Cold Water Fisheries Program - Ecological studies on the forage fish populations are being conducted. Stocking and monitoring of Atlantic Salmon, Steelhead Trout, and Lake Trout populations are also being conducted (Jon Anderson & Jim Stuart).

* Additional studies are listed under the International Joint Commission.

UNIVERSITY OF VERMONT, BURLINGTON, VERMONT*

1. Limnological studies on Missisquoi Bay (1965-1974) have been completed and the data are in manuscript form (E. B. Henson and Milton Potash, Department of Zoology).

2. Studies on the distribution of zooplankton populations in various basins of Lake Champlain are in progress (Jeffrey Kantor, Department of Zoology).

3. Studies on the distribution and biology of the deep water crustacean *Mysis relicta* are near completion (Thomas Gutowski, Department of Zoology).

4. Studies on the feasibility of commercial fishing on Lake Champlain are in progress (George W. LaBar, Department of Natural Resources).

5. Rates of protease activity in waters of different trophic conditions (J. Little).

6. LANDSAT studies of agricultural systems in New England (crop specific) (A. O. Lind).

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, ALBANY, NEW YORK*

1. New York is presently maintaining two water quality surveillence stations at Rouses Point and Crown Point, New York (Ronald Maylath).

2. Monitoring stations are maintained on the following New York tributaries: Saranac (at Treadwell Mills), Ausable (at Keeseville), Bouquet (at Willsboro), and Ticonderoga Ck. (at Ticonderoga). Twenth-five water quality parameters are measured monthly for nine months of the year (Ronald Maylath).

3. The effluent from the International Paper Company Plant in Ticonderoga, New York is monitored on a continuous basis.

4. Cold Water Fisheries Program - Ecological studies on the forage fish and smelt populations are being conducted. Stocking and monitoring of Atlantic Salmon, Steelhead Trout, and Lake Trout populations are also being conducted (Douglas Sheppard, Daniel Plosila, and Walter Kretser).

5. New York Wetlands Mapping Program - Cover type mapping of the major New York State wetlands on Lake Champlain is being completed (Eric Fried).

STATE UNIVERSITY OF NEW YORK, PLATTSBURGH, NEW YORK*

1. Studies on the vertical and horizontal water movements (currents, seiche activity, etc.) in various basins in the lake are in progress. Mathematical models of these phenomena are being developed (Glenn Myer, Department of Earth Sciences and Physics).

* Additional studies are listed under the International Joint Commission.

2. Studies on the seasonal and spatial dynamics of phytoplankton populations throughout the lake are in manuscript form (Gerhard K. Gruendling, Department of Biological Sciences).

INTERNATIONAL JOINT COMMISSION

The following studies are being supervised, in part, by the I.J.C. in relation to the environmental impact of water level regulation of Lake Champlain. Most of these studies will be completed in July, 1977.

1. Fisheries Studies (New York Department of Environmental Conservation and Vermont Conservation Agency).

2. Wildlife and Waterfowl Studies (New York Department of Environmental Conservation and Vermont Conservation Agency).

3. Wetlands Mapping and Ecology of Wetland Plant Associations (Donald J. Bogucki and Gerhard K. Gruendling, State University of New York, Plattsburgh, N. Y.).

4. Contour Mapping of Shoreline and Wetland Areas (Chicago Aerial Surveys Inc., Chicago, Illinois).

5. Studies on nutrients in Malletts Creek wetland (E. B. Henson, Department of Zoology, University of Vermont, Burlington, Vermont, and John Turk, U. S. Geological Survey, Albany, N. Y.).

6. Assessment of Impact on Aquatic Plants (William Countryman, Aquatec, South Burlington, Vermont).

NEW ENGLAND RIVER BASINS COMMISSION, BOSTON, MASSACHUSETTS

1. Presently phasing into a "Level B Study" which would develop strategies for addressing some of the issues of water quality of Lake Champlain. Study would plan for future development in the area as well as identify alternative projects and uses of water and related land uses.

2. "Lake Champlain Planning Guide for Water and Related Land Resources" which was published in June, 1976, provides additional information about management programs and research plans of various local, state, and federal agencies for Lake Champlain.

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SECTION 11

APPENDIX

LIST OF APPENDICES

APPENDIX A

CONVERSION FACTORS USED IN THIS MANUSCRIPT

A.	Time:	1 year	= 31.5569×10^6 seconds
			= 365.25 days
B.	Length:	1 mile	= 1.60935 Km
			= 1,609.35 m
		1 meter	=
		1 Km	= 0.62137 mile
C.	Area:	1 Acre	= 4,046.873 m^2
		1 Sq. mile	= 2.589998 Km^2
			= 2.589998×10^6 m^2
		1 sq. Km	= 0.3861 sq. mi.
			= 1×10^6 m^2
D.	Volume:	1 cu. ft.	= 0.02831701 m^3
		1 m^3	= 1000 1
			= 35.31445 cu. ft.
		1 gal.	= 0.0037854 m^3
E.	Weight	1 pound	= 0.4535924 kg
			= 453.5924 g
		1 kg	= 2.2046 pounds
			= 1000 grams
		1 mg	= 0.001 g
			= 1000 μg
			= 1×10^{-6} kg
		1 μg	= 0.001 mg
F.	Miscl:	PO_4-P	= 0.32614 PO_4
		1 cfs	= 0.028317 m^3/sec
			= 31.5569×10^6 c.f. yr.
		1 cfs/sq. mi.	= 0.0109332 m^3/km^2
		1 gal/day	= 1.3826 m^3/yr
		1 μg/1	= 1 mg/m^3

APPENDIX B

METHOD FOR ESTIMATING THE CHAMPLAIN BASIN POPULATION, 1810-1970

In the introductory section of the text, Figure 2 graphically presents the estimated loading of phosphorus into Lake Champlain from 1810 to 1970, a 160 year history. We are interested in presenting some historical perspective to the phosphorus loadings, and this has not been done before. We must speculate on the best information at hand. To construct this graph, we have attempted to evaluate the population in the Champlain Valley during the past 160 years, and plot the probable phosphate loading.

The Census

The first problem is the evaluation of the present population in the basin. The method for estimating the contemporary basin population was as follows: With the 1970 Census report, the population of all of the towns completely within the drainage basin were totaled. This left these towns along the outer boundaries to be appraised. The Vermont Water Resources Department, as background information for their "Water Quality and Pollution Control" series, examined topographic maps, counted houses, etc., and estimated the number of persons of each town in or out of a drainage basin. These percentages were used to asses the 1970 population in the basin. On the New York side, where such information was not available, we examined the maps, and determined which village was or was not in the drainage. The population outside the drainage was then subtracted from the town census. Canada presented a problem in that the census reports consulted were incomplete, but a best estimate was made.

The final population estimate for the basin was 438,255. This figure evolved about a week or so before Fischer (1976) came out with the "Lake Champlain Basin Planning Guide", and we were pleased to note that the two independent population evaluations were within 2%.

For the 1970 census, therefore, the estimated total population in the entire Champlain basin is 438,255, or 98.63% of the total State of Vermont population of 444,330 (U.S. Census).

To evaluate the population in the Champlain basin for the past years it was deemed impossible to apply the same technique for the 160 years, so short-cut estimates were needed. Knowing that in 1970, the population in the Champlain basin was 98.63% of the Vermont State population, this ratio was applied to the previous years, resulting in estimated population data that were obviously incorrect. In other words, population growth in the Champlain basin did not parallel growth in the State of Vermont.

As a second approach, we had available in the files some data from Soper (1905) (who presented census data from 1810-1900) for 11 of the 16 towns of New York bordering the lake, and 6 of the 22 Towns and Cities bordering the lake in Vermont. With this sampling of 45% of the bordering towns on the lake, we have in Appendix B, Table 1 estimated the population in the basin for the last 160 years. To make this estimate, we first noted that the population of the sampled towns bordering Lake Champlain was 27.67% of the Champlain basin population, which was 98.63% of the Vermont State population. Instead of tying the basin population to the Vermont State population, it was tied to the bordering town population, on the assumption that the town populations would more effectively reflect the populations in the entire basin. We therefore estimated the basin population by multiplying the border town population by 1/.27665 = 0.361468.

To estimate phosphorus loadings from these populations, we have used a conservative estimate of 1.6 kg/C/yr. For advanced societies, the value of 1.7 kg/C/yr has been suggested. We have no real evaluation for early society. Our estimates are calculated on the basis of 1.6 kg/C/yr., a figure that is conservative in modern times, but liberal for the early years.

APPENDIX B (Cont.)

Table 1. Estimations of the population in the Lake Champlain basin, and estimates of the total phosphorus loadings into the lake for the years 1810 - 1970.

Year	Population in selected lakeside towns N. Y.[a]	Vt.[b]	Totals	Total Vt. Pop.	% Vt. Pop. lakeside	Estimated basin population	Phosphorus load kg/yr.
1810			24,002	217,895	11.02	86,762	138,816
1820	17,523	8,472	25,995	235,981	11.02	93,964	150,342
1830	25,176	10,735	35,911	280,652	12.80	129,807	207,691
1840	32,408	11,671	44,079	291,948	15.10	159,331	254,930
1850	38,574	14,406	52,980	314,120	16.87	191,506	306,409
1860	37,089	15,813	52,902	315,098	16.79	191,223	305,958
1870	39,786	26,120	65,906	330,551	19.94	238,229	381,167
1880	44,555	23,287	67,842	332,286	20.42	245,227	392,363
1890	44,095	26,691	70,786	332,422	21.29	255,869	409,390
1900	43,002	30,696	73,698	343,641	21.45	266,395	426,231
1910	-	32,190	(81,194)	355,956	22.51	293,490	469,585
1920	-	35,651	(85,182)	352,428	(23.57)	307,906	492,649
1930	-	37,956	(88,141)	359,611	(24.63)	318,602	509,762
1940	51,411	40,868	92,279	359,231	25.69	333,559	533,694
1950	53,431	47,058	100,489	377,747	26.60	363,236	581,177
1960	67,677	50,156	117,833	389,881	30.22	425,929	681,486
1970	67,344	53,901	121,245	444,330	27.29	438,262	701,219

a. Total census figures for the towns: Champlain, Chazy, Plattsburgh (including the City), Chesterfield, Willsboro, Essex, Westport, Moriah, Crown Point, Ticonderoga, and Whitehall.

b. Total census figures for the towns: St. Albans (including city), Burlington, Orwell, Benson, Westhaven, and Vergennes.

APPENDIX C

INVENTORY OF TRIBUTARIES ENTERING LAKE CHAMPLAIN

Table 1. Inventory of the tributaries entering Lake Champlain.

No.	Region	Code	Name	Area mi^2	Lake Code	Location
1	H	4-0010		3.29	055	Windmill Pt., east
2	H	4-0030		0.94	055	Mud Point, north
3	H	4-0031		0.41	055	Mud Point, north
4	H	4-0033		0.37	055	Mud Point, north
5	H	4-0050	Sucker Brook	1.78	053	LaMotte Passage
6	H	4-0070		0.91	050	S. Hero Is., Nichols Pt.
7	H	4-0073		0.30	050	S. Hero Is., Wilcox Bay
8	H	4-0077		0.49	043	S. Hero Is., Sawyer Bay
9	H	4-0090		0.48	043	S. Hero Is., Barnes Bay
10	H	4-0093		1.29	071	S. Hero, Outer Mal-letts Bay
11	H	4-0097		0.26	081	S.W. Savage Sea
12	H	4-0099		0.35	081	Paradise Bay
13	H	4-0101		1.62	082	Keeler Bay
14	H	4-0103		0.58	082	Keeler Bay
15	H	4-0105		1.46	082	Keeler Bay
16	H	4-0107		0.32	081	Cooper Bay
17	H	4-0110		1.94	081	Pearl Bay, south
18	H	4-0113		1.44	081	Pearl Bay
19	H	4-0130		1.30	086	The Gut
20	H	4-0133		0.63	086	Hibbard Bay, The Gut
21	H	4-0135		0.87	095	N. Hero, Macomb Bay
22	H	4-0137		1.21	094	N. Hero, S. of Stony Pt.
23	H	4-0150		0.13	094	Dillenbeck Bay
24	H	4-0170	Mud Creek	11.55	094	Ransoms Bay
25	A	4-0190		0.93	093	Chapman Bay
26	A	4-0195		2.63	093	Chapman Bay
27	A	4-0210	Bloods Creek	1.91	092	Campbell Point
28	A	4-0230		5.26	090	Peel Head Bay

29	A	4-0250		2.37	092	Peel Head Bay
30	A	4-0270	Pike River	199.80	092	Missisquoi Bay
31	A	4-0330	Rock River	57.68	091	Missisquoi Bay
32	A	4-0350	Carman Brook	2.34	091	Missisquoi Bay
33	A	4-0370	Dead Creek	5.90	091	Goose Bay
34	A	4-0390	Missisquoi R., (E)	862.25	092	Missisquoi Bay
		4-0410	Missisquoi R., (N)		092	
		4-0430	Missisquoi R., (W)		093	
35	A	4-0450	Charcoal Creek	3.07	093	Donaldson Bay
36	B	4-0470	Maquam Creek	2.60	088	Maquam Bay
37	B	4-0490		0.59	088	Maquam Bay
38	B	4-0510		1.62	088	Cheney Point, north
39	B	4-0530	Stevens Brook	22.68	083	St. Albans Bay
40	B	4-0550	Mine Brook	2.45	083	St. Albans Bay
41	B	4-0570	Mill River	24.78	083	St. Albans Bay
42	B	4-0590		1.28	080	N.E. Savage Sea
43	B	4-0595		0.18	080	Beans Point, north
44	B	4-0610	Stone Bridge Br.	10.77	080	E. Savage Sea
45	B	4-0630		0.40	080	S.E. Savage Sea
46	B	4-0650	Trout Brook	4.50	080	S.E. Savage Sea
47	B	4-0670		0.06	080	S.E. Savage Sea
48	B	4-0690		0.21	080	S.E. Savage Sea
49	B	4-0710		0.23	080	Sandbar Wildlife Refuge
50	B	4-0730		0.26	080	Sandbar Wildlife Refuge
51	B	4-0750		1.20	080	Sandbar Wildlife Refuge
52	C	4-0770	Lamoille River, (N)	737.20	071	Outer Malletts Bay
		4-0790	Lamoille River, (S)			
53	C	4-0810		0.27	072	Malletts Bay
54	C	4-0830		0.22	072	Malletts Bay
55	C	4-0850		1.38	072	Malletts Bay
56	C	4-0870		0.37	072	Malletts Bay
57	C	4-0890		0.70	072	Malletts Bay
58	C	4-0895	Allen Brook	4.71	072	Malletts Bay
59	C	4-0910		0.04	072	Malletts Bay
60	C	4-0930	Malletts Creek	18.90	072	Malletts Bay
61	C	4-0935	Pond Brook	4.37	072	Malletts Bay
62	C	4-0950	Indian Brook	12.14	072	Malletts Bay
63	C	4-0970		1.96	072	Malletts Bay
64	C	4-0990		0.15	072	Malletts Bay
65	C	4-1010		0.27	072	Malletts Bay
66	C	4-1030		1.45	072	Malletts Bay
67	C	4-1050		0.54	072	Malletts Bay

68	D	4-1070	Winooski River	1,092.00	037	Colchester Pt., south
69	D	4-1090		0.14	033	Burlington Bay
70	D	4-1095	Burlington sewer	-	033	Burlington Bay
71	D	4-1110		0.79	033	Burlington Bay
72	D	4-1130		0.36	033	Burlington Bay
73	D	4-1150	Potash Brook	7.49	030	Shelburne Bay
74	D	4-1170		0.40	030	Shelburne Bay
75	D	4-1190		0.96	030	Bartletts Bay
76	D	4-1195		0.38	030	Bartletts Bay
77	D	4-1210		0.12	030	Bartletts Bay
78	D	4-1230		0.17	030	Shelburne Bay
79	D	4-1250	Munroe Brook	5.32	030	Shelburne Bay
80	D	4-1270	LaPlatte River	53.48	030	Shelburne Bay
81	D	4-1290		0.20	030	Shelburne Bay
82	E	4-1310		0.52	021	Quaker Smith Pt., south
83	E	4-1313		1.43	021	Meach Cove
84	E	4-1315		0.21	021	Meach Cove
85	E	4-1317		0.22	021	Hill Point, north
86	E	4-1330	Holmes Creek	6.00	021	Hill Point, south
87	E	4-1335		0.50	020	Converse Bay
88	F	4-1350	Thorpe Brook	5.23	016	Town Farm Bay
89	F	4-1370	Kimball Brook	2.80	016	Town Farm Bay
90	F	4-1390	Lewis Creek	85.80	016	Hawkins Bay
91	F	4-1410	Little Otter Cr.	70.50	016	Hawkins Bay
92	F	4-1430	Otter Creek	950.50	017	Fort Cassin Pt.
93	F	4-1435		0.24	015	Basin Harbor
94	F	4-1450		0.59	014	Button Bay
95	F	4-1451		0.70	014	Button Bay
96	F	4-1452		0.64	012	Arnold Bay
97	F	4-1453		0.52	012	White Bay
98	F	4-1454		0.21	012	Spaulding Bay
99	F	4-1455		0.43	012	Potash Point, north
100	F	4-1456		0.15	012	Potash Point, north
101	F	4-1457		0.16	012	Potash Point
102	F	4-1458		0.21	012	Potash Point
103	F	4-1459		0.12	011	Potash Bay
104	F	4-1470		0.16	011	Potash Bay
105	F	4-1471		0.12	011	Potash Bay
106	F	4-1472		0.03	011	Potash Bay
107	F	4-1473		0.07	011	Potash Bay
108	F	4-1474		0.03	011	Potash Bay
109	F	4-1475		0.15	011	Potash Bay
110	F	4-1476		0.90	011	Potash Bay
111	F	4-1477		0.68	011	Owls Head Bay
112	F	4-1478		0.08	011	Crane Point, north
113	F	4-1479	Hospital Creek	3.26	011	Chimney Point, north

114	G	4-1490	Whitney Creek	3.18	009	Willow Point, north
115	G	4-1491		0.55	009	Willow Point, north
116	G	4-1493		0.12	009	Willow Point
117	G	4-1495		0.41	009	Plumies Point, north
118	G	4-1497		0.71	009	Plumies Point, north
119	G	4-1499		0.25	009	Plumies Point, north
120	G	4-1510		0.21	009	Plumies Point
121	G	4-1515		0.23	009	Plumies Point, south
122	G	4-1530		0.22	009	Giards Bay
123	G	4-1550	Braisted Brook	2.32	009	Giards Bay
124	G	4-1570		0.48	009	Leonard Bay
125	G	4-1590		0.49	009	Leonard Bay
126	G	4-1610		0.73	008	Lapham Bay
127	G	4-1630		1.14	008	Five Mile Point
128	G	4-1650		3.00	008	Stony Cove
129	G	4-1670		1.33	008	Stony Cove
130	G	4-1690		0.31	008	Stony Cove
131	G	4-1710		0.57	008	Watch Point, south
132	G	4-1730		0.13	008	Watch Point, south
133	G	4-1735		0.28	008	Watch Point, south
134	G	4-1750		2.87	008	Hands Cove
135	G	4-1770		4.12	007	Beadles Cove
136	G	4-1790	East Creek	34.75	007	Larrabees Point, south
137	G	4-1810		0.72	006	Allen Bay, north
138	G	4-1830	Big Brook	1.30	006	Stevens Bay
139	G	4-1850		0.49	006	Benson Bay
140	G	4-1870		0.85	006	Stony Point, north
141	G	4-1890		0.67	006	Stony Point
142	G	4-1910		2.04	006	Benson Landing
143	G	4-1930		1.82	005	
144	G	4-1950		0.87	005	
145	G	4-1970		1.67	005	Red Rock Bay
146	G	4-1990		0.18	005	
147	G	4-2010	Horton Brook	2.50	003	Narrows of Dresden
148	G	4-2030		0.38	003	Maple Bend
149	G	4-2050		0.22	003	
150	G	4-2070		1.06	003	
151	G	4-2090		0.88	003	
152	G	4-2110		0.10	003	
153	G	4-2130		0.23	003	
154	G	4-2150		1.11	003	
155	G	4-2170		0.25	003	
156	G	4-2190	Poultney River	267.20	003	East Bay
157	J	4-0020		0.98	056	Kings Bay
158	J	4-0040	Great Chazy River	309.80	056	Kings Bay
159	J	4-0060	Little Chazy River	67.60	054	Long Point, south
160	J	4-0062		0.54	054	Long Point, south
161	J	4-0064		0.19	054	Trombley Bay
162	J	4-0066		0.72	054	Trombley Bay

163	J	4-0080		0.21	054	Trombley Bay
164	J	4-0100	Guay Creek	3.50	054	Monty Bay
165	J	4-0120		1.12	054	Monty Bay
166	J	4-0140	Riley Brook	10.71	054	Monty Bay
167	J	4-0160	Woodruff Pond outlet	1.58	051	Treadwell Bay
168	J	4-0162		0.42	051	Martin Bay
169	J	4-0164		0.12	051	Martin Point
170	K	4-0180	Scomotion Creek	40.34	046	Cumberland Bay
171	K	4-0200	Saranac River	649.20	046	Cumberland Bay
172	K	4-0202		0.25	044	
173	K	4-0204		0.43	044	
174	K	4-0206		0.61	044	
175	K	4-0208		0.81	044	Bluff Point, north
176	K	4-0210		0.63	044	Bluff Point, south
177	K	4-0220	Salmon River	64.10	044	
178	K	4-0240	Silver Stream	6.83	044	Day Point
179	K	4-0260	Little Ausable R.	60.70	042	Ausable Point, north
180	K	4-0262	Dead Creek	1.29	042	Ausable Point
181	K	4-0280 4-0300	Ausable R., (N) Ausable R., (S)	513.45	042	Ausable Point
182	K	4-0320	Marsh Brook	3.62	039	Wickham Marsh
183	K	4-0340	Watson Brook	1.40	039	Port Kent
184	K	4-0341		0.09	039	Trembleau Point
185	K	4-0342		0.08	039	Trembleau Point
186	K	4-0343		0.25	039	Trembleau Point
187	K	4-0344		0.31	039	Corlear Bay
188	K	4-0345		0.29	039	Corlear Bay
189	K	4-0346		0.24	036	Corlear Bay
190	K	4-0347		0.07	036	Corlear Bay
191	K	4-0348		0.40	036	Corlear Bay
192	K	4-0360	Little Trout Br.	4.99	036	Corlear Bay
193	K	4-0362		0.34	036	Corlear Bay
194	K	4-0364		0.65	036	Brown Point
195	K	4-0380		1.02	031	Willsboro Bay
196	K	4-0382		0.26	031	Willsboro Bay
197	K	4-0384		0.37	031	Willsboro Bay
198	K	4-0400	Warm Pond Creek	12.73	031	Willsboro Bay
199	K	4-0402		0.52	031	Willsboro Bay
200	K	4-0404		0.87	031	Willsboro Bay
201	K	4-0420	Big Brook	2.56	031	Willsboro Bay
202	K	4-0424		0.35	035	Willsboro Point
203	L	4-0440	Bouquet River	278.05	022	Bouquet River Pt.
204	L	4-0442		0.68	022	Bouquet R. Pt., south
205	L	4-0460		2.45	022	
206	L	4-0462		0.23	022	
207	L	4-0464		1.98	020	Essex
208	L	4-0480		3.26	020	Whallon Bay

209	L	4-0481		0.32	020	Whallon Bay
210	L	4-0482		0.31	020	Whallon Bay
211	L	4-0483		0.20	020	Whallon Bay
212	M	4-0484		0.19	017	Ore Bed Point
213	M	4-0485		0.10	017	Louis Clearing Bay
214	M	4-0486		0.12	017	Louis Clearing Bay
215	M	4-0487		0.11	017	Louis Clearing Bay
216	M	4-0488		0.14	017	Snake Den Harbor
217	M	4-0500		0.51	017	Barn Rock Harbor
218	M	4-0520		0.43	015	Rock Harbor
219	M	4-0522		0.39	015	Rock Harbor
220	M	4-0540		0.43	015	Hunter Bay
221	M	4-0542		0.21	015	Hunter Bay
222	M	4-0544		0.17	015	Northwest Bay
223	M	4-0560		0.62	015	Northwest Bay
224	M	4-0562		0.37	013	Northwest Bay
225	M	4-0564		0.19	013	Northwest Bay
226	M	4-0565		0.13	013	Northwest Bay
227	M	4-0566		1.01	013	Northwest Bay
228	M	4-0580	Hoisington Brook	12.12	013	Northwest Bay
229	M	4-0582		0.94	013	Northwest Bay
230	M	4-0600		0.52	012	Moore Point
231	M	4-0602		0.26	012	Coll Bay
232	M	4-0604		0.27	012	Coll Bay
233	M	4-0620	Stacy Brook	5.61	012	Coll Bay
234	M	4-0622		0.12	012	Coll Bay
235	M	4-0640	Beaver Brook	4.60	012	Stevenson Bay
236	M	4-0660	Mullen Brook	5.64	011	Mullen Bay
237	M	4-0680	Kenney Brook	1.46	011	Mullen Bay
238	M	4-0682		0.09	011	
239	M	4-0700		0.85	011	
240	M	4-0702		0.92	011	Craig Harbor
241	M	4-0720	Mill Brook	27.99	011	Port Henry
242	M	4-0721		0.21	011	Port Henry
243	M	4-0722		0.19	011	Port Henry
244	M	4-0740	Stony Brook	1.79	011	Port Henry
245	M	4-0760	McKenzie Brook	9.92	010	Port Henry
246	M	4-0762		0.76	010	Bulwagga Bay
247	M	4-0764		0.20	010	Bulwagga Bay
248	M	4-0780	Grove Brook	7.57	010	Bulwagga Bay
249	M	4-0782		1.03	010	Bulwagga Bay
250	M	4-0800		2.36	010	Bulwagga Bay
251	M	4-0802		2.93	010	Bulwagga Bay
252	N	4-0804		0.13	009	Murdocks Point, south
253	N	4-0806		0.10	009	Murdocks Point, south
254	N	4-0820		0.13	009	Schoolhouse Bay
255	N	4-0840		0.47	009	Porters Marsh
256	N	4-0860	Putnam Creek	61.33	009	Gilligans Bay

257	N	4-0862		0.44	099	
258	N	4-0864		0.32	008	Spar Mill Bay
259	N	4-0880	Grant Brook	4.31	008	Miller Marsh
260	N	4-0900		0.09	008	
261	N	4-0920	Fivemile Creek	9.20	008	Stony Point
262	N	4-0940		0.64	008	Kerby Point, north
263	N	4-0960		1.00	008	Kerby Point, north
264	N	4-0980		1.04	008	
265	N	4-1000	Ticonderoga Creek	256.30	007	Ticonderoga Bay
266	N	4-1020	Charter Brook	6.81	007	Charter Marsh
267	N	4-1040		0.36	006	Gourlie Point, north
268	N	4-1042		0.10	006	Gourlie Point, south
269	N	4-1060	Nigger Marsh	5.35	006	Sixmile Point
270	N	4-1064		1.10	006	Mill Bay
271	N	4-1080	Mill Creek	11.26	006	Mill Bay
272	N	4-1100		0.22	006	
273	N	4-1120		0.10	005	
274	N	4-1140		0.12	005	
275	N	4-1160		0.39	005	
276	N	4-1162		0.19	005	
277	N	4-1180		0.13	005	Pulpit Point
278	N	4-1182		0.16	005	Chilson Bend
279	N	4-1200		0.56	005	Chilson Bend
280	N	4-1220		1.83	005	
281	N	4-1240		2.16	005	Narrows of Dresden
282	N	4-1260		0.27	003	Barrel Bay
283	N	4-1280		0.51	003	Maple Bend
284	N	4-1282		0.78	003	Maple Bend
285	N	4-1284		0.85	003	Maple Bend
286	N	4-1285		0.58	003	Maple Bend
287	N	4-1286	Chubbs Brook	2.49	003	Maple Bend
288	N	4-1300	Pease Brook	2.00	003	
289	N	4-1320	Pine Lake Brook	3.58	003	
290	N	4-1340		0.38	003	
291	N	4-1360		0.48	003	Cat Den Bay
292	N	4-1380		0.55	003	
293	N	4-1400		0.44	003	Duso Marsh
294	N	4-1420		0.63	003	
295	N	4-1440		0.25	003	
296	N	4-1460	South Bay portal	39.90	003	
297	P	4-1480	Mettawee River and Canal	423.62	003	

APPENDIX C

Table 2. Lake Champlain tributaries draining basins of ten square miles or more.

District	No.	Code	Name	Region	Area Mi²	Accum. Area	Accum. % Total Area
D	1.	1070	Winooski River	Vt.	1,092.0	1,092.0	14.4
F	2.	1430	Otter Creek	Vt.	950.5	2,042.5	26.9
A	3.	0410	Missisquoi River	Vt./Que.	862.3	2,904.8	38.3
C	4.	0790	Lamoille River	Vt.	737.2	3,642.0	48.0
K	5.	0200	Saranac River	NY	649.2	4,291.2	56.6
K	6.	0280	Ausable River	NY	513.5	4,804.7	63.4
P	7.	1480	Metawee River and Canal	NY./Vt.	423.6	5,228.3	69.0
J	8.	0040	Great Chazy River	NY./Vt.	309.8	5,538.1	73.0
L	9.	0440	Bouquet River	NY	278.1	5,816.2	76.7
G	10.	2190	Poultney River	Vt.	267.2	6,083.4	80.2
N	11.	1000	Ticonderoga Creek	NY	256.3	6,339.7	83.6
G	12.	0270	Pike River	Que.	199.8	6,539.5	86.3
F	13.	1390	Lewis Creek	Vt.	85.8	6,625.3	87.4
F	14.	1410	Little Otter Creek	Vt.	70.5	6,695.8	88.3
J	15.	0060	Little Chazy River	NY	67.6	6,763.4	89.2
K	16.	0220	Salmon River	NY	64.1	6,827.5	90.1
N	17.	0860	Putnam Creek	NY	61.3	6,888.8	90.9
K	18.	0260	Little Ausable River	NY	60.7	6,949.5	91.7
A	19.	0330	Rock River	Que./Vt.	57.7	7,007.2	92.4
D	20.	1270	Laplatte River	Vt.	53.5	7,060.7	93.1
K	21.	0180	Scomotion Creek	NY	40.3	7,101.0	93.7
N	22.	1460	South Bay Portal	NY	39.9	7,140.9	94.2
G	23.	1790	East Creek	Vt.	34.8	7,175.7	94.6
M	24.	0720	Mill Brook	NY	28.0	7,203.7	95.0
B	25.	0570	Mill River	Vt.	24.8	7,228.5	95.3
B	26.	0530	Stevens Brook	Vt.	22.7	7,521.2	95.6
C	27.	0930	Malletts Creek	Vt.	18.9	7,270.1	95.9
K	28.	0400	Warm Pond Creek	NY	12.7	7,282.8	96.1
N	29.	1080	Mill Creek	NY	12.4	7,295.2	96.2
M	30.	0580	Hoisington Brook	NY	12.1	7,307.3	96.4
C	31.	0950	Indian Brook	Vt.	12.1	7,319.4	96.5
H	32.	0170	Mud Creek	Vt.	11.6	7,331.0	96.7
B	33.	0610	Stone Bridge Brook	Vt.	10.8	7,341.8	96.8
J	34.	0144	Riley Brook	NY	10.7	7,352.5	97.0

APPENDIX D

PRIMARY DATA ON MEDIAN CONCENTRATIONS OF TOTAL PHOSPHATE-PHOSPHORUS OF THE MAJOR TRIBUTARIES IN EACH DISTRICT, AND THE CALCULATIONS FOR LOADING OF TOTAL PHOSPHORUS FOR THE STREAMS IN THE DISTRICTS.

In the following sequence of tables is presented, for each District, the name of the tributary with its drainage area, the median concentration of total PO^4-P values measured between 1970 and 1974, the number of measurements made, and the calculated load of PO^4-P in Kg/Yr (Refer to page). Below each table are the calculations that provide estimates of direct loading from the District, and the estimated loading from the unmonitored tributaries. Table headings are given only for the first table.

Table D-1. District A, Missisquoi. Discharge Coef., 1.3

Tributary	Area	mg/l	No.	Kg/PO^4-P/Yr	Kg/P/Sq. Mi.
Pike River	199.80	0.080	11	14,283.04	71.5
Rock River	57.68	0.124	12	6,391.20	110.8
Missisquoi River	862.25	0.084	7	64,712.47	75.1
Charcoal Brook	3.07	0.086	5	306.70	99.9

Weighted District concentration:	0.085 mg/l
Total tributary loading	85,693.41
Diffuse loading	1,228.33
Total District loading	86,921.74

Table D-2. District B; Northeast and St. Albans. Disch. Coef. 1.1

Stevens Brook	22.68	0.752	9	16,764.44	739.2
Mill River	24.78	0.040	10	974.29	39.3
Stone Bridge Brk.	10.77	0.106	12	1,122.15	104.2
Trout Brook	4.50	0.078	12	345.01	76.7

Weighted District concentration:	0.311 mg/l
Total tributary loading	19,205.89
Diffuse loading	3,357.47
Total District Loading	22,563.36

Table D-3. District C; Lamoille-Malletts Bay. Disch. Coef.: 1.4

Lamoille River	737.20	0.041	11	37,812.26	51.3
Allen Brook	4.71	0.087	17	512.63	108.8
Malletts Creek	18.90	0.065	16	1,536.88	81.3
Pond Brook	4.37	0.053	13	302.78	69.3
Indian Brook	12.14	0.037	16	573.97	47.3

Weighted mean concentration:	0.042
Total tributary loading	40,738.52
Diffuse loading	392.03
Total District loading	41,130.55

Table D-4. District D: Burlington-Winooski. Disch. Coef.: 1.4

Winooski River	1,092.00	0.073	11	99,726.13	91.3
Potash Brook	7.49	0.111	19	742.92	99.2
Munroe Brook	5.32	0.095	18	632.26	118.8
LaPlatte River	53.48	0.130	20	8,697.58	162.6

Weighted mean concentration:	0.076
Total tributary loading	109,798.89
Diffuse loading	662.91
Total District loading	110,461.80

Table D-5. District F: Otter Creek-Vergennes. Disch. Coef.: 1.3

Otter Creek	950.50	0.103	11	113,728.19	119.7
Lewis Creek	85.80	0.058	17	5,780.88	67.4
Little Otter Creek	70.50	0.132	17	10,810.40	153.3
Thorpe Brook	5.23	0.122	17	741.21	141.7
Hospital Creek	3.26	0.134	7	507.46	155.7

Weighted mean concentration:	0.102
Total tributary loading:	131,568.14
Diffuse loading	2,172.59
Total District loading:	133,740.73

Table D-6. District H: The Islands. Disch. Coef.: 1.1.

Mud Creek	11.6	0.194	5	2,212.01	190.7

Weighted mean concentration:	0.194
Total tributary loading:	2,212.01
Diffuse loading	2,069.00
Total District Loading	4,281.01

Table D-7. District J: Chazy. Disch. Coef. 1.15.

Great Chazy River	309.80	0.130	7	35,988.20	116.2
Little Chazy River	67.90	0.091	7	6,321.52	93.5

Weighted mean concentration:	0.123
Total tributary loading:	42,309.72
Diffuse loading	7,933.27
Total District loading:	50,242.99

Table D-8. District K: Saranac-Plattsburgh. Disch. Coef. 1.1

Scomotion Creek	40.34	0.106	5	4,203.10	104.2
Salmon River	64.10	0.061	6	3,843.40	60.0
Saranac River	649.20	0.108	8	68,917.63	106.2
Silver Stream	6.83	0.094	7	631.07	92.4
Little Ausable R.	60.70	0.231	5	13,782.52	227.1
Ausable River	513.45	0.067	7	33,814.35	65.9

Weighted mean concentration:	0.095
Total tributary loading:	125,192.07
Diffuse loading:	2,737.88
Total District loading:	127,929.95

Table D-9. District L: Bouquet. Disch. Coef. 1.15

Bouquet River	278.05	0.068	7	19,429.65	69.9

Weighted mean concentration:	0.068
Total tributary loading:	19,429.65
Diffuse loading:	660.14
Total District loading	20,089.79

Table D-10. District M: Port Henry. Disch. Coef. 1.2

Hammond Brook	12.12	0.093	6	1,208.65	99.7
Stacy Brook	5.61	0.122	5	733.90	130.8
Beaver Brook	4.60	0.188	4	927.33	201.6
Mullen Brook	5.64	0.020	6	120.96	21.4
Mill Brook	27.99	0.212	6	6,362.90	227.3

Weighted mean concentration:	0.156
Total tributary loading:	9,353.74
Diffuse loading:	6,281.82
Total District loading	15,635.56

APPENDIX E

INVENTORY OF POINT SOURCE LOADINGS IN THE CHAMPLAIN DISTRICTS

Definitions

Point sources are defined as those discharges into a receiving water from a single pipe or conveyor. Non Point sources are those discharges spread over a large area, such as runoff from the land through channeled or unchanneled pathways, sheet runoff, drainage from highways, and ground water seepage. It also includes input from precipitation (Loehr, 1974). In addition to these standard terms, the term semi point source refers to those situations where distinct non-point sources are concentrated in a short stretch of a stream. Specifically it distinguishes those small communities with septic tanks, leach fields, and other individualized means of waste disposal clustered in a small area.

Calculation of loading

The amount of loading is a function of disposal type, and distance from the lake. In calculating loading, a base value of 1.6 kg/P/capita/yr was used, reduced according to the following formula:

	kg/C/yr
a. Semi point source communities with individual means of disposal:	0.75
b. Communities on a sewer system without any treatment:	1.60
c. Communities with primary treatment facilities, less 10%:	1.44
d. Communities with secondary treatment facilities, less 20%:	1.28

These values are further scaled down according to distance from the lake as follows:

0-25 river miles	100% of value
25-50 river miles	75% of value
50 and more miles	50% of value

The following table summarizes the constants used in calculating loadings; these constants, when multiplied by the population, yield the estimated phosphorus loading in kg/yr:

Disposal class	River miles from Lake Champlain 0 - 25	25 - 50	50 plus
a	0.75	0.5625	0.375
b	1.60	1.20	0.750
c	1.44	1.08	0.720
d	1.28	0.96	0.64

APPENDIX E

POINT SOURCE INVENTORY

Table 1. Inventory of contributions of phosphorus from District A (Missisquoi). Loading values in kg/yr of total PO_4-P.

				Disposal Type				Kg/yr Phosphorus loading from		
	Community	Miles	Popul.	a	b	c	d	semi-point	point	
1.	Swanton	7.5	2,630				X	-	3,366	
2.	Pike River	c 8.0	250		X			-	200	Canada
3.	Venise en Quebec	1.0 e	100	X				75	-	Canada
4.	Phillipsburg	1.0	391	X				293	-	Canada
5.	Highgate Cntr.	-	350		X			-	560	
6.	E. Highgate	18.6	200	X				150	-	
7.	Sheldon	25.2	250	X				188	-	
8.	Sheldon Sprgs.	26.0	568		X				682	
9.	Fairfield Sta.	31.6 e	50	X				28	-	
10.	Fairfield	31.9	180	X				101	-	
11.	E. Fairfield	31.9	182		X			-	218	
12.	Enosburg Falls	33.5	1,266		X			-	1,519	
13.	E. Berkshire	40.4 e	50	X				28	-	
14.	E. Fletcher	41.6 e	50	X				28	-	
15.	Montgomery	45.7	200	X				113	-	
16.	Richford	45.9	1,527				X	-	1,466	
17.	Montgomery Ctr.	47.8	275	X				155	-	
18.	Bakersfield	c.50.0	200	X				113	-	
19.	E. Richford	52.3	70	X				26	-	
20.	Glen Sutton	52.4 e	100*	X				38	-	Canada
21.	Dunkin		486	X				182	-	Canada
22.	Highwater	e	100	X				38	-	Canada
23.	N. Troy	67.9	774		X			-	619	
24.	Troy	77.3	253		X			-	202	
25.	Westfield	81.1	120	X				25	-	
26.	Lowell	87.8	160	X				60	-	
27.	Newport Center	75.8	700		X			-	560	
28.	Mansonville, Que.	50 +	725 +	X				272	-	
29.	S. Bolton		436	X				164	-	Canada
30.	Bolton Centre	e	100	X				38	-	
31.	Eastman	52.7	681 +		X			-	511	
32.	Abercorne, Que.		368				X	-	236	Canada
33.	Sutton, Que.		1,684				X	-	1,078	Canada
34.	Notre Dame Standbg		100				X	-	80	Canada

APPENDIX E

Table 1 (cont'd).

Community	Miles	Popul.	a	b	c	d	Load semi-point	point	
35. Freilighsburg		345		X			-	276	
36. Bedford, Que.		2,876			X		-	2,071	Canada
37. Standbridge		200	X				75	-	Canada
38. St. Armond		100	X				38	-	Canada

Table 2. Inventory of contributions of phosphorus from District C (Malletts Bay-Lamoille). Loading values in kg/yr of total PO_4-P.

1. Milton	7.6	1,164		X			-	1,862
2. Fairfax	16.5	500		X			-	800
3. Cambridge	23.5	235	X				176	-
4. Jeffersonville	31.0	383		X			-	460
5. Westford	20.2	90	X				68	-
6. Jericho Vlg.	30.3	275	X				155	-
7. Watervilie	35.6	397		X			-	476
8. Belvidere Cr.	40.0 e	100	X				56	-
9. Johnson College	41.0	250			X		-	270
10. E. Johnson	42.5 e	100	X				56	-
11. Belvidere Ctr.	42.8	179		X			-	215
12. Johnson	41.0	1,296				X	-	1,244
13. Hyde Park	47.0	418		X			-	502
14. N. Hyde Park	48.8	100	X				56	-
15. Morrisville	50.3	2,116				X	-	2,031
16. Underhill Ctr.	35.9	1,198	X				674	-
17. Wolcott	59.0	676		X			-	507
18. Eden	53.4	513		X			-	385
19. Eden Mills	54.8 e	100	X				38	-
20. N. Wolcott	61.0 e	100	X				38	-
21. Hardwick	66.5	1,500		X			-	1,125
22. E. Hardwick	71.0	195		X			-	146
23. Greensboro Bnd.	74.5 e	100	X				38	-
24. Craftsbury	94.0	175		X			-	131

APPENDIX E

Table 3. Inventory of the contributions of total phosphate-phosphorus from District D (Burlington-Winooski). Loading values in kg/P/yr.

No.	Community	Miles	Popul.	a	b	c	d	Loadings Semi-Pt.	Pt. sources
1.	WTP, S. Burl., Bartl.	0	1,000				X	-	1,280
2.	WTP, Shelburne FD#1	0	1,328				X	-	1,700
3.	WTP. Burlington, main	0	21,500				X	-	27,520
4.	WTP. Burlington, N. End	2.1	7,000				X	-	8,960
5.	Hinsburg	10.0	350				X	-	448
6.	Shelburne FD#2	4.0	800				X	-	1,152
7.	WTP, Burlington, Rvrsde	9.6	9,000				X	-	11,520
8.	WTP, Winooski City	9.7	7,400				X	-	9,472
9.	WTP, S. Burl., Airpt.	11.3	5,600				X	-	7,168
10.	WTP, Colchester FD#1	12.4	2,200				X	-	3,520
11.	Essex Town	14.1	1,000			X		-	1,444
12.	Essex Jct., Vlg.	17.8	6,350			X		-	9,144
13.	Essex Jct., IBM, Dom.	18.9	875				X	-	1,120
14.	Williston	20.7	300	X				225	-
15.	Richmond Vlg.	29.7	926				X	-	889
16.	Waterbury Vlg.	43.2	2,800				X	-	2,688
17.	Vt. St. Hospital	44.1	860			X		-	929
18.	Stowe Village	53.7	1,760		X			-	1,320
19.	Jonesville		e 50	X				19	-
20.	Montpelier	54.7	8,860			X		-	6,379
21.	Williamstown	58.5	510				X	-	326
22.	Berlin	59.1	1,500				X	-	950
23.	Barre City	61.5	10,575			X		-	7,514
24.	Northfield Vlg.	63.8	3,300				X	-	2,112
25.	Websterville	66.2	e 50			X		-	488
26.	E. Barre	67.0	4,430			X		-	3,190
27.	Plainfield Vlg.	71.1	e 100				X	-	282
28.	Marshfield	80.4	322		X			-	241

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Table 3 (cont'd).

No.	Community	Miles	Popul.	a	b	c	d	Loadings Semi-Pt.	Pt. sources
29.	Cabot	85.4	244	X				102	-
30.	Moretown	50 +	150	X				56	-
31.	Waitsfield	50 +	175	X				66	-
32.	Duxbury	50 + e	50	X				19	-
	Totals:							487	111,756 = 112,243 kg

Table 4. Inventory of the contributions of total phosphate-phosphorus from District F (Otter Creek-Vergennes). Loading values in kg/P/yr.

1.	Vergennes City	7.3	2,242			X		-	3,228
2.	Vergennes City	7.3	-		X			-	664
3.	Weybridge	e	50	X				38	-
4.	Middlebury	25.7	3,688			X		-	3,983
5.	Leicester Jct.		100	X				56	-
6.	Brandon	49.6	1,720				X	-	1,858
7.	Otter Valy Un.	51.7 e	600	X				225	-
8.	Ferrisburg		170	X				64	-
9.	Pittsford	62.6	682				X	-	436
10.	Proctor	63.4	1,978			X		-	1,424
11.	Rutland Twn, FD#1	70.6	2,248			X		-	1,619
12.	Rutland City	71.8	19,293			X		-	13,891
13.	W. Rutland	72.6	2,250				X	-	1,140
14.	Walingford	84.4	1,676				X	-	1,085
15.	Panton	50 +	35	X				13	-
16.	Bridgeport	50 + e	100	X				38	-
17.	Shoreham	50 +	130	X				49	-
18.	Shoreham Ctr.	50 + e	50	X				19	-
19.	Whiting	50 +	70	X				26	-
20.	Sudbury	50 +	50	X				19	-
21.	Cornwall	50 +	40	X				15	-
22.	W. Cornwall	50 + e	40	X				15	-
23.	New Haven Mills	50 +	150	X				56	-
24.	Bristol	50 +	1,421		X			-	1,066
25.	W. Lincoln	50 +	70	X				26	-
26.	Lincoln	50 + e	50	X				19	-
27.	S. Lincoln	50 +	30	X				11	-
28.	E. Middlebury	50 +	320	X				120	-
29.	Ripton	50 +	70	X				26	-
30.	Salisbury	50 +	130	X				49	-
	Totals:		39,453					884	30,394

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Table 5. Inventory of the contributions of total phosphate phosphorus from District S (South end). Loading values in kg/P/yr.

No.	Community	Miles	Popul.	a	b	c	d	Loading Semi-Pt.	Loading Point	(*)
Poultney River:										
1.	Benson	15.0	583				X	-	746	*
2.	Fair Haven	16.5	2,777				X	-	3,555	*
3.	Hortonville	20.0 e	100	X				75	-	*
4.	Hydesville	20.4	300	X				225	-	*
5.	Castelton	24.0	2,837				X	-	3,631	*
6.	Poultney	26.1	3,217				X	-	3,088	*
7.	E. Poultney	28.0	300		X			-	360	*
8.	E. Hubbardton	31.6 e	100	X				56	-	*
9.	W. Rutland	34.0	2,302	X				1,295	-	*
	Subtotal:		12,516					1,651	11,380	
Metawee River:										
1.	Pawlet		1,184		X			-	1,894	*
2.	Wells		200	X				150	-	*
3.	Dorset		300	X				225	-	*
4.	Rupert		150	X				113	-	*
5.	Granville		2,784		X			-	4,454	
6.	N. Rupert	e	50	X				38	-	*
7.	Whitehall		3,764		X			-	6,022	
8.	Middle Granville		869	X				652	-	
9.	N. Granville	e	50	X				38	-	
10.	Comstock	e	100	X				75	-	
11.	Fort Anne		453		X			-	725	
12.	Smith's Basin	e	50	X				38	-	
13.	Kingsbury	e	50	X				38	-	
14.	Queensbury	e	50	X				38	-	
	Subtotals:		10,054					1,405	13,095	

Appendix E

Table 5 (cont'd).

No.	Community	Miles	Popul.	a	b	c	d	Loading Semi-Pt.	Loading Point
Lake George South Shore District:									
1.	Ticonderoga		3,568			X		-	5,318
2.	Chilson	e	50	X				38	-
3.	Clemons		500		?			-	800
4.	Dresden Station	e	50	X				38	-
5.	Putnam	e	100	X				75	-
6.	Putnam Station	e	50	X				38	-
7.	Wright	e	50	X				38	-
8.	Chipman's Point		100	X				75	-
9.	Ironville	e	50	X				38	-
10.	Crown Point Center		50	X				38	-
	Subtotals:		4,568					378	6,118
	Grand totals:		27,138					3,434	30,593

Table 6. Inventory of contributions of phosphorus from District J (Chazy-Rouses Point). Values in kg/yr of total PO_4-P.

No.	Community	Miles	Popul.	Disposal Type a	b	c	d	Annual Load Semi-point	Point
1.	Rouses Point, WTP	0	2,320				X	-	2,970
2.	Coopersville	1.2	200	X				150	-
3.	Chazy	5.0	600		X			-	960
4.	Champlain	6.5	1,620				X	-	2,074
5.	West Chazy	12.0	566		X			-	906
6.	Ingraham	-	e 50	X				38	-
7.	Moers	18.9	536		X			-	858
8.	Altona	24.9	400	X				300	-
9.	Alder Bend	-	e 50	X				38	-
10.	Crazy Lake	37.2	e 100	X				56	-
11.	Ellenburg Depot	37.7	e 100	X				56	-
12.	Ellenburg	39.7	e 150		X			-	180
	Totals:		6,682					638	7,948

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Table 7. Inventory of point source contributions of phosphorus from District K (Saranac-Ausable-Plattsburg). Values in kg/yr of total PO_4-P.

No.	Community	Miles	Popul.	Disposal class a	b	c	d	Annual Load Semi-point	Point
Saranac River:									
1.	Plattsburg Town WTP	0	1,000			X		-	1,440
2.	Plattsburgh	0.1	30,000				X	-	38,400
3.	Morrisonville	6.6	5,300		X			-	8,480
4.	Picketts Corner	10.9 e	50	X				38	-
5.	Saranac	16.7	400		X			-	640
6.	Moffitsville	18.8 e	50	X				38	-
7.	Dannemora Village	20.0	1,800			X		-	2,592
8.	Dannemora Prison	20.0	3,300			X		-	4,752
9.	Redford	23.3 e	50	X				38	-
10.	Clayburg	25.3 e	50	X				28	-
11.	Franklin Falls	e	50	X				28	-
12.	Trudeau	e	50	X				28	-
13.	Riverview	29.3 e	100	X				56	-
14.	Bloomingdale	45.0	536		X			-	643
15.	Saranac Lake	55.0	6,915			X		-	4,979
	Subtotals:								
Ausable River:									
1.	Ausable Chasm	4.1 ee	100	X				75	-
2.	Keeseville	5.2	2,213				X	-	2,833
3.	Clintonville	11.7 e	50	X				38	-
4.	Rogers	13.2 e	50	X				38	-
5.	Ausable Forks	17.3	500		X			-	800
6.	Haselton	e	50	X				38	-
7.	Jay	22.3	400		X			-	640
8.	Upper Jay	25.5 e	50	X				28	-
9.	Wilmington	26.4	700		X			-	840
10.	Keene	31.5 e	50	X				28	-
11.	Keene Valley	36.5	500		X			-	600
12.	Lake Placid	42.5	2,731			X		-	2,949
13.	North Elba	e	50	X				28	-
14.	St. Huberts	38.5 e	50	X				28	-
	Subtotals:								

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Table 7 (cont'd).

No.	Community	Miles		Popul.	Disposal class a	b	c	d	Annual Load Semi-point	Point
1.	Lapham Mills		e	100	X				75	-
2.	Peru			2,800			X		-	4,032
3.	Harkness		e	50	X				38	-
	Subtotals:									
	Salmon River:									
1.	S. Plattsburgh	2.5	e	100	X				75	-
2.	Schuyler Falls	6.1	e	100	X				75	-
3.	Peasleeville	11.2	e	50	X				38	-
	Subtotals:									
	Totals:			60,345					856	74,620

Table 8. Inventory of point source contributions of phosphorus from District L (Bouquet). Values in kg/yr of total PO_4-P.

No.	Community	Miles		Popul.	a	b	c	d	Semi-point	Point
1.	Essex	0	e	100	X				75	-
2.	Bouquet	8.1	e	100	X				75	-
3.	Whallensburg	11.9	e	50	X				38	-
4.	Wadhams	15.0	e	50	X				38	-
5.	Reber	-	e	50	X				38	-
6.	Lewis	-	e	50	X				38	-
7.	Elizabethtown	22.3		607		X			-	971
8.	New Russia	28.0	e	50	X				28	-
9.	Euba Mills	-	e	50	X				28	-
	Totals:			1,107					358	971

Table 9. Inventory of point source contributions of phosphorus from District M (Westport-Port Henry). Values in kg/yr of total PO_4-P.

No.	Community	Miles		Popul.	a	b	c	d	Semi-point	Point
1.	Westport	0		673				X	-	861
2.	Port Henry	0		1,800			X		-	2,592
3.	Willsboro	3.0		838		X			-	1,341
4.	Moriah, SD#2	2.0		2,900			X		-	4,175
5.	Moriah, SD#1	4.0		270			X		-	389
	Totals:			6,481						9,358

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16. ABSTRACT

Information on the trophic status of the several basins of Lake Champlain is summarized, the amounts and distribution of total phosphorus loading into the lake are evaluated, and recommendations for further study are made. The general objective is to provide basic background information to assist in the development of nutrient control policies for proper lake management. There is a short discussion of the role of phosphorus in the lake ecosystem, how recent thinking is leading to studies of eutrophication models, and a presentation of estimated historical loadings. Ongoing studies by various agencies and universities are listed and an extensive bibliography is provided.

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