PERSPECTIVES ON EUTROPHICATION IN LAKE CHAMPLAIN

prepared for

State of Vermont
Department of Fish and Wildlife

by

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INTRODUCTION

Potential effects of discharges from the proposed Kingsland Bay State Fish Hatchery on phosphorus and related water quality conditions in Lake Champlain have been assessed in previous reports (Smeltzer,1985; Walker et al.,1986). The impacts have been evaluated on two spatial scales: near-field (immediate discharge zone in and around Hawkins Bay) and far-field (lakewide). The analyses indicate that near-field effects of an offshore discharge will be limited to less than a 5 ppb phosphorus increase in the Hawkins Bay area. Because the phosphorus discharge from the hatchery at full production will amount to .26-.39% of the existing total phosphorus loadings to the lake, the whole-lake impact issue is related more to general water quality management policy for Lake Champlain than to the specific effects of this discharge. With the addition of treatment facilities to remove phosphorus and at the proposed discharge permit levels (VDWR,1986), the projected near-field impacts of the hatchery are less than 2.5 ppb in the immediate discharge zone (40-acre cell) and less than 1.3 ppb in Hawkins Bay. The annual loading from the hatchery (1140 kg/yr) will be .14-.21% of the existing whole-lake total phosphorus loading, based upon the range of loading estimates developed by Bogden (1978).

To assist in developing perspectives on localized and lakewide impacts of the hatchery discharge, this report summarizes recent information on Lake Champlain water quality. Henson and Gruendling (1977) presented a thorough discussion and analysis of eutrophication in the lake, based upon data available through 1976. This report analyzes data collected primarily by the Vermont Department of Water Resources and Environmental Engineering between 1979 and 1985. Spatial variations in trophic state indicators (total phosphorus, chlorophyll-a, and transparency) are examined by comparing data from different sampling stations within the lake. Year-to-year variations are examined by analyzing data from stations which have been sampled consistently since 1979. Finally, regional perspectives on lake conditions are developed by comparing Lake Champlain data with data from other lakes in Vermont, New York, and other northern states.

DATA SOURCES

Table 1 lists morphometric and hydrologic features of Lake Champlain. The lake's size, morphometry, hydrodynamic features, and nutrient loading patterns lead to a wide range of water quality conditions (Henson and Gruendling,1977). Major sampling efforts are required in order to establish baseline conditions and track water quality variations in a system of this size and complexity.

The following analysis is based primarily upon data from the lay monitoring program operated by the Vermont Department of Water Resources and Environmental Engineering since 1979 (Warren,1984). Station names and locations are identified in Table 2 and Figure 1. The nominal sampling schedule has been weekly between June and August, although actual sampling schedules have varied at specific locations. Chlorophyll-a and phosphorus measurements are derived from mixed-layer samples. Duplicate samples for chlorophyll-a have been averaged by date prior to analysis. A total of 1624 samples collected under this monitoring program have been retrieved from STORET (USEPA's nationwide water quality data base). Complete statistical summaries by station are given in the Appendix.

Additional sources of water quality data include: (1) the long-term monitoring station operated by the USGS at Rouses Point as part of the National Stream Accounting Network (Station 04295000, 1972-1985); and (2) data summaries for 1974-1976 presented by Henson and Gruendling (1977).

BASIC CONCEPTS

Nutrients are essential components of lake ecosystems. Empirical studies have indicated that fish production generally increases with phosphorus loading (Lee et al., 1985), lake phosphorus concentration

Table 1

Lake Champlain Morphometric and Hydrologic Characteristics

Segment		Area km^2	Mean Depth m	Mean Outflow hm^3/yr	Residence Time years
1	South Lake	56.9	2.8	1270	.125
2	Port Henry	97.3	24.5	2702	.883
3	Mid Lake	127.6	55.6	3018	2.349
4	Main Lake	446.5	25.2	8855	1.272
5	Mallets Bay	54.2	12.9	958	.730
6	Northeast Arm	270.2	14.7	2509	1.583
7	Missisquoi Bay	77.5	2.8	1461	.149
	Whole Lake	1130.2	22.8	8855	2.910

Data Source: VanBenscoten(1979)

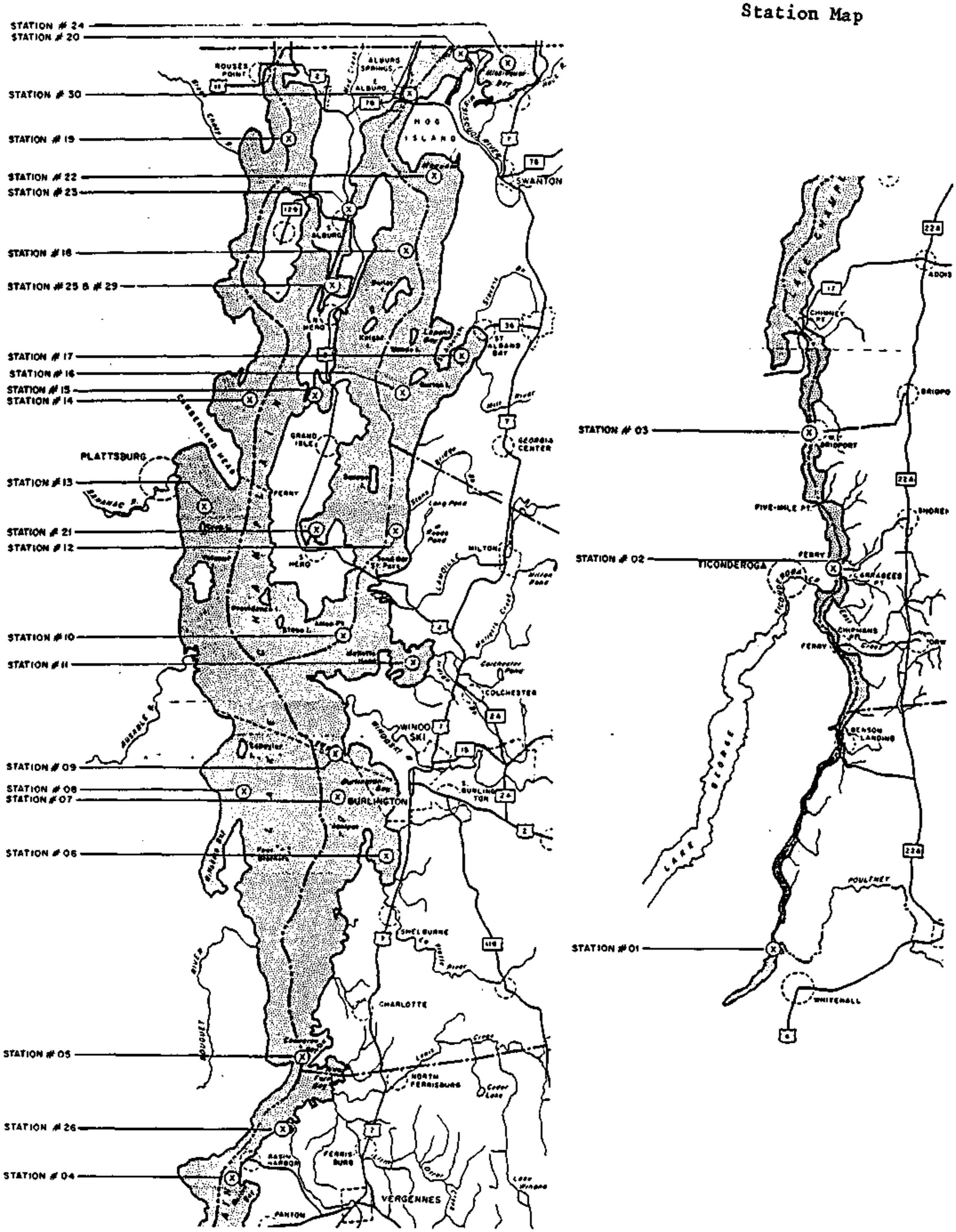
Table 2

Lake Champlain Lay Monitoring Stations

No.	Location	79	80	81	82	83	84	85
		Years Sampled						
01	South Bay	x	x	x	x			
02	Larrabee's Point	x	x	x	x	x	x	x
03	Crown Point	x	x	x	x	x	x	
04	Button Bay		x			x	x	x
05	Thompsons Point	x	x	x	x	x	x	x
06	Shelburne Bay	x	x	x	x			x
07	Burlington Bay	x	x	x	x		x	x
08	Willsboro Point	x	x	x	x	x	x	x
09	Southern Main Lake	x		x		x		x
10	Outer Mallets Bay	x	x	x			x	x
11	Inner Mallets Bay	x	x	x		x	x	x
12	Fish Bladder Island	x	x			x	x	x
13	Cumberland Bay		x		x		x	x
14	Treadwell Bay	x	x	x	x	x	x	x
15	The Gut	x	x	x	x	x	x	x
16	Ball Island	x	x	x		x	x	x
17	St. ALbans Bay	x	x	x	x	x	x	x
18	Butler Island	x	x	x	x	x	x	x
19	Point Au Fer	x	x	x	x	x	x	x
20	Outer Missisquoi Bay	x		x		x	x	x
21	Keeler Bay	x	x	x	x	x	x	x
22	Maquam Bay			x	x	x	x	x
23	Alburg Passage				x			x
24	Inner Missisquoi Bay				x	x	x	x
25	Pelots Point				x	x		x
26	Kellogg Bay				x	x	x	x
27	Pellots Point				x			x
28	Pellots Point				x			x
29	Alburg Passage				x	x		x
30	Alburg Bridge					x	x	x

Figure 1

Station Map



(Hanson and Leggett, 1981), and lake chlorophyll-a concentration (Jones and Hoyer, 1982). An excessive nutrient supply may lead to an ecological imbalance and to excessive growths of algae and/or aquatic weeds which may interfere with various water uses. Lakes with excessive nutrient supplies leading to problem conditions are commonly described as "eutrophic". The nutrient assimilation capacity of a lake, as controlled by such factors as depth, area, and flushing rate, determines whether a given nutrient supply is "excessive" and leads to problem conditions.

In the case of Lake Champlain, point sources (direct or indirect sewage effluents) account for about 42% of the phosphorus supply and non-point sources (runoff from forested, agricultural, and urban watersheds) account for about 58% of the total supply (Henson and Gruendling,1977). Because of the relatively large surface area (1130 km^2, mean depth (23 meters), and long hydraulic residence time (2.9 years) of Lake Champlain, its nutrient assimilative capacity is much greater than that of other lakes in the region. As demonstrated below, algal-related problems have been observed in certain embayments, whereas the open waters of the lake appear to be relatively free of such problems. Thus, the question of whether the existing nutrient supply is "excessive" depends upon the particular area of the lake being considered. Modeling studies are needed to quantify the nutrient assimilative capacities of various lake segments and to provide a basis for long-term management of lake eutrophication in the context of future watershed development.

Lake eutrophication can be assessed based upon phosphorus, chlorophyll-a, and transparency measurements. Phosphorus is generally the nutrient which limits or controls lake algal growth. Chlorophyll-a (photosynthetic pigment) is a measure of algal density. Transparency (Secchi Depth) is a measure of water clarity, which is a function of algal density, inorganic turbidity, and color. Because they are all related to algal density, these three factors are generally correlated when average values from different lakes (or different stations within lakes) are examined. Lakes or stations with higher phosphorus concentrations will generally tend to have higher chlorophyll-a concentrations and lower transparencies. Such correlations are imperfect, however, because other factors may influence each of the measurements under various conditions.

The following scheme has been widely used for lake trophic state classification based upon surface phosphorus, chlorophyll-a, and transparency measurements averaged over the growing season (Reckhow and Chapra, 1983; Maloney,1979):

		Trophic State				
			Boundary		Boundary	
Measurement	Units	Oligotrophic		Mesotrophic		Eutrophic
Phosphorus	ppb	"	10-12	"	20-25	"
Chlorophyll-a	ppb	"	2.5-4	"	7-12	"
Transparency	meters	"	5-3.7	"	3-2	"

The classification scheme is rather subjective and the definitions of trophic state boundaries vary from limnologist to limnologist. Despite limitations, it provides some frame of reference for interpreting lake measurements.

Of these variables, chlorophyll-a is the most direct measure of algal density. At high concentrations of chlorophyll-a, aesthetics, recreational water uses, and water supplies can be impaired. The extent of use impairment at a specific chlorophyll-a level depends upon the types and intensities of water use, regional factors, user adaptation, and dominant algal species. Reports of systematic studies aimed at defining chlorophyll-a criteria for specific water uses are generally scarce in the literature.

A study of 21 South African reservoirs (Walmsley and Butty, 1984; Walmsley, 1984) involved simultaneous collection of water quality data (including nutrients, chlorophyll-a, transparency, etc.), aesthetic data (general water appearance, extent of surface scums, etc.), and evidence of use impairment (derived from interviews with recreational area managers and water treatment plant operators). Based upon results of these surveys, Walmsley and Butty assigned "nuisance values" to certain instantaneous chlorophyll-a ranges, according to the following scheme:

Chlorophyll-a Range (ppb)	Nuisance Value	Equivalent Transparency (meters)
< 10	"No Problems Encountered"	> 2.9
10-20	"Algal Scums Evident"	1.7 - 2.9
20-30	"Nuisance Conditions Encountered"	1.2 - 1.7
> 30	"Severe Nuisance Conditions Encountered"	< 1.2

While the applicability of this classification scheme to Vermont lakes and lake users has not been systematically evaluated, there is a consensus among limnologists that chlorophyll-a concentrations exceeding 20-40 ppb are aesthetically displeasing and generally pose problems for most water uses. Although attempts at formal regulation of water bodies based upon chlorophyll-a levels have been limited, the state of North Carolina has adopted a chlorophyll-a standard of 40 ppb to protect water bodies from severe nuisance conditions relating to algal growth.

The "equivalent transparency" values in the above table have been calculated from the corresponding chlorophyll-a using a model which has been tested against Vermont lake data (Walker, 1982) and assuming a non-algal turbidity level of .1 m^{-1} (typical of open waters of Lake Champlain). The "severe nuisance" category corresponds to a transparency less than 1.2 meters or 4 feet, which equals the informal standard for bathing beaches in Massachusetts and New York based upon safety considerations.

Note that nuisance values are defined based upon **instantaneous** chlorophyll-a levels (at a specific location and time, coincident with water use), whereas the trophic state categories discussed above are based upon **seasonal mean** levels. Temporal variability in chlorophyll-a is typically high. Coefficients of variation are generally in the range of .4 to .8 and the maximum concentration detected in a weekly sampling program is often 2 to 3 times the seasonal mean.

While limited by the subjectivity of the categories, nuisance level frequency (percent of the time sampled chlorophyll exceeds a given nuisance value) is a useful alternative expression of lake condition which more clearly reflects variability in lake conditions and the tendency of water users to perceive and react to extreme conditions, as compared with trophic state classification based upon seasonal mean values. Statistical models have been developed for relating chlorophyll-a nuisance-level frequencies to seasonal mean values, based upon data from Vermont lakes (Walker,1984).

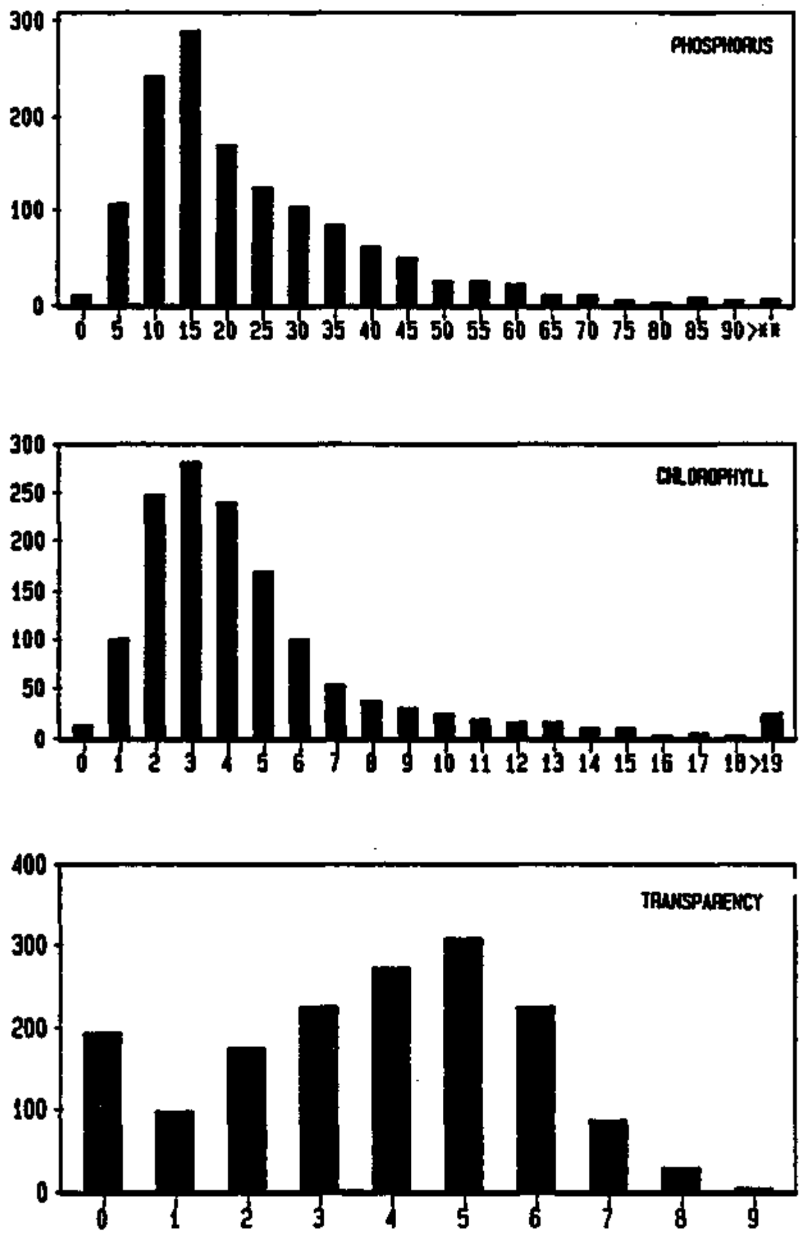
DATA ANALYSIS

Frequency distributions of phosphorus, chlorophyll-a, and transparency measurements from all lay monitoring stations and years are shown in Figure 2. The X-axes give the instantaneous sample values (phosphorus and chlorophyll-a in ppb and transparency in meters) at the lower end of each frequency interval. The Y-axes give the total number of measurements in each interval. The most frequent intervals are 15-20 ppb for phosphorus, 3-4 ppb for chlorophyll-a, and 5-7 meters for transparency. The phosphorus and chlorophyll-a distributions are markedly skewed and suggest log-normal behavior, which is typical of lake nutrient and algal data (Heyman et al.,1984). The frequency distributions reflect the combined influences of spatial variations within the lake, yearly and seasonal variations at each station, and sampling errors.

Frequency distributions at the Thompson's Point station (closest to the proposed hatchery discharge) are shown in Figure 3. For 66 samples over a seven-year period, observed phosphorus concentrations ranged from 7 to 56 ppb, chlorophyll-a from 1.2 to 9.5 ppb, and transparency from 1.5 to 8 meters. Based upon the nuisance-level criteria for chlorophyll-a discussed above, the Thompson's Point station has been free from nuisance conditions relating to algal growth. Periods of low

Figure 2

Frequency Distributions - All Data



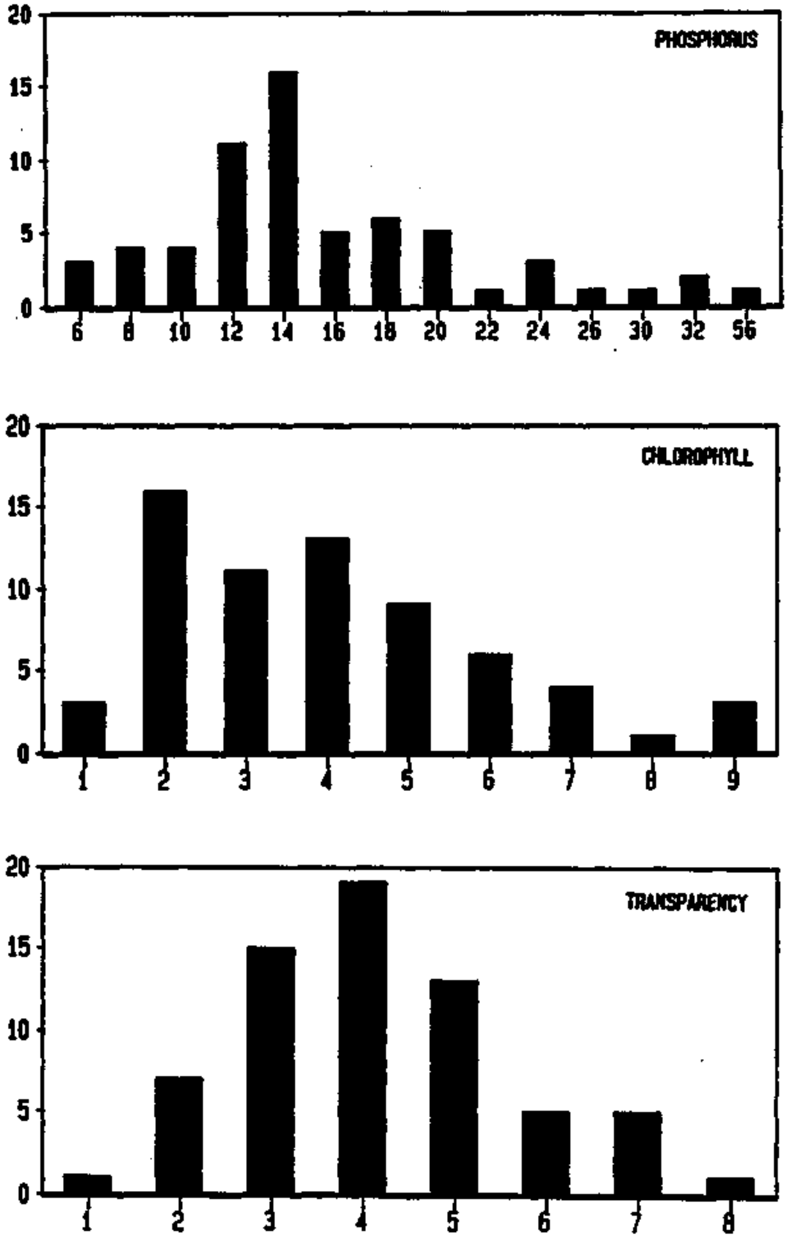
X-Axis: Total Phosphorus (ppb), Chlorophyll-a (ppb), or Transparency (m)

Minimum of Interval

Y-Axis: Number of Observations

Figure 3

Frequency Distributions - Thompson's Point (Station 5)



X-Axis: Total Phosphorus (ppb), Chlorophyll-a (ppb), or Transparency (m)

Minimum of Interval

Y-Axis: Number of Observations

transparency (< 3 meters) have generally occurred in late spring/early summer and may be related to spring diatom populations, pollen, and inorganic suspended solids discharged into the lake during spring high flows.

Spatial variations are illustrated in Figure 4. These summaries are based upon long-term means from stations which were sampled at least 4 years since 1979. Stations 1-20 are generally oriented in a south-to-north direction (see Table 2 and Figure 1 for station locations). Spatial variations in water quality reflect differences in morphometry, hydrodynamics, and nutrient loadings among lake segments.

The most distinctive spatial feature in the water quality profile is the south-to-north gradient. Stations 1, 2, and 3 have considerably higher phosphorus, higher chlorophyll-a, and lower transparency values than the open-water stations. These are located in the relatively shallow and narrow southern end of the lake. The higher phosphorus levels do not necessarily mean that streams discharging into the South Lake have higher concentrations than streams discharging into other lake segments. Dilution volumes and hydraulic residence times in the South Lake are much lower; this provides less time for sedimentation of inflowing nutrients and suspended solids. Resuspension of shallow bottom sediments by wind and boat traffic may also contribute to high phosphorus and turbidity in the South Lake.

The South Lake stations are most distinct with respect to transparency. Two factors contribute to reduced transparency in this area (1) higher algal densities (chlorophyll-a) and (2) higher inorganic turbidity levels. Spatial variations in non-algal turbidity levels are illustrated in Figure 5. South Lake stations have average non-algal turbidity levels of 1.5 to 3.1 $meters^{-1}$, as compared with values less than .2 $meters^{-1}$ in the remaining portion of the lake. Based upon studies of nutrient/algal/transparency relationships in Corps of Engineer reservoirs (Walker,1985), non-algal turbidity not only reduces transparency, but also reduces algal growth rates and results in lower

Figure 4

Mean Concentrations by Station

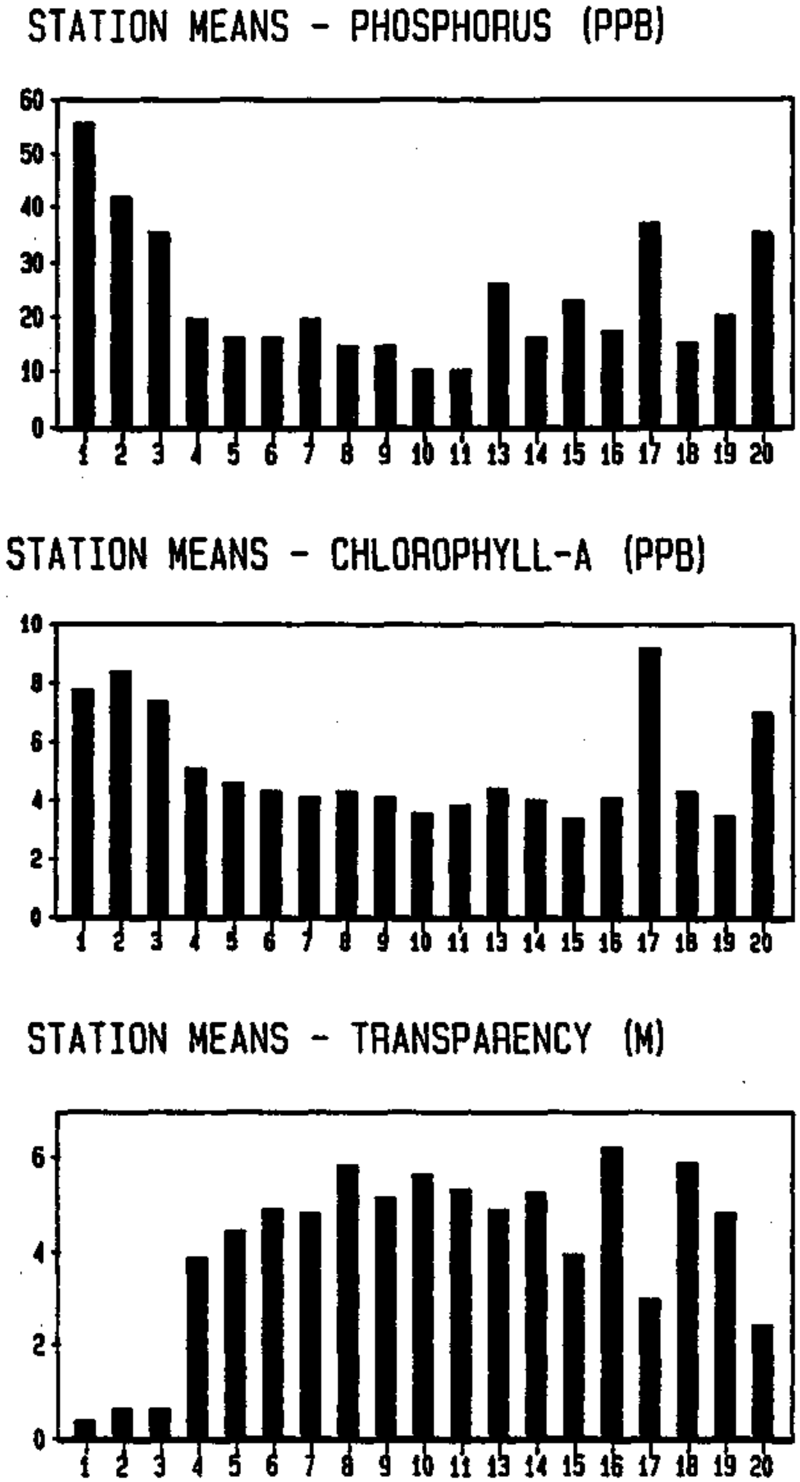
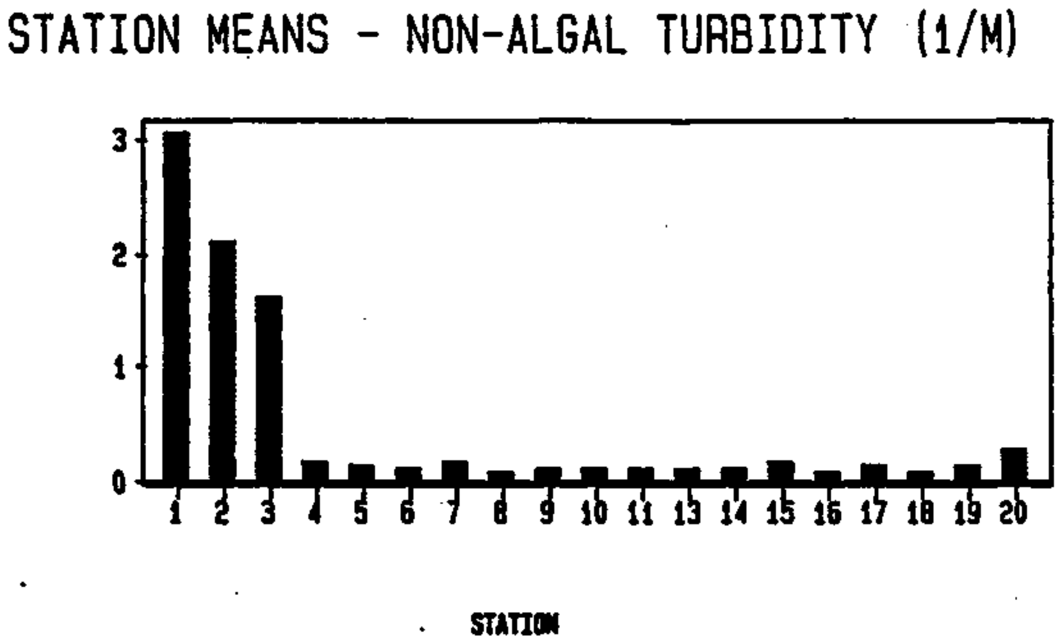


Figure 5

Average Spatial Variations in Non-Algal Turbidity



Non-Algal Turbidity Is Calculated From Chlorophyll-a and Transparency Measurements Using the Following Equation:

Non-Algal Turbidity (m^{-1}) = 1/Secchi - .025 Chl-a

Reference: Walker, 1982,1985

mean chlorophyll-a concentrations than would otherwise exist at a given nutrient level.

Based upon Figure 4, Stations 17 (St. Albans Bay) and 20 (Missisquoi Bay) also stand out as having higher phosphorus, higher chlorophyll-a, and lower transparency than other lake stations. Higher algal productivity in these bays reflects elevated tributary nutrient loadings and bay morphometric features which limit mixing with open lake waters. Variations among the remaining stations are relatively minor. For the Mid Lake, Main Lake, and Northeast Arm, mean phosphorus ranges from 10 to 20 ppb, mean chlorophyll-a ranges from 3 to 5 ppb, and mean transparency ranges from 4 to 6 meters. Based upon station mean concentrations, these areas would be classified in lower end of the mesotrophic range, whereas the South Lake, St. Albans Bay, and Missisquoi Bay would be classified as eutrophic. The least productive area of the lake appears to be Mallets Bay (Stations 10-11, mean phosphorus = 10 ppb, chlorophyll-a = 3.5-3.8 ppb, transparency = 5.3-5.6 meters).

Based upon lake configuration and hydrodynamics, the far-field impact zone for the proposed hatchery discharge consists of the main lake areas from Thompson's Point north to Rouses Point. This area includes Stations 5, 7, 8, 9, 13, 14, and 19. Because of the intensity of mixing in the open waters of the lake, spatial variations among these stations are generally minor. Mean concentrations for this zone as follows:

			Trophic Classification
Phosphorus	18	ppb	Mesotrophic
Chlorophyll-a	4.0	ppb	Oligo-Mesotrophic
Transparency	5.0	meters	Oligotrophic

Discrepancies among the trophic classifications derived from the measurements reflect the fact that the chlorophyll-a/phosphorus ratio in Lake Champlain appears to be unusually low (.22), in relation to values typically observed in Vermont Lakes and other northern lakes (approximately 0.5, Walker, 1982; Warren,1984). Factors possibly contributing to this are discussed below.

In some lakes, nitrogen limits algal growth and causes lower algal response to phosphorus (Smith,1980; Walker,1985). Based upon algal assays and nutrient analyses conducted by the U.S. Environmental Protection Agency (1974), phosphorus was the limiting nutrient at most lake stations in 1972. Nitrogen limitation was indicated at one station in the Northeast Arm of the lake, however. Long-term monitoring conducted by the U.S. Geologic Survey at Rouses Point indicates an average total nitrogen concentration of 550 ppb and total N/P ratio of 25, which suggests phosphorus limitation. Henson and Gruendling (1977) also concluded that algal productivity in the lake was limited by phosphorus.

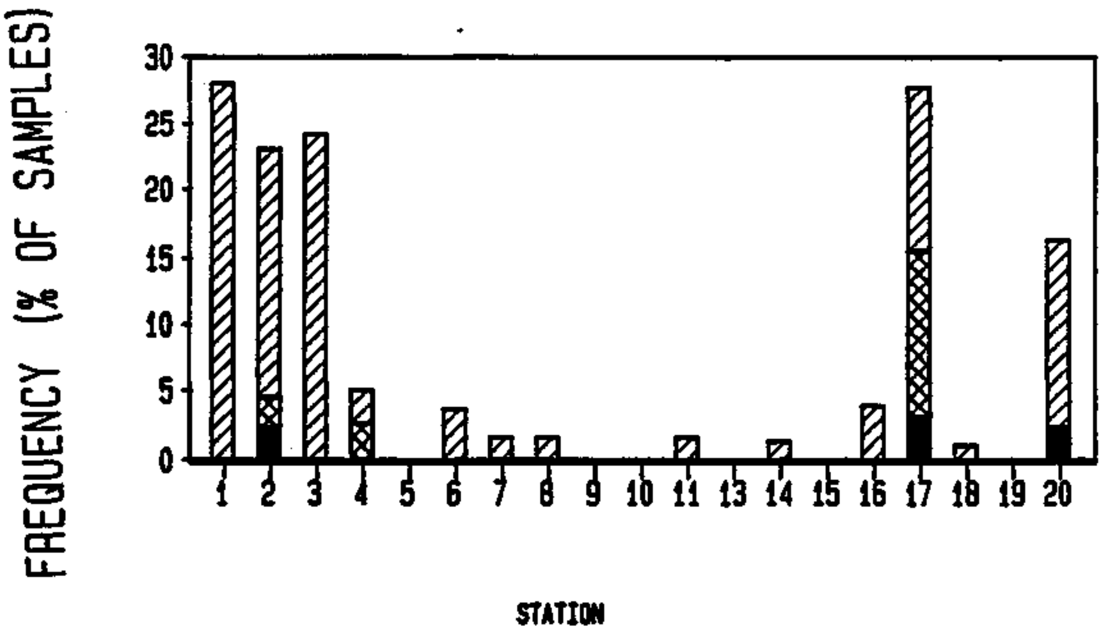
Lake hydrodynamic factors may also influence algal productivity. Because of the size and long wind fetch of Lake Champlain, the mixed layer tends to be deeper (10-13 meters) than that typically found in other Vermont Lakes (5-7 meters). This distributes algal biomass over a larger volume and may result in lower mean cell densities than would otherwise develop in lakes with shallower thermoclines. Mixed layer depth may also be a factor in the open waters of the Great Lakes, which also have chlorophyll-a/phosphorus in the .2 -.3 range (Schelske, 1977; Chapra and Dobson, 1981).

The frequencies of instantaneous chlorophyll-a concentrations exceeding various nuisance levels are shown in Figure 6. Stations with higher mean chlorophyll-a concentrations (1-3, 17,20) generally have higher nuisance-level frequencies, although the station-to-station variations are more marked for nuisance level-frequencies (Figure 6) than for seasonal mean concentrations (Figure 4). Theoretically, Figure 6 would more accurately reflect user perceptions of the relative differences among stations with respect to algal-related problems.

Occurrences of "Nuisance" and "Severe Nuisance" conditions are limited to the South Lake (1-3), St. Albans Bay (17), and Missisquoi Bay

Figure 6

Chlorophyll-a Extreme-Value Frequencies by Station



Instantaneous Chlorophyll-a (ppb)	Algal Nuisance Value *
> 30 ppb	"Severe Nuisance Conditions"
20 - 30 ppb	"Nuisance Conditions"
10 - 20 ppb	"Algal Scums Evident"

* (Walmsley,1984)

(20). Remaining portions of the lake are in the "Scums Evident" category 0-4% of the time, but are free of "Nuisance" and "Severe Nuisance" conditions. All of the chlorophyll-a samples taken at Station 5 (Thompsons Point, closest to proposed hatchery discharge) have been below the 10 ppb nuisance criterion ("No Problems Evident Category"). Out of 420 chlorophyll-a samples taken in the hatchery far-field impact zone (Stations 5,7,8,9,13,19), only 3 exceeded 10 ppb.

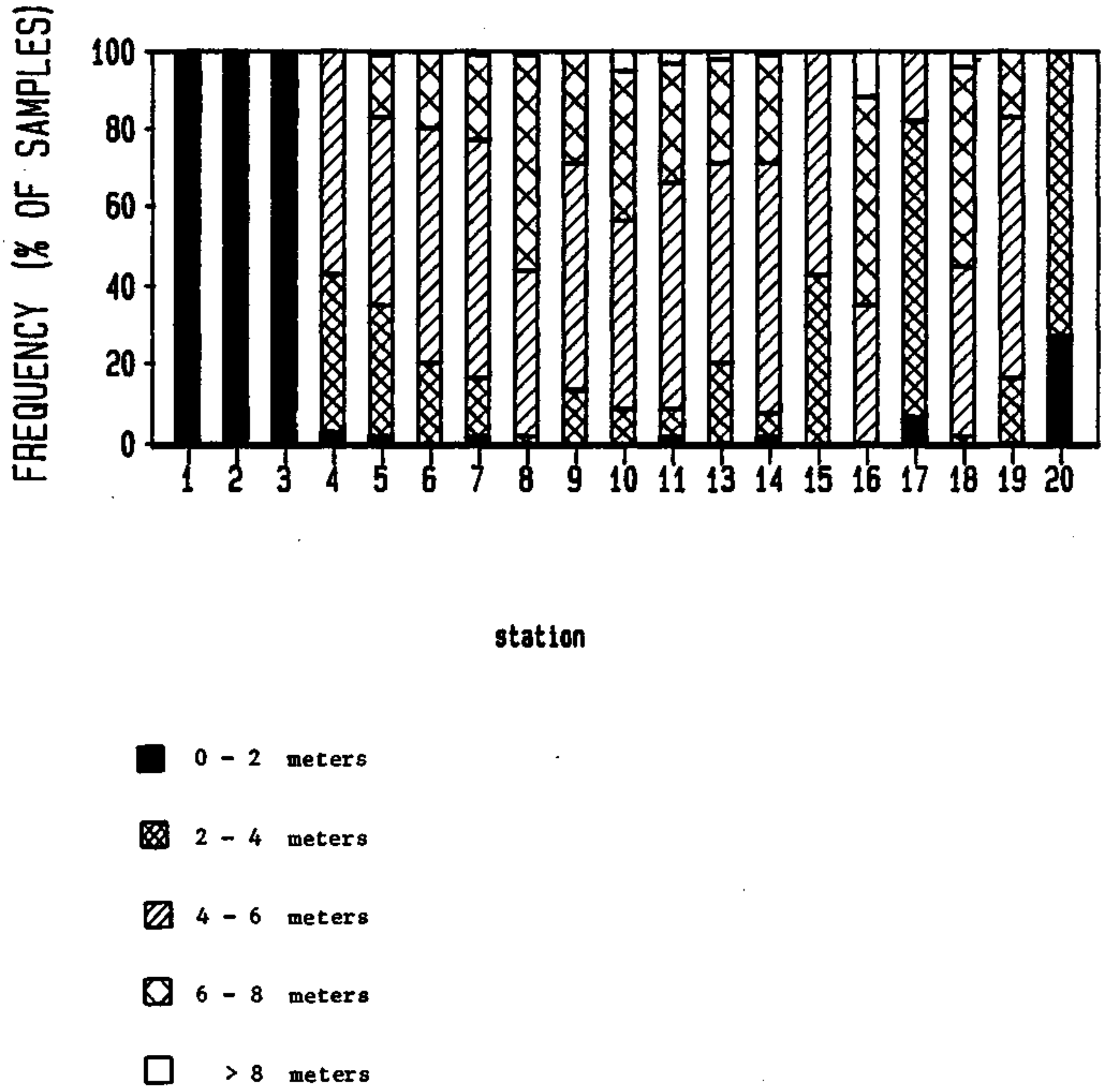
Because the nuisance-level criteria have not been "calibrated" against Lake Champlain users, the frequencies displayed in Figure 6 are more useful for making relative comparisons among stations than for predicting complaint frequencies. Both the nuisance level frequencies and trophic state classifications suggest, however, that algal-related water quality problems are generally restricted to the South Lake, St. Albans Bay, and Missisquoi Bay. Problems may also exist in other, unmonitored embayments.

Transparency observation frequencies are summarized by station in Figure 7. The percent of transparency measurements are shown in 2-meter intervals. Secchi depths less than 2 meters were recorded for 100% of the measurements made at South Lake Stations (1,2,3), 8% in St. Albans Bay, and 26% in Missisquoi Bay. At the other extreme, transparency always exceeded 4 meters at Station 16 (Ball Island, Northeast Arm). The frequencies of transparencies less than 4 meters declined steadily moving north from Station 4 (42%) to Station 10 (<10%). This decline most likely reflects the sedimentation of phosphorus loads and inorganic turbidity as the lake flows north.

As discussed above, phosphorus limits algal growth throughout most of Lake Champlain. Statistical relationships between phosphorus and chlorophyll-a reflect the influences of limiting nutrient concentration on algal populations. Such relationships can be explored by plotting station-mean chlorophyll-a vs. station-mean total phosphorus concentrations. An alternative approach, which is feasible in this case because of the relatively large size of the Lake Champlain data base, is based upon a cross-tabulation of individual phosphorus and chlorophyll-a

Figure 7

Transparency Observation Frequencies by Station



measurements. This permits examination of the frequency distribution of chlorophyll-a levels as a function of total phosphorus range, using data from all stations. A similar cross-tabulation can be developed for transparency.

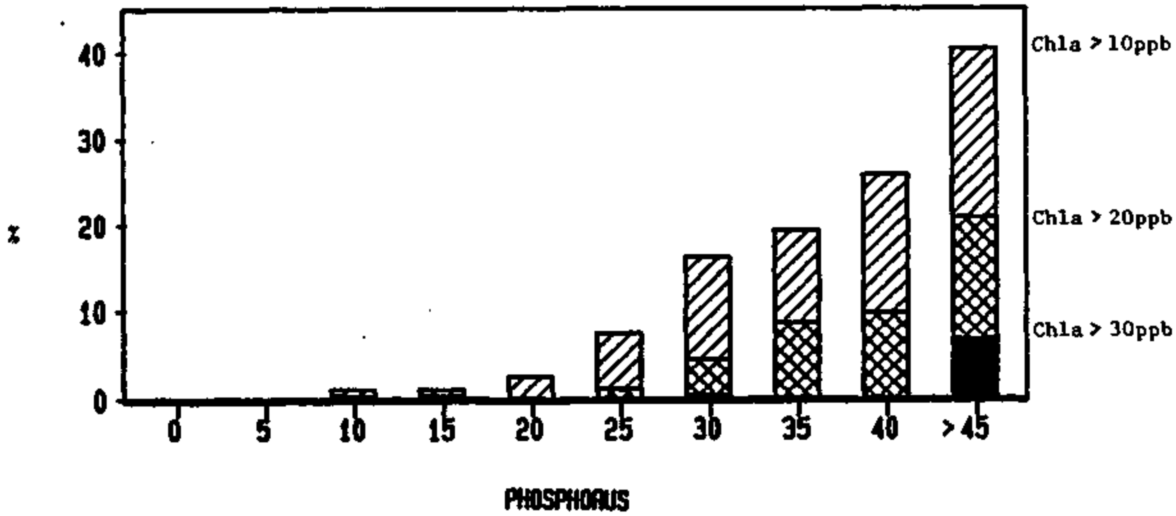
Cross-tabulation results are displayed in Figure 8. Because of the elevated non-algal turbidity levels in the South Lake, algal dynamics and correlations among these measurements are expected to be significantly different in this area, as compared with the rest of the lake. Accordingly, data from Stations 1-3 have been excluded from the analysis. Phosphorus categories have been defined at 5 ppb intervals from 0 to 40 ppb; the last interval (">45") contains all samples with phosphorus concentrations exceeding 45 ppb. Within each phosphorus category, the frequencies of chlorophyll-a observations have been computed at 10 ppb intervals (corresponding to the nuisance-level criteria discussed above). A corresponding calculation has been done for transparency observations at 1-meter intervals.

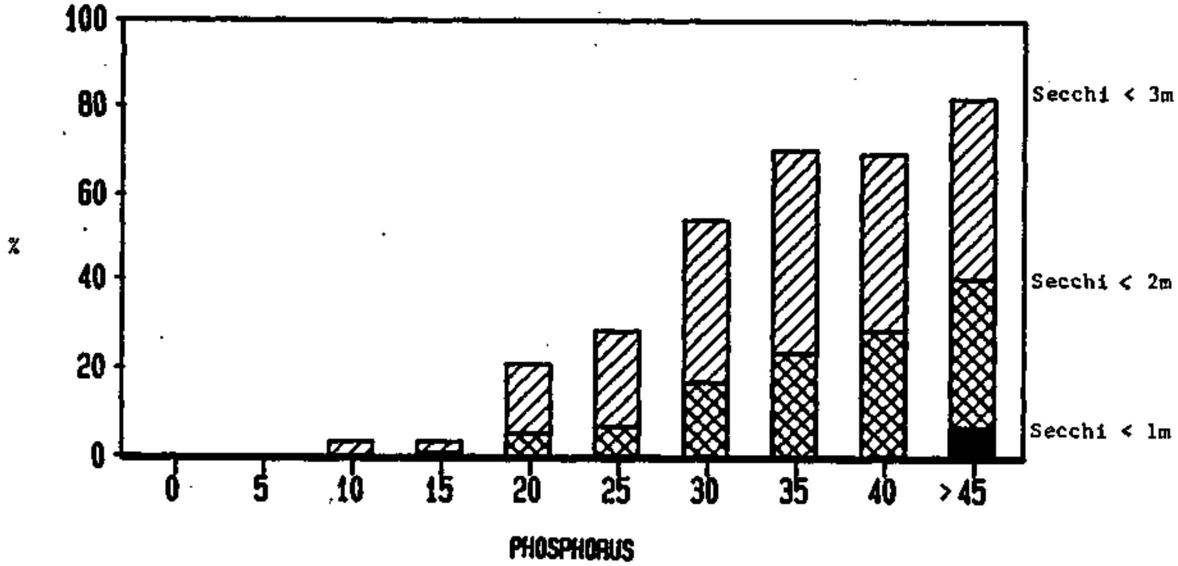
Results (Figure 8) suggest a generally well-behaved relationship between phosphorus and extreme-value frequencies for chlorophyll-a and transparency. One very useful feature of this type of analysis is that the results are expressed in terms of probabilities. These probabilities reflect the combined influences of temporal variability in the system and random factors which influence the phosphorus/chlorophyll or phosphorus/transparency relationship. For example, results indicate that if a phosphorus measurement is in the 25 ppb category (i.e. between 25 and 30 ppb), then the probabilities of chlorophyll-a values exceeding 10 ppb and 20 ppb are 7.3% and 1.0%, respectively.

For phosphorus concentrations less than 25 ppb (categories 0, 5, 10, 15, 20) the probabilities of nuisance conditions related to algal growth (chlorophyll-a > 10 ppb or transparency < 2 meters) are very small. As phosphorus increases beyond 25 ppb, the nuisance-level probabilities increase steadily. "Severe nuisance conditions" (Chlorophyll-a > 30 ppb, Transparency < 1 meter) have only been observed in Lake Champlain at phosphorus concentrations exceeding 45 ppb.

Figure 8

Chlorophyll-a and Transparency Observation Frequencies
vs. Total Phosphorus





X Axis: Total Phosphorus , Minimum of 5 ppb Interval
i.e., '5' Includes All Samples with 5 <= P < 10 ppb

Y Axis: Frequency of Chlorophyll-a or Transparency Interval (%)

Data Set: All Lay Monitoring Stations and Years,
Excluding South Lake Stations (1-3)

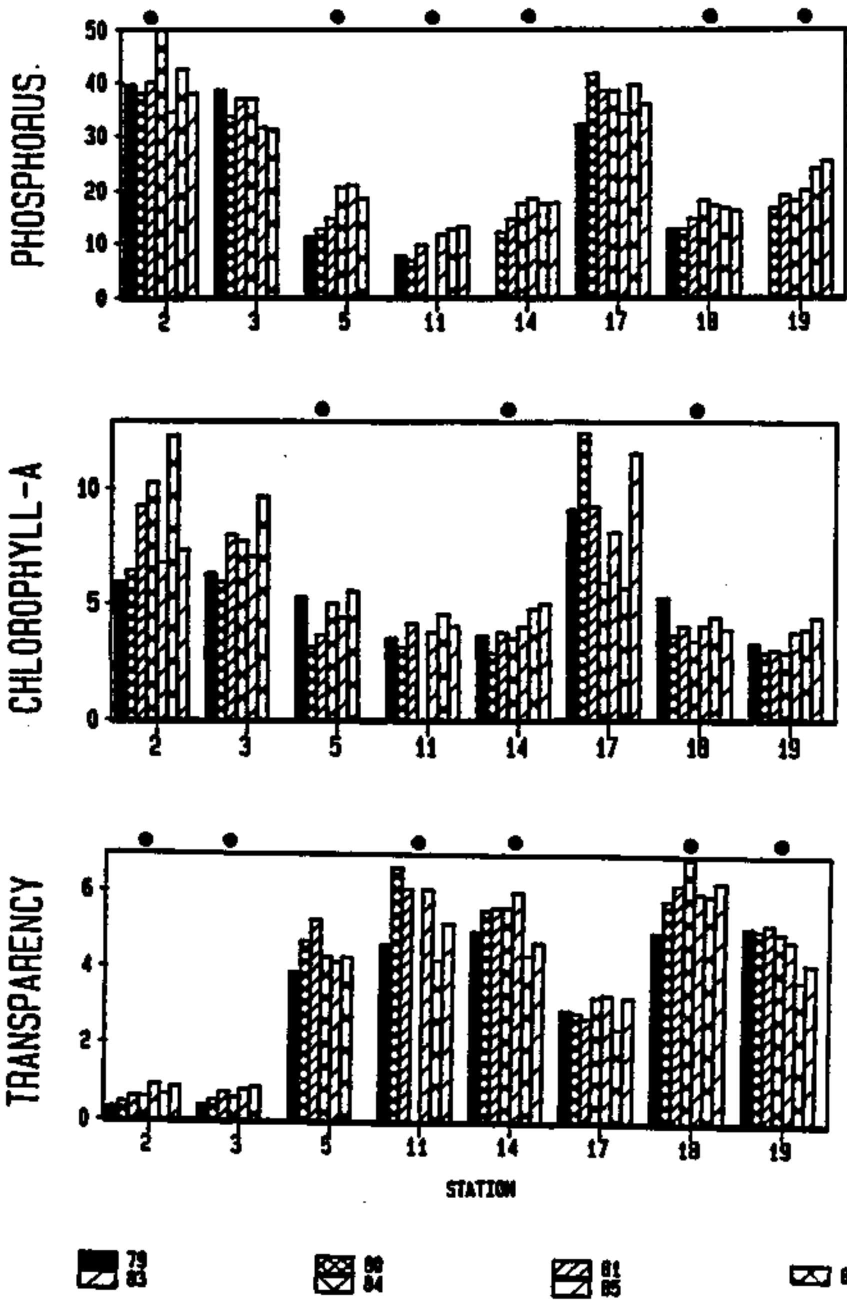
The cross-tabulation provides information on "risk" (based upon nuisance-level chlorophyll-a or transparency criteria) as a function of phosphorus level. This type of information seems useful for predicting the effects of changes in phosphorus and for selecting a reasonable phosphorus standard or criterion to protect the lake from undesirable algal-related impacts. As discussed above (see INTRODUCTION), it is projected that the offshore hatchery discharge will increase the total phosphorus concentration in the immediate discharge zone (40-acres) by less than 2.5 ppb (from 15 to 17.5 ppb) under critical August/September conditions. Based upon Figure 8, average phosphorus concentrations in the discharge zone will remain within the 15-20 ppb phosphorus category and nuisance-level frequencies will remain small.

Figure 9 depicts year-to-year variations in average concentrations at eight stations which have been monitored consistently since 1979. These stations have been selected as having the most reliable data for assessing long-term trends in the lake (Warren,1984). Analyses of variance have been conducted to test the statistical significance of differences among yearly means for each station and variable. Year-to-year variations may reflect random, climatologic factors and/or trends resulting from changes in nutrient loadings.

Yearly variations are statistically significant in 6 out of the 8 stations for phosphorus, 3 stations for chlorophyll-a, and 6 stations for transparency. At 5 stations (5-Thompsons Point, 11-Mallets Bay, 14-Treadwell Bay (Main Lake), 18-Butler Island (Northeast Arm), and 19-Point Au Fer (Main Lake)), the yearly variations in phosphorus appear to represent an increasing trend, with higher concentrations during 1982-1985 as compared with 1979-1981. Mean chlorophyll-a concentrations were also higher in later years at stations 4, 14, and 19, although the 1979 data do not conform to a general increasing trend and yearly variations at Station 19 are not statistically significant. Corresponding reductions in mean transparency during 1984-1985 are indicated at stations 14 and 19.

Figure 9

Year-to-Year Variations at Consistently-Sampled Stations



● Differences Among Yearly Means Statistically Significant at 95% Confidence Level, Based upon One-Way Analysis of Variance

Stations: 2 = Crown Point 3 = Gilligans Bay 5 = Thompsons Point
11 = Mallets Bay 14 = Treadwell Bay 17 = St. Albans Bay
18 = Butler Isl. 19 = Point Au Fer

While Figure 9 suggests increasing eutrophication at some locations (particularly main lake stations 14 and 19), the year-to-year variations do not necessarily constitute a "trend" attributed to increased cultural impacts on the lake. Fluctuations in climatologic factors can have major influences on lake conditions by influencing stream flows, non-point nutrient loadings, lake hydrodynamics, and algal dynamics. Statistical analyses of data from other Vermont lakes (Walker, 1982) indicate that expected range of yearly-mean values for a 7-year period of record (expressed as the ratio of the maximum to minimum yearly mean value) is 2.3 for total phosphorus, 2.0 for chlorophyll-a, and 1.5 for transparency. This natural variability makes it difficult to reliably detect modest long-term trends based upon relatively short periods of record.

Data from other monitoring programs suggest that conditions have not changed dramatically since the mid 1970's. Table 3 compares mean values for 1974-1976 compiled by Henson and Gruendling (1977) with 1979-1985 averages at various lake stations. Figure 10 plots yearly mean total phosphorus concentrations measured by the USGS at Rouses Point between 1972 and 1985. This station is closest to lay monitoring Station 19 (Point Au Fer). The power of the USGS data for trend detection is limited by infrequent sampling schedule (4-8 samples/year) and low resolution of the phosphorus analyses ($\pm$10 ppb). The lower sampling frequency following the 1981 change in administration leads to relatively high standard errors in the calculated mean concentrations for these years.

There appears to be considerable serial correlation and/or cyclical behavior in the yearly mean phosphorus values at Rouses Point. Mean concentrations were relatively low (10-15 ppb) in 1972, 1974, and 1978-1980 and relatively high (25-30 ppb) in 1975-76, and 1981-1984. Given the general pattern at this station, it seems inappropriate to interpret yearly variations at some lay monitoring stations between 1979 and 1985 as "trends". A longer period of record under consistent sampling regimes is required to quantify variance components and to separate natural year-to-year variations from long-term trends.

Table 3

Lay Monitoring Station Means Compared with Values Reported by Henson and Gruendling (1977)

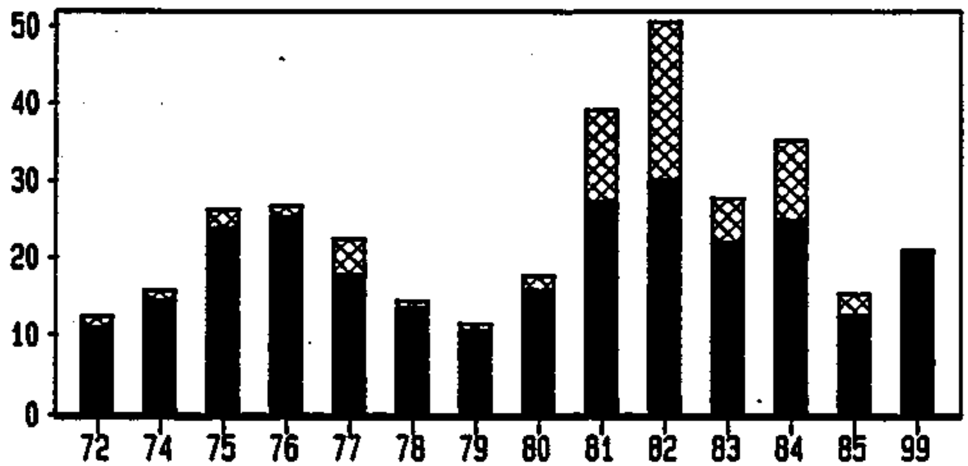
Lake Segment	Station	Phosphorus ppb	Chl-a ppb	Secchi m
Main Lake	Henson and Gruendling	18	3.7	4.4
	LMP 8	15	4.2	5.8
	LMP 14	16	3.9	5.2
	LMP 19	20	3.4	4.8
Missisquoi Bay	Henson and Gruendling	50	10.0	1.6
	LMP 20	35	6.9	2.4
	LMP 24	43	7.8	2.4
Northeast Arm	Henson and Gruendling		3.5	5.5
	LMP 12	20	5.0	5.9
	LMP 16	17	4.0	6.2
	LMP 18	15	4.2	5.9
St. Albans Bay	Henson and Gruendling	37	6.7	2.4
	LMP 17	37	9.1	3.0
Mallets Bay	Henson and Gruendling	12	6.2	4.4
	LMP 10	10	3.5	5.6
	LMP 11	10	3.8	5.3
South Lake	Henson and Gruendling	50-110	10.2	0.7
	LMP 1	56	7.6	0.4
	LMP 2	42	8.3	0.6
	LMP 3	35	7.3	0.6
Shelburne Bay	Henson and Gruendling	20		3.8
	LMP 6	16	4.2	4.9
Burlington Bay	Henson and Gruendling	22	5.8	3.9
	LMP 7	19	4.0	4.8
Cumberland Bay	Henson and Gruendling	25	5.5	2.9
	LMP 13	26	4.3	4.9

Henson and Guendling (1977) average values, miscellaneous data sources, 1974-1976.

LMP = Vermont Lay Monitoring Station, Means 1979-1985.

Figure 10

Time Series of Yearly-Mean Total Phosphorus Concentrations Measured by the USGS at Rouses Point, 1972-1985.



Mean - 1 Standard Error of Mean

Mean + 1 Standard Error of Mean

Y-Axis : Yearly Mean Total Phosphorus (ppb)

Sampling Frequencies :

8 Samples/Year - 1972-1981

4-5 Samples/year - 1982-1985

Year 99 = All Samples

Because of the high natural variability of phosphorus and chlorophyll-a measurements, long-term trends in lake eutrophication (which may lead to increased hypolimnetic oxygen depletion) would be more reliably detected based upon oxygen and temperature profile measurements taken in a network of consistently-monitored and strategically-placed stations.

LAKE COMPARISONS

Additional perspectives on eutrophication in Lake Champlain can be obtained by comparing mean values or phosphorus, chlorophyll-a, and transparency for different lake segments with mean values reported for other lakes in the region. The comparisons are made among four groups of lakes:

(1) Vermont Lakes
(2) Lake Champlain
(3) North American Great Lakes
(4) New York Lakes

Histograms of phosphorus, chlorophyll-a, and transparency values are shown in Figures 11, 12, and 13, respectively. Lake names are abbreviated in six characters. A complete tabulation of the data and sources is given in the Appendix.

A wide range of conditions is apparent within each group. Phosphorus concentrations in Lake Champlain are generally higher than the median value for other Vermont Lakes. This primarily reflects point-source loadings to Champlain which are generally absent from other Vermont lakes. Because of the lower algal response to phosphorus in Champlain (as discussed above), chlorophyll-a and transparency levels are more typical Vermont. Transparency levels in the South Lake are the lowest in the entire data set because of elevated non-algal turbidity levels.

Figure 11

Lake Comparisons - Mean Total Phosphorus

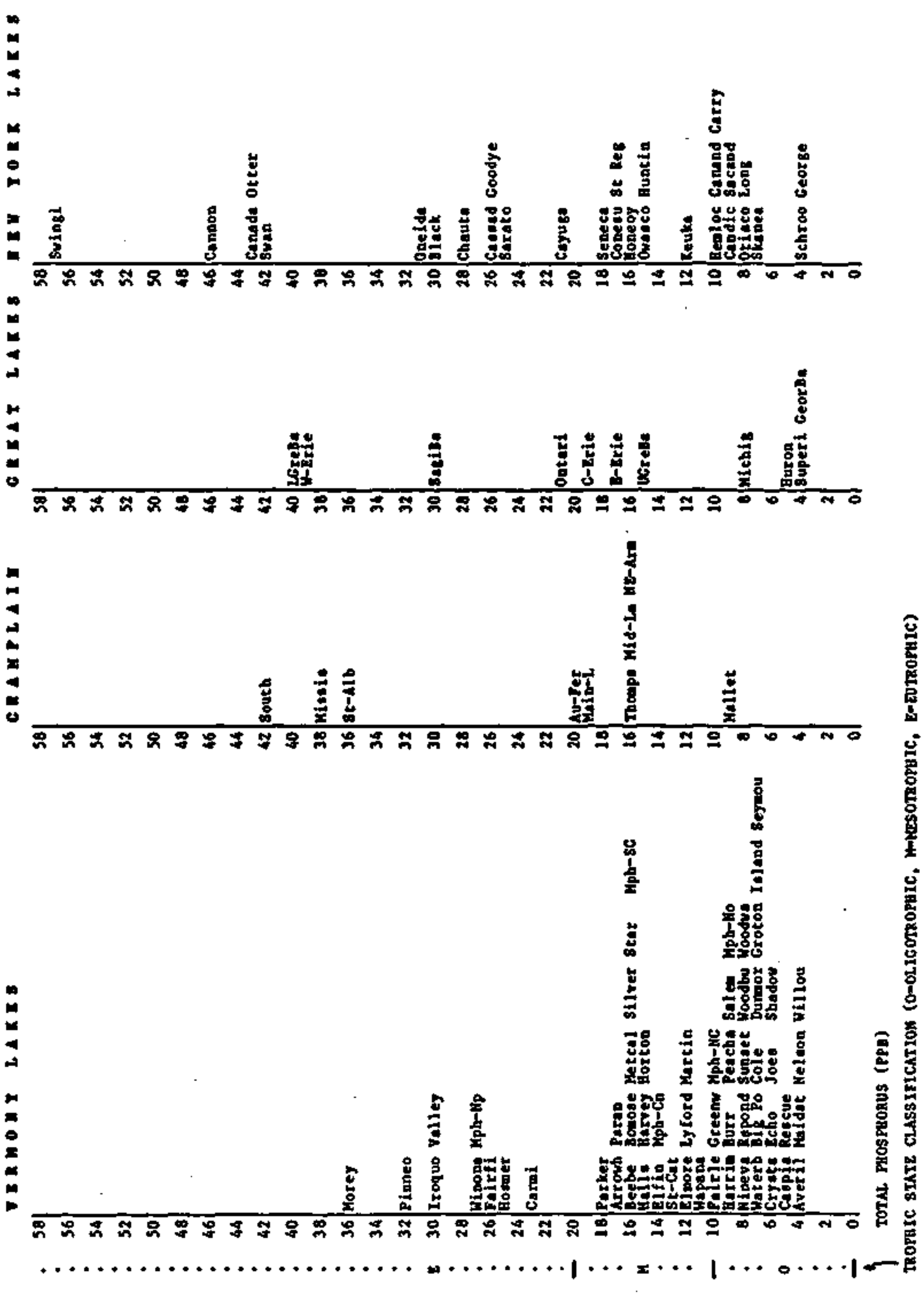


Figure 12

Lake Comparisons - Mean Chlorophyll-a

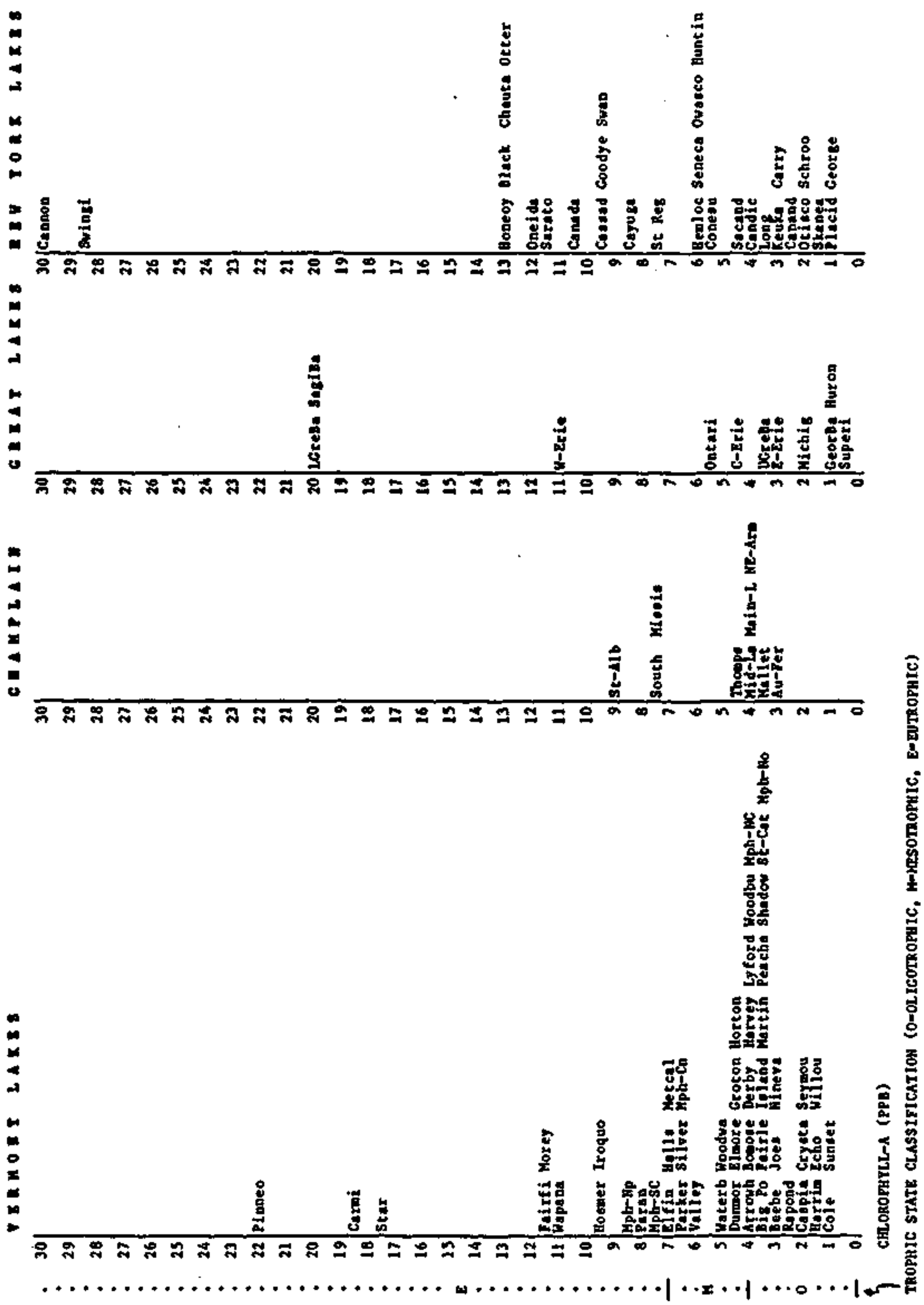
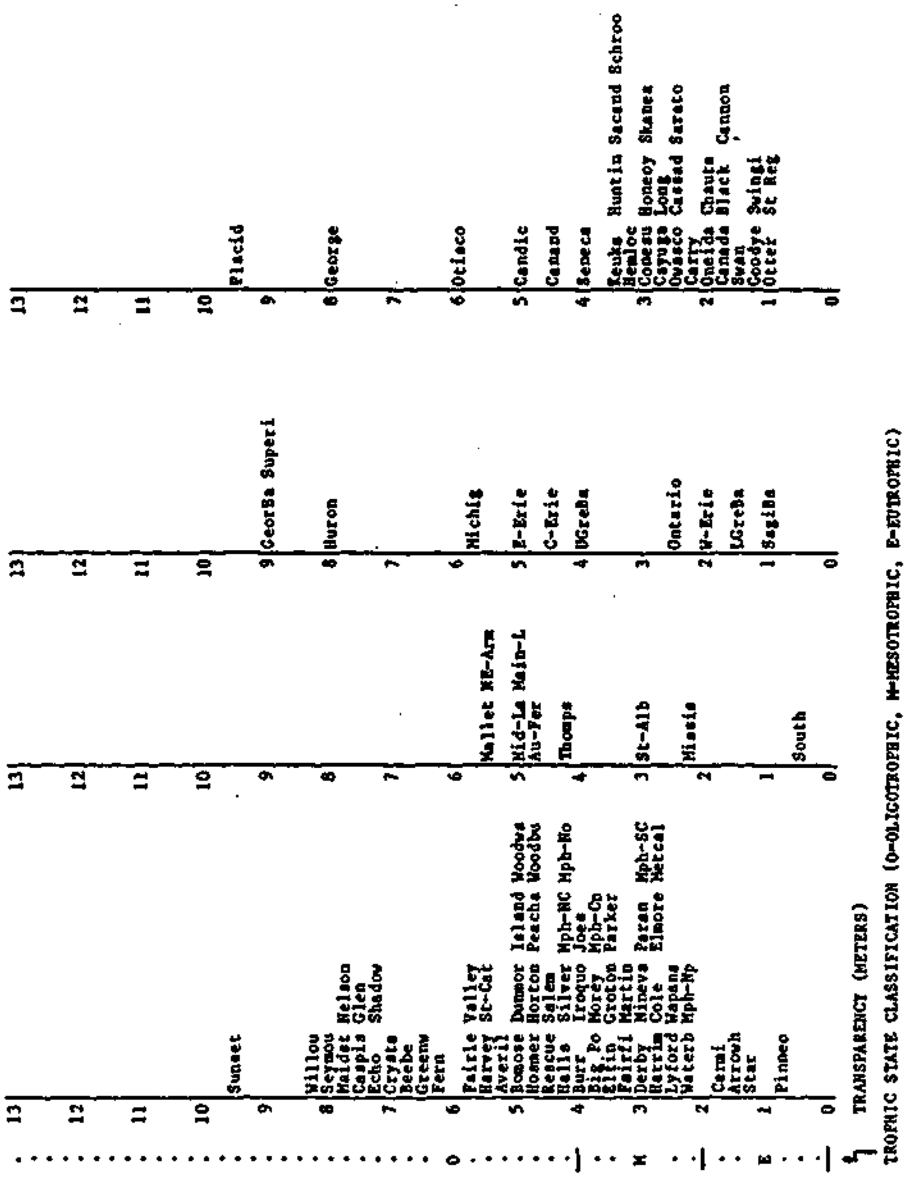


Figure 13

Lake Comparisons - Mean Transparency



The distributions of conditions in the Great Lakes (data summaries for early-mid 1970's) are analogous to those found in Lake Champlain. Elevated phosphorus and chlorophyll-a levels are found in embayments impacted by point sources and with limited exchange with open lake waters (Lower Green Bay, Saginaw Bay) and in Western Lake Erie. The open waters of Michigan, Superior, and Huron are more oligotrophic (Phosphorus 4-8 ppb, Chl-a 1-2 ppb) than the open waters of Lake Champlain (Phosphorus 15-20 ppb, Chl-a 3-5 ppb). This reflects greater mean depths (91, 145, and 66 meters vs. 23 meters for Champlain) and longer hydraulic residence times (95, 174, and 15 years vs. 2.9 years for Champlain). Greater depths and longer residence times promote phosphorus sedimentation and increase lake assimilative capacity for phosphorus loadings.

Lake George is also less productive than Champlain (Phosphorus 4.3 ppb, Chl-a 1.1 ppb, Transparency 8.2 meters). While Lake George is shallower (mean depth 18 meters), it has a relatively small watershed and long hydraulic residence time (8 years) (Ferris and Clesceri, 1977). Point-source phosphorus discharges do not influence Lake George, whereas they account for about 42 percent of the total loading to Champlain. Conditions in Champlain are generally within the ranges of those found in the Finger Lakes of Upper New York.

CONCLUSIONS

(1) Problem conditions relating to algal growth have been detected in the South Lake, Missisquoi Bay, and St. Albans Bay. They may also exist in other (unmonitored) embayments. The open waters of Champlain appear to be relatively free of algal-related problems, based upon the frequency distributions of chlorophyll-a and transparency measurements. While certain embayments are classified as eutrophic, the open waters are generally oligo-mesotrophic.

(2) Chlorophyll-a/phosphorus ratios in Champlain are generally below typical values for other Vermont lakes. Greater mixed layer depth may contribute to the lower algal response to phosphorus in Champlain, as is also observed in the open waters of the Great Lakes.

(3) Cross-tabulations of chlorophyll-a and transparency measurements against phosphorus concentrations indicate that nuisance conditions (chlorophyll-a > 10 ppb or transparency < 2 meters) are experienced at low frequencies (< 1.3 % of summer samples) in waters with phosphorus concentrations less than 25 ppb. As phosphorus increases beyond 25 ppb, the frequency of nuisance conditions increases sharply. Severe nuisance conditions (chlorophyll-a > 30 ppb or transparency < 1 meter) have been observed only at phosphorus concentrations exceeding 45 ppb.

(4) While 1979-1985 data suggest increasing trends in phosphorus and chlorophyll-a and decreasing trends in transparency at some stations, average conditions during this period were similar to those reported by Henson and Gruendling (1977) for the 1974-1976 period. Long-term monitoring by the USGS at Rouses Point (1972-1985) do not suggest a significant trend in total phosphorus. Because of random variations induced by climate and other factors, intensive, long-term monitoring is required to detect trends. A network of oxygen and temperature profile stations should be

established to provide a more reliable basis for tracking long-term variations in lake trophic status.

(5) While the open waters of Champlain are somewhat more productive that those of other large lakes in the region, the level of productivity is generally consistent with the lake's morphometry, hydrology, and phosphorus loadings.

(6) Modeling studies are needed to quantify the phosphorus assimilative capacities of the various segments of Lake Champlain and to provide a basis for long-term management of lake eutrophication in the context of potential future watershed development. This should be coupled with a monitoring program designed for quantifying point-source and non-point-source loadings under existing watershed conditions.

(7) Under the proposed effluent limitations for the Kingsland Bay Fish Hatchery, average phosphorus concentrations in immediate discharge zone and Hawkins Bay will remain below 20 ppb during the critical August-September period. Based upon the frequency analysis described above (3), the development of algal nuisance conditions in Hawkins Bay (or other lake areas) as a result of the hatchery discharge is unlikely.

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APPENDIX

LAKE CHAMPLAIN LAY MONITORING STATIONS - VERMONT DEPT OF WATER RESOURCES

STORET RETRIEVAL DATE 86/05/23 PGM=INDEX - VERSION OF MAY 1,1986

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AGENCY         ST-CO COUNTY              STATE           LOCATION NAME
PRIME STN NO   SECONDARY STATION NUMBERS                 MINOR BASIN                              BASIN CODE
               LAT/LONG/PREC             STORED DATE     MAJOR BASIN                         DEPTH
               STATION TYPE CODE
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
21VTLMP        50021 RUTLAND             VERMONT         SOUTH BAY - BASIN 4
503412         LC003-01     9CH01                        LAKE CHAMPLAIN                             012422
               43 34 26.0 073 25 57.0  2 STORED 800524   ST. LAWRENCE                  DEPTH    9
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
21VTLMP        50001 ADDISON             VERMONT         LARRABEES PT. - BASIN 4
503414         LC008-01     9CH02                        LAKE CHAMPLAIN                             012422
               43 51 21.0 073 22 58.0  2 STORED 800524   ST. LAWRENCE                  DEPTH    9
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
21VTLMP        36031 ESSEX               NEW YORK        GILLIGANS BAY - BASIN 4
503413         LC009-01     9CH03                        LAKE CHAMPLAIN                             012422
               43 57 06.0 073 24 28.0  2 STORED 800524   ST. LAWRENCE                  DEPTH    9
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
21VTLMP        50001 ADDISON             VERMONT         NEAR BUTTON BAY - BASIN 4
503415         LC015-01     9CH04                        LAKE CHAMPLAIN                             012422
               44 11 03.0 073 22 52.0  2 STORED 801108   ST. LAWRENCE                  DEPTH  173
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
21VTLMP        50007 CHITTENDEN          VERMONT         THOMPSONS POINT - BASIN 5
503536         LC017-01     9CH05                        LAKE CHAMPLAIN                             012422
               44 16 06.0 073 18 44.0  2 STORED 800524   ST. LAWRENCE                  DEPTH  350
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
21VTLMP        50007 CHITTENDEN          VERMONT         SHELBURNE BAY - BASIN 5
503506         LC025-02     9CH06                        LAKE CHAMPLAIN                             012422
               44 25 33.2 073 13 55.2  2 STORED 800524   ST. LAWRENCE                  DEPTH   72
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - ^$- - - - - - - -
21VTLMP        50007 CHITTENDEN          VERMONT         SOUTHERN MAIN LAKE - BASIN 5
503411         LC034-01     9CH07                        LAKE CHAMPLAIN                             012422
               44 27 59.0 073 17 43.0  2 STORED 800524   ST. LAWRENCE                  DEPTH  131
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
21VTLMP        36031 ESSEX               NEW YORK        CORLEAR BAY - BASIN 5
503529         LC036-01     9CH08                        LAKE CHAMPLAIN                             012422
               44 28 10.0 073 22 34.0  2 STORED 800524   ST. LAWRENCE                  DEPTH  164
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
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21VTLMP	50007 CHITTENDEN	VERMONT	SOUTHERN MAIN LAKE - BASIN 5		
503409	LC038-01 9CH09		LAKE CHAMPLAIN		012422
	44 32 46.0 073 19 39.0	2 STORED 880524	ST. LAWRENCE	DEPTH 16	
21VTLMP	50007 CHITTENDEN	VERMONT	MALLETTS BAY - BASIN 5		
503519	LC071-03 9CH10		LAKE CHAMPLAIN		012422
	44 34 55.1 073 17 52.5	2 STORED 880524	ST. LAWRENCE	DEPTH 104	
21VTLMP	50007 CHITTENDEN	VERMONT	MALLETTS BAY - BASIN 5		
503490	LC072-01 9CH11		LAKE CHAMPLAIN		012422
	44 33 54.1 073 12 30.0	2 STORED 880524	ST. LAWRENCE	DEPTH 75	
21VTLMP	50007 CHITTENDEN	VERMONT	SOUTHERN INLAND SEA - BASIN 5		
503530	LC080-02 9CH12		LAKE CHAMPLAIN		012422
	44 40 19.0 073 14 01.0	2 STORED 880524	ST. LAWRENCE	DEPTH 98	
21VTLMP	36019 CLINTON	NEW YORK	CUMBERLAND BAY - BASIN 5		
503538	LC046-01 9CH13		LAKE CHAMPLAIN		012422
	44 40 48.0 073 25 00.0	2 STORED 881108	ST. LAWRENCE	DEPTH 29	
21VTLMP	36019 CLINTON	NEW YORK	TREADWELL BAY - BASIN 5		
503531	LC050-01 9CH14		LAKE CHAMPLAIN		012422
	44 45 22.0 073 22 15.0	2 STORED 880524	ST. LAWRENCE	DEPTH 118	
21VTLMP	50013 GRAND ISLE	VERMONT	THE GUT - BASIN 5		
503532	LC086-01 9CH15		LAKE CHAMPLAIN		012422
	44 45 18.0 073 18 40.0	2 STORED 880524	ST. LAWRENCE	DEPTH 13	
21VTLMP	50011 FRANKLIN	VERMONT	CENTRAL INLAND SEA - BASIN 5		
503533	LC084-02 9CH16		LAKE CHAMPLAIN		012422
	44 45 30.0 073 13 16.0	2 STORED 880524	ST. LAWRENCE	DEPTH 88	
21VTLMP	50011 FRANKLIN	VERMONT	ST. ALBANS BAY - BASIN 5		
503488	LC083-03 9CH17		LAKE CHAMPLAIN		012422
	44 47 06.7 073 09 35.7	2 STORED 880524	ST. LAWRENCE	DEPTH 19	
21VTLMP	50013 GRAND ISLE	VERMONT	CENTRAL INLAND SEA - BASIN 5		
503534	LC087-01 9CH18		LAKE CHAMPLAIN		012422
	44 51 44.0 073 12 55.0	2 STORED 880524	ST. LAWRENCE	DEPTH 49	
21VTLMP	50013 GRAND ISLE	VERMONT	NORTHERN LAKE CHAMPLAIN - BASIN 5		
503535	LC055-01 9CH19		LAKE CHAMPLAIN		012422
	44 56 54.0 073 20 24.0	2 STORED 880524	ST. LAWRENCE	DEPTH 19	
21VTLMP	50011 FRANKLIN	VERMONT	MISSISQUOI BAY - BASIN 5		
503515	LC092-01 9CH20		LAKE CHAMPLAIN		012422
	45 00 48.4 073 10 26.4	2 STORED 880524	ST. LAWRENCE	DEPTH 13	
21VTLMP	50013 GRAND ISLE	VERMONT	KEELER BAY - BASIN 5		
503528	LC082-01 9CH21		LAKE CHAMPLAIN		012422
	44 59 53.0 073 18 12.0	2 STORED 880524	ST. LAWRENCE	DEPTH 32	

21VTLMP	50011 FRANKLIN	VERMONT	MAQUAM BAY - BASIN 5		
501605	LC088-02 9CH22		LAKE CHAMPLAIN		012422
	44 55 04.0 073 11 11.0	2 STORED 820109	ST. LAWRENCE	DEPTH	26
21VTLMP	50013 GRAND ISLE	VERMONT	ALBURG PASSAGE - BASIN 5		
503539	LC095-02 9CH23		LAKE CHAMPLAIN		012422
	44 53 09.0 073 16 20.0	2 STORED 821204	ST. LAWRENCE	DEPTH	13
21VTLMP	50011 FRANKLIN	VERMONT	MISSISQUOI BAY - BASIN 5		
503540	LC091-02 9CH24		LAKE CHAMPLAIN		012422
	45 00 01.0 073 07 33.0	2 STORED 821204	ST. LAWRENCE	DEPTH	9
21VTLMP	50013 GRAND ISLE	VERMONT	PELOTS POINT - BASIN 5		
503541	LC095-03 9CH25		LAKE CHAMPLAIN		012422
	44 50 12.0 073 10 06.0	2 STORED 821204	ST. LAWRENCE	DEPTH	16
21VTLMP	50001 ADDISON	VERMONT	KELLOG BAY - BASIN 5		
503542	LC015-05 9CH26		LAKE CHAMPLAIN		012422
	44 13 18.0 073 19 32.0	2 STORED 821204	ST. LAWRENCE	DEPTH	6
21VTLMP	50013 GRAND ISLE	VERMONT	PELOTS POINT - BASIN 5		
503543	9CH27		LAKE CHAMPLAIN		012422
	44 50 13.0 073 18 08.0	2 STORED 821210	ST. LAWRENCE	DEPTH	16
21VTLMP	50013 GRAND ISLE	VERMONT	PELOTS POINT - BASIN 5		
503544	LC095-05 9CH28		LAKE CHAMPLAIN		012422
	44 50 20.0 073 18 02.0	2 STORED 821204	ST. LAWRENCE	DEPTH	22
21VTLMP	50013 GRAND ISLE	VERMONT	ALBURG PASSAGE - BASIN 5		
503545	LC095-06 9CH29		LAKE CHAMPLAIN		012422
	44 50 23.0 073 17 48.0	2 STORED 821204	ST. LAWRENCE	DEPTH	26
21VTLMP	50013 GRAND ISLE	VERMONT	MISSISQUOI BAY - BASIN 5		
503547	LC093-02 9CH30		LAKE CHAMPLAIN		012422
	44 58 33.0 073 12 54.0	2 STORED 831203	ST. LAWRENCE	DEPTH	13

D A T A   S U M M A R Y   B Y   S T A T I O N

VERMONT LAY MONITORING PROGRAM

VARIABLES:

totalp = total phosphorus (ppb)

chla = chlorophyll-a (ppb)

secchi = secchi depth (meters)

year = year of sample

STATISTICS:

n = number of measurements

mean = arithmetic mean

stdev = arithmetic standard deviation

gmean = geometric mean

gstdev = geometric standard deviation

min = minimum value

max = maximum value

cv(mean) = coefficient of variation of arithmetic mean

= standard error / arithmetic mean

DATA SUMMARY FOR ALL STATIONS:

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	1337.00	25.25	16.36	21.06	0.60	3.00	160.00	0.02
chla	1388.00	5.37	4.47	4.36	0.61	0.30	50.00	0.02
secchi	1590.00	3.98	2.02	3.14	0.84	0.10	9.00	0.01
year	1624.00	81.93	2.07	81.91	0.02	79.00	85.00	0.00

station = 1

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	45.00	55.62	15.52	53.48	0.29	29.00	91.00	0.04
chla	43.00	7.64	3.60	6.87	0.47	2.50	18.50	0.07
secchi	45.00	0.36	0.13	0.34	0.36	0.20	0.70	0.05
year	45.00	80.36	1.11	80.35	0.01	79.00	82.00	0.00

station = 2

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	87.00	41.49	13.24	39.68	0.30	18.00	92.00	0.03
chla	87.00	8.29	6.13	6.93	0.56	2.60	37.00	0.08
secchi	93.00	0.61	0.31	0.52	0.62	0.10	1.50	0.05
year	93.00	81.80	2.01	81.77	0.02	79.00	85.00	0.00

station = 3

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	68.00	35.07	8.59	34.00	0.26	17.00	59.00	0.03
chla	66.00	7.30	3.28	6.61	0.45	1.90	17.50	0.06
secchi	65.00	0.63	0.24	0.59	0.35	0.30	1.50	0.05
year	68.00	81.25	1.66	81.23	0.02	79.00	84.00	0.00

station = 4

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	40.00	19.55	6.45	18.40	0.38	5.00	37.00	0.05
chla	40.00	5.10	4.62	4.10	0.57	1.50	29.20	0.14
secchi	40.00	3.85	1.19	3.63	0.36	1.30	5.70	0.05
year	40.00	82.70	2.03	82.68	0.02	80.00	85.00	0.00

station = 5

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	63.00	16.33	7.63	15.07	0.39	7.00	56.00	0.06
chla	66.00	4.52	1.97	4.10	0.45	1.20	9.50	0.05
secchi	66.00	4.41	1.43	4.17	0.35	1.50	8.00	0.04
year	66.00	81.48	1.80	81.47	0.02	79.00	85.00	0.00

station = 6

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	53.00	15.83	5.66	14.86	0.37	6.00	32.00	0.05
chla	54.00	4.18	2.25	3.68	0.51	1.10	13.00	0.07
secchi	55.00	4.86	1.19	4.70	0.27	2.00	7.80	0.03
year	56.00	81.21	2.03	81.19	0.02	79.00	85.00	0.00

station = 7

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	59.00	19.15	19.84	16.08	0.50	6.00	160.00	0.13
chla	62.00	4.02	2.41	3.48	0.54	1.00	15.60	0.08
secchi	61.00	4.82	1.44	4.52	0.42	0.50	8.00	0.04
year	63.00	81.46	2.01	81.44	0.02	79.00	85.00	0.00

station = 8

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	53.00	14.58	3.73	14.15	0.24	9.00	26.00	0.04
chla	68.00	4.22	1.98	3.81	0.46	1.10	12.80	0.06
secchi	67.00	5.83	0.85	5.77	0.15	3.50	8.00	0.02
year	68.00	82.09	2.09	82.06	0.03	79.00	85.00	0.00

station = 9

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	29.00	14.45	4.87	13.50	0.41	3.00	24.00	0.06
chla	29.00	4.04	2.16	3.43	0.66	0.30	10.00	0.10
secchi	31.00	5.15	1.03	5.03	0.23	2.50	6.90	0.04
year	32.00	82.63	2.18	82.60	0.03	79.00	85.00	0.00

station = 10

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	52.00	9.88	5.82	8.58	0.53	3.00	32.00	0.08
chla	55.00	3.48	0.95	3.36	0.27	2.00	6.00	0.04
secchi	57.00	5.64	1.37	5.46	0.27	2.50	8.50	0.03
year	58.00	81.17	2.33	81.14	0.03	79.00	85.00	0.00

station = 11

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	72.00	9.89	4.15	9.16	0.39	3.00	26.00	0.05
chla	72.00	3.79	1.78	3.47	0.41	1.10	13.50	0.06
secchi	74.00	5.33	1.33	5.13	0.31	1.00	8.50	0.03
year	76.00	81.74	2.28	81.71	0.03	79.00	85.00	0.00

station = 12

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	17.00	20.06	4.72	19.60	0.22	14.00	31.00	0.06
chla	18.00	5.04	5.30	3.83	0.71	0.80	25.30	0.25
secchi	52.00	5.85	1.18	5.74	0.20	3.50	9.00	0.03
year	52.00	80.81	2.19	80.78	0.03	79.00	85.00	0.00

station = 13

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	33.00	25.73	22.76	21.55	0.52	9.00	138.00	0.15
chla	32.00	4.31	2.22	3.77	0.54	1.20	9.60	0.09
secchi	35.00	4.88	1.39	4.71	0.27	3.50	8.00	0.05
year	35.00	83.29	1.87	83.27	0.02	80.00	85.00	0.00

station = 14

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	69.00	16.19	4.37	15.61	0.28	7.00	32.00	0.03
chla	83.00	3.93	1.70	3.61	0.42	1.30	10.70	0.05
secchi	83.00	5.22	1.01	5.11	0.23	1.50	8.00	0.02
year	84.00	81.95	2.07	81.93	0.02	79.00	85.00	0.00

station = 15

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	45.00	22.67	6.80	21.62	0.32	9.00	43.00	0.04
chla	45.00	3.30	1.48	2.93	0.55	0.30	7.00	0.07
secchi	85.00	3.91	0.55	3.87	0.15	2.50	5.00	0.02
year	88.00	81.90	2.04	81.87	0.02	79.00	85.00	0.00

station = 16

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	51.00	16.98	5.32	16.26	0.30	7.00	39.00	0.04
chla	52.00	4.02	1.98	3.60	0.48	1.10	11.00	0.07
secchi	57.00	6.18	1.02	6.11	0.16	4.50	8.50	0.02
year	58.00	82.40	2.01	82.37	0.02	79.00	85.00	0.00

station = 17

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	99.00	36.79	13.07	34.66	0.35	15.00	86.00	0.04
chla	98.00	9.11	8.10	6.74	0.74	1.90	37.00	0.09
secchi	101.00	2.98	0.93	2.83	0.33	1.00	6.50	0.03
year	104.00	81.56	2.06	81.53	0.02	79.00	85.00	0.00

station = 18

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	97.00	14.92	3.79	14.39	0.28	6.00	24.00	0.03
chla	97.00	4.22	1.68	3.92	0.39	1.50	10.20	0.04
secchi	96.00	5.87	1.05	5.78	0.18	3.50	8.50	0.02
year	99.00	81.44	2.06	81.42	0.02	79.00	85.00	0.00

station = 19

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	64.00	20.03	6.42	19.04	0.33	7.00	43.00	0.04
chla	80.00	3.41	1.74	3.00	0.53	0.60	8.70	0.06
secchi	83.00	4.79	0.88	4.70	0.20	3.00	6.00	0.02
year	83.00	81.63	2.04	81.60	0.02	79.00	85.00	0.00

station = 20

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	38.00	35.16	20.79	30.19	0.55	11.00	90.00	0.10
chla	43.00	6.91	6.36	5.40	0.68	1.20	40.90	0.14
secchi	44.00	2.38	0.60	2.30	0.27	1.00	3.70	0.04
year	45.00	82.31	2.14	82.28	0.03	79.00	85.00	0.00

station = 21

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	13.00	18.92	3.73	18.62	0.18	14.00	29.00	0.05
chla	12.00	3.00	1.25	2.73	0.48	0.90	5.20	0.12
secchi	76.00	4.36	0.88	4.27	0.20	3.00	7.00	0.02
year	76.00	81.86	2.23	81.83	0.03	79.00	85.00	0.00

station = 22

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
secchi	35.00	6.19	0.95	6.11	0.17	3.50	8.20	0.03
year	35.00	82.77	1.54	82.76	0.02	81.00	85.00	0.00

station = 23

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	12.00	27.75	7.28	26.95	0.25	19.00	44.00	0.08
chla	11.00	9.96	7.43	7.68	0.77	1.90	21.80	0.22
secchi	17.00	2.48	0.54	2.41	0.25	1.20	3.10	0.05
year	17.00	84.29	1.31	84.28	0.02	82.00	85.00	0.00

station = 24

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	37.00	42.76	13.00	40.78	0.32	15.00	79.00	0.05
chla	33.00	7.82	7.33	5.00	1.01	0.50	25.50	0.16
secchi	36.00	2.39	0.56	2.33	0.25	1.10	3.80	0.04
year	38.00	83.39	1.26	83.39	0.01	82.00	85.00	0.00

station = 25

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	28.00	25.14	8.26	23.97	0.31	14.00	50.00	0.06
chla	27.00	4.78	2.97	4.11	0.55	1.70	14.30	0.12
secchi	25.00	2.68	0.49	2.63	0.21	1.50	3.50	0.04
year	28.00	83.36	1.31	83.35	0.02	82.00	85.00	0.00

station = 26

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	43.00	48.91	19.09	45.06	0.42	18.00	90.00	0.06
chla	42.00	7.60	4.28	6.65	0.52	2.40	25.50	0.09
secchi	43.00	1.36	0.33	1.31	0.26	0.60	2.00	0.04
year	43.00	83.21	1.01	83.20	0.01	82.00	85.00	0.00

station = 27

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	10.00	24.70	7.90	23.65	0.31	15.00	39.00	0.10
chla	10.00	3.64	1.57	3.29	0.50	1.10	6.30	0.14
secchi	8.00	2.79	0.65	2.73	0.22	2.00	4.20	0.08
year	10.00	82.00	0.00	82.00	0.00	82.00	82.00	0.00

station = 28

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	10.00	28.70	6.07	28.13	0.21	20.00	39.00	0.07
chla	10.00	4.03	1.72	3.68	0.48	1.30	7.80	0.13
secchi	9.00	2.72	0.27	2.71	0.10	2.40	3.00	0.03
year	10.00	82.00	0.00	82.00	0.00	82.00	82.00	0.00

station = 29

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	28.00	28.68	13.47	26.60	0.37	14.00	85.00	0.09
chla	28.00	4.71	2.99	4.09	0.53	1.20	17.40	0.12
secchi	25.00	2.71	0.70	2.62	0.26	1.50	4.00	0.05
year	28.00	83.36	1.31	83.35	0.02	82.00	85.00	0.00

station = 30

variable	n	mean	stdev	gmean	gstdev	min	max	cv(mean)
totalp	22.00	38.91	10.16	37.60	0.27	20.00	62.00	0.06
chla	25.00	9.05	9.25	7.17	0.60	2.80	50.00	0.20
secchi	26.00	2.29	0.46	2.25	0.21	1.50	3.00	0.04
year	26.00	83.88	0.77	83.88	0.01	83.00	85.00	0.00

LAKE CHAMPLAIN LAY MONITORING DATA

MEANS BY STATION AND YEAR

Variable: Total Phosphorus (ppb)

		YEAR							
		79	80	81	82	83	84	85	ALL
S	1	62.2	46.9	55.3	58.1				55.6
T	2	39.5	38.1	39.8	58.4	34.3	42.3	37.9	41.5
A	3	38.5	33.5	36.9	36.8	31.4	31.3		35.1
T	4		14.7			20.9	24.1	21.3	19.6
I	5	11.1	12.4	14.3	20.4	20.9	18.5	32.0	16.3
O	6	12.7	13.2	15.9	19.4			18.8	15.8
N	7	13.3	14.1	16.5	19.8		19.9	43.2	19.2
	8		14.8	12.3	16.4	15.0	16.5	12.8	14.6
	9	11.0		10.8		20.0		16.8	14.4
	10	6.2	6.8	13.3			14.8	14.4	9.9
	11	7.5	6.4	9.6		11.6	12.4	13.1	9.9
	12					19.9	21.5	19.0	20.1
	13		15.5		30.4		37.8	18.5	25.7
	14		11.8	14.4	17.6	18.4	17.6	17.5	16.2
	15				23.4	24.8	20.4	22.1	22.7
	16		12.6	18.0		17.9	18.3	18.0	17.0
	17	32.1	41.3	38.6	38.5	34.3	39.4	36.1	36.8
	18	12.7	12.6	14.5	17.8	16.8	16.5	16.1	14.9
	19		16.3	19.1	17.8	19.8	24.0	25.3	20.0
	20	16.4		52.9		27.4	37.3	38.9	35.2
	21							18.9	18.9
	22								
	23							27.8	27.8
	24				44.8	38.7	50.9	37.5	42.8
	25				26.2	18.6		29.3	25.1
	26				47.8	52.8	43.3	54.8	48.9
	27				24.7				24.7
	28				28.7				28.7
	29				30.1	27.5		28.2	28.7
	30					31.3	43.6	38.7	38.9
ALL		22.9	20.7	23.9	31.2	25.1	27.1	25.0	25.2

LAKE CHAMPLAIN LAY MONITORING DATA

MEANS BY STATION AND YEAR

Variable: Chlorophyll-a (ppb)

		YEAR							
		79	80	81	82	83	84	85	ALL
S	1	6.3	9.5	6.1	9.0				7.6
T	2	6.0	6.5	9.2	10.3	6.8	12.3	7.4	8.3
A	3	6.3	5.9	7.9	7.8	7.0	9.7		7.3
T	4		4.4			4.1	4.1	7.6	5.1
I	5	5.3	3.1	3.7	5.0	4.4	5.5	4.4	4.5
O	6	5.5	4.5	3.6	3.4			3.7	4.2
N	7	4.6	4.3	3.6	3.0		4.5	3.8	4.0
	8	4.3	3.1	3.6	3.6	4.3	5.6	4.9	4.2
	9	2.9		4.6		4.6		3.8	4.0
	10	3.4	3.4	3.4			3.6	3.7	3.5
	11	3.5	3.1	4.1		3.8	4.5	4.1	3.8
	12					3.8	9.2	3.9	5.0
	13		4.2		3.5		2.9	5.6	4.3
	14	3.6	2.8	3.8	3.5	4.0	4.8	5.1	3.9
	15				2.7	3.2	4.4	3.0	3.3
	16		4.1	3.2		4.0	5.3	3.5	4.0
	17	9.1	12.4	9.2	5.9	8.0	5.7	11.5	9.1
	18	5.2	3.6	4.0	3.4	4.0	4.4	3.9	4.2
	19	3.2	2.9	3.1	2.9	3.7	3.9	4.4	3.4
	20	2.7		7.5		6.9	10.1	5.4	6.9
	21							3.0	3.0
	22								
	23							9.9	9.9
	24				2.9	12.1	13.7	7.1	7.8
	25				3.6	3.4		7.0	4.8
	26				8.8	7.6	7.1	5.7	7.6
	27				3.6				3.6
	28				4.0				4.0
	29				3.8	3.7		6.4	4.7
	30					5.0	13.5	6.5	9.1
	ALL	5.0	5.2	5.2	4.9	5.1	6.6	5.5	5.4

LAKE CHAMPLAIN LAY MONITORING DATA

MEANS BY STATION AND YEAR

Variable: Transparency (meters)

		YEAR							
		79	80	81	82	83	84	85	ALL
S	1	0.3	0.3	0.4	0.4				0.4
T	2	0.3	0.4	0.6	0.6	0.9	0.6	0.9	0.6
A	3	0.4	0.5	0.7	0.6	0.8	0.9		0.6
T	4		3.6			3.7	3.2	4.8	3.8
I	5	3.9	4.7	5.3	4.3	4.2	4.3	3.5	4.4
O	6	3.9	4.8	5.4	5.2			5.1	4.9
N	7	4.0	5.2	5.5	5.6		3.8	4.8	4.8
	8	5.6	6.0	6.2	5.6	5.6	5.6	6.2	5.8
	9	4.8		5.2		3.6		5.5	5.2
	10	5.4	7.0	6.0			4.8	4.8	5.6
	11	4.6	6.6	6.1		6.1	4.2	5.2	5.3
	12	5.5	6.9			5.8	5.1	6.3	5.9
	13		5.8		6.9		4.1	4.0	4.9
	14	5.0	5.5	5.6	5.6	6.0	4.3	4.7	5.2
	15	3.4	3.3	3.9	3.8	4.4	4.2	4.5	3.9
	16	5.0	6.3	7.3		5.9	5.8	6.2	6.2
	17	2.9	2.8	2.7	3.3	3.4	2.5	3.3	3.0
	18	5.0	5.8	6.2	6.9	6.0	5.9	6.3	5.9
	19	5.1	5.0	5.2	5.0	4.8	3.7	4.2	4.8
	20	2.9		2.1		2.6	1.9	2.8	2.4
	21	4.0	4.8	3.5	4.9	4.3	4.2	4.7	4.4
	22			5.9	6.9	6.0	6.5	5.7	6.2
	23				2.8			2.4	2.5
	24				2.5	2.3	1.9	2.5	2.4
	25				2.9	3.1		2.2	2.7
	26				1.5	1.2	1.3	1.5	1.4
	27				2.8				2.8
	28				2.7				2.7
	29				2.7	3.5		2.2	2.7
	30					2.7	2.0	2.3	2.3
ALL		3.9	4.3	4.3	3.7	4.0	3.6	4.1	4.0

LAKE COMPARISON DATA (Figures 11, 12, 13)

ABBREV	LAKE	TOTALP	CHLA	SECCHI	REF
	VERMONT LAKES				
Arrowh	Arrowhead Mt	17.0	4.3	1.6	1
Averil	Averill	4.3		5.3	1
Beebe	Beebe	16.3	3.1	6.9	1
Big Po	Big Pond	7.0	3.5	3.8	1
Bomose	Bomoseen	16.8	4.4	5.2	1
Burr	Burr	9.6		4.1	1
Carmi	Carmi	23.4	18.7	1.8	1
Caspia	Caspian	5.6	2.2	7.6	1
Cole	Cole	7.0	1.4	3.0	1
Crysta	Crystal	6.0	2.1	7.2	1
Derby	Derby		4.2	3.2	1
Dunmor	Dunmore	7.0	4.5	5.1	1
Echo	Echo	6.4	1.8	7.4	1
Elfin	Elfin	14.0	7.0	3.7	1
Elmore	Elmore	12.7	4.6	2.9	1
Fairfi	Fairfield	26.5	11.8	3.3	1
Fairle	Fairlee	10.4	3.7	6.0	1
Fern	Fern			6.3	1
Glen	Glen			7.5	1
Greenw	Greenwood	10.0		6.5	1
Groton	Groton	7.4	4.5	3.5	1
Halls	Halls	15.0	7.0	4.3	1
Harrim	Harriman	9.0	1.8	2.8	2
Harvey	Harveys	15.3	4.4	5.5	1
Horton	Hortonia	15.0	4.5	4.9	1
Hosmer	Hosmer	25.0	9.7	4.8	1
Iroquo	Iroquois	30.5	9.8	4.0	1
Island	Island	7.0	3.8	5.2	1
Joes	Joes	6.0	3.0	4.2	1
Lyford	Lyford	12.0	4.4	2.6	1
Maidst	Maidstone	4.5		8.0	1
Martin	Martins	12.5	3.7	3.3	1
Metcal	Metcalf	16.3	7.4	2.9	1
Morey	Morey	36.4	11.6	4.0	1
Mph-Cn	Memphremagog - Central	14.7	6.6	3.8	3
Mph-NC	Memphremagog - N Central	10.8	4.4	4.4	3
Mph-No	Memphremagog - North	9.2	3.7	4.4	3
Mph-Np	Memphremagog - Newport Bay	27.0	8.5	2.4	3
Mph-SC	Memphremagog - S Central	16.1	7.9	3.1	3
Nelson	Nelson	4.8		8.0	1
Nineva	Ninevah	8.3	3.2	3.0	1
Paran	Paran	17.0	8.0	3.2	1
Parker	Parker	18.9	6.8	3.6	1
Peacha	Peacham	9.0	3.5	4.8	1
Pinneo	Pinneo	32.9	22.0	0.9	1
Rapond	Raponda	8.8	2.6		1

ABBREV	LAKE	TOTALP	CHLA	SECCHI	REF
Rescue	Rescue	5.5		4.5	1
Salem	Salem	9.6		4.7	1
Seymou	Seymour	7.9	2.4	8.1	1
Shadow	Shadow	6.0	3.8	7.3	1
Silver	Silver	16.0	6.5	4.4	1
St-Cat	St Catherine	13.8	3.5	5.5	1
Star	Star	16.5	17.7	1.3	1
Sunset	Sunset	8.3	1.5	9.6	1
Valley	Valley	30.3	6.5	6.0	1
Wapana	Wapanacki	11.0	11.0	2.5	1
Waterb	Waterbury	7.0	5.2	2.4	2
Willou	Willoughby	4.0	1.5	8.4	1
Winona	Winona	27.0			1
Woodbu	Woodbury	8.0	4.0	4.9	1
Woodwa	Woodward	8.0	5.4	5.0	1
	LAKE CHAMPLAIN				
Au-Fer	Point Au Fer	20.0	3.4	4.8	4
Main-L	Main Lake	19.3	4.0	5.1	4
Mallet	Mallets Bay	9.9	3.7	5.5	4
Mid-La	Mid Lake	16.3	4.1	5.2	4
Missis	Missisquoi Bay	38.9	7.7	2.4	4
NE-Arm	Northeast Arm	16.3	4.2	5.6	4
South	South Lake	42.5	7.8	0.6	4
St-Alb	St Albans Bay	36.8	9.1	3.0	4
Thomps	Thompsons Point	16.3	4.5	4.4	4
	GREAT LAKES				
C-Erie	Central Erie	19.4	4.5	4.7	5
E-Erie	Eastern Erie	17.2	3.3	5.0	5
GeorBa	Georgian Bay - Huron	4.5	1.2	9.0	6
Huron	Huron	5.5	1.2	8.2	5
LGreBa	Lower Green Bay	40.0	20.0	1.5	6
Michig	Michigan	8.0	2.0	5.9	5
Ontari	Ontario	21.0	5.4	2.6	5
SagiBa	Saginaw Bay - Huron	30.9	20.0	1.2	6,7
Superi	Superior	4.6	0.7	9.2	5
UGreBa	Upper Green Bay	15.0	3.5	4.0	6
W-Erie	Western Erie	39.3	11.1	2.0	5
	NEW YORK LAKES				
Black	Black	30.0	13.1	1.9	2
Canada	Canadarago	43.0	10.5	1.8	8,9
Canand	Canandaigua	10.1	2.6	4.5	8,9
Candic	Candice	9.2	4.4	5.2	8,9
Cannon	Cannonsville	46.0	30.0	1.8	2
Carry	Carry Falls	10.0	3.1	2.3	2
Cassad	Cassadaga	26.0	9.7	2.6	2
Cayuga	Cayuga	21.0	8.5	2.8	8,9

ABBREV	LAKE	TOTALP	CHLA	SECCHI	REF
Chauta	Chautauqua	28.0	13.3	2.0	2
Conesu	Conesus	17.6	5.6	3.2	8,9
George	George	4.3	1.1	8.2	10
Goodye	Goodyear	26.0	9.6	1.4	2
Hemloc	Hemlock	10.9	6.2	3.3	8,9
Honeoy	Honeoye	16.2	13.2	3.0	8,9
Huntin	Huntington	15.0	6.4	3.5	2
Keuka	Keuka	12.0	3.3	3.6	8,9
Long	Long	8.0	3.5	2.9	2
Oneida	Oneida	31.0	12.0	2.2	8,9
Otisco	Otisco	8.4	2.2	6.0	8,9
Otter	Otter	43.0	13.3	1.1	2
Owasco	Owasco	15.0	6.0	2.7	8,9
Placid	Placid		1.3	9.5	8,9
Sacand	Sacandaga	9.0	4.8	3.5	2
Sarato	Saratoga	25.0	11.8	2.5	2
Schroo	Schroon	4.0	2.1	3.7	2
Seneca	Seneca	18.0	6.0	4.0	8,9
Skanea	Skaneateles	7.7	1.5	3.0	8,9
St Reg	Lower St. Regis	17.0	7.9	1.2	2
Swan	Swan	42.0	9.5	1.7	2
Swingi	Swinging Bridge	57.0	28.7	1.3	2

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