

**Lake Simcoe Water Quality Update,
with Emphasis on Phosphorus Trends.**

by:

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LSEMS Implementation
Technical Report No. Imp.B.18

November, 1998

Introduction

Lake Simcoe is a valuable natural resource, easily accessible to more than one-half of the Ontario population and generating approximately \$160 Million in the local economies through recreational activities alone (LSEMS, 1995). The goal of the Lake Simcoe Environmental Management Strategy (LSEMS) Implementation program is to restore water quality and fish habitat to conditions that support self-reproducing populations of lake whitefish and lake trout (species that are presently maintained in the lake through stocking programs).

A major objective of the LSEMS program is to reduce phosphorus loading to the lake by about 25% in an attempt to increase end-of-summer deepwater dissolved oxygen concentrations (volume-weighted through the depth interval 18-42 metres) from present levels of about 3 mg L⁻¹ to 5 mg L⁻¹ (Nicholls, 1995, 1997). Phosphorus concentrations, when measured regularly at several locations, provide an indication of the trophic (or “nutrient enrichment”) status of the lake, and when continued over long term can reveal progress (or lack of progress) towards the phosphorus loading objective. Several other lake processes can influence phosphorus concentrations in Lake Simcoe besides phosphorus loading (biotic interactions, invading species effects and year-to-year weather differences); long periods of monitoring are often necessary to gain some understanding of these impacts on lake function. This report updates phosphorus trend information summarized from several regularly sampled locations on Lake Simcoe. Some ancillary water quality data deemed important for their indicator value (e.g. chloride, dissolved oxygen) are briefly updated as well.

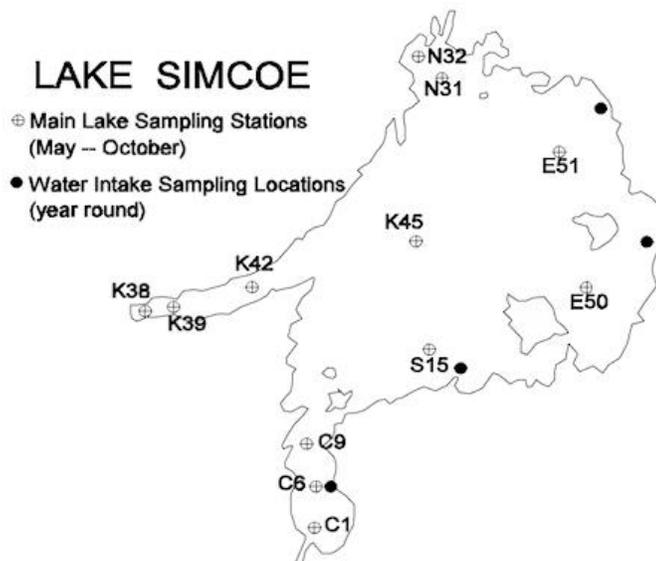


Fig. 1. Locations of 12 main lake and four water intake sampling sites in Lake Simcoe.

Methods

The Ontario Water Resources Commission established water quality sampling stations in Lake Simcoe in 1971 (K39, K42 and K45); nine others (Fig. 1) were added in 1980 when approximately biweekly May-October sampling was initiated by the Ministry of the Environment. At all stations, temperature and dissolved oxygen were recorded at one metre intervals of depth with an electronic sensing device (Yellow Springs Instruments model #58). At each station, composite samples of the euphotic zone (the lower depth determined as $2^{1/2}$ times the Secchi disc visibility, but not deeper than one metre above bottom at the shallower stations) were collected with a tygon tube. The tube contents were mixed in a pail and subsampled for nutrients (mainly inorganic and total forms of nitrogen, phosphorus and silica), chlorophyll a and phytoplankton (fixed immediately with Lugol's solution). Additional samples for nutrients and some metals were collected at 1, 5, 10 and 15 metres above bottom at the deep stations. Sampling of the Holland River stations (Fig. 10) was done in mid-channel with a weighted narrow-mouthed bottle allowed to fill evenly over a depth interval of 0-1 metre. Chemical analysis protocols followed "Standard Methods" used routinely by the Laboratory Services Branch, Ministry of the Environment.

The Ministry of the Environment, with the assistance of municipalities drawing drinking water from Lake Simcoe, analyzes "raw" (untreated) lake water collected weekly, year-round at the Keswick, Sutton, Beaverton and Brechin water treatment plant intakes (no sampling at Brechin after 1997). This is a cost effective way to obtain lake water quality data at times of the years when "conventional" sampling protocols are unworkable. Analysis of trends in this report used robust non-parametric statistical techniques especially useful for water quality data that are characterized by seasonality and serial dependency (Cluis, 1989).

Results and Discussion

Chloride

Chloride concentrations in Lake Simcoe increased at a rate of about $0.6 \text{ mg Cl L}^{-1} \text{ year}^{-1}$ during the 1971-1996 period (Fig. 2). This is in sharp contrast to declining chloride concentrations in the Lower Great Lakes (about -0.7 and $-0.4 \text{ mg Cl L}^{-1} \text{ year}^{-1}$, in Lake Erie and Lake Ontario, respectively) - mainly as a result of abatement of industrial sources in southwestern Ontario). About 20 years ago, Lake Ontario chloride concentrations were about twice as high as those measured in Lake Simcoe. By about 1992, concentrations in both

lakes were identical (Fig. 2), but a continuation of the trends in both lakes since 1992 is leading to a reversal of the 1970's relative chloride status of these two lakes. The increase in Lake Simcoe is believed to be a direct result of winter road de-icing in rapidly expanding urban areas of the watershed.

One consequence of the rising salt level in Lake Simcoe may be an apparent increase in the importance of *Bangia*, a halophilic filamentous red alga that grows attached to rocks in the shoreline splash zone, and which had very limited distribution in Lake Simcoe in the early 1980's (Jackson, 1985), but now appears to be widespread. Although, having doubled in the past 20 years, the Lake Simcoe chloride concentrations still increased only from 0.2% to 0.3% of the chloride concentrations typifying brackish estuarine waters where *Bangia* grows well. This is an example of the sensitivity of the biota of lakes to relatively small changes in some environmental variables.

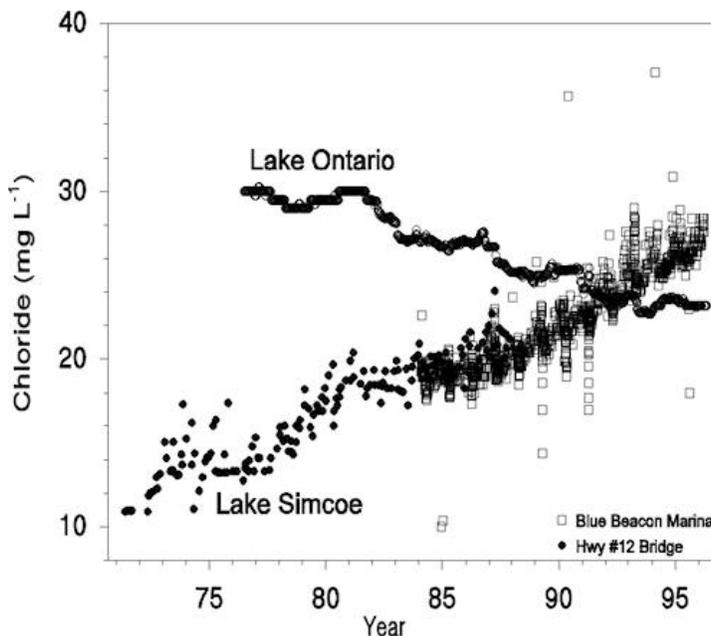


Fig. 2. Chloride concentrations in the Lake Simcoe outflow at Atherley and in western Lake Ontario (52-week moving median of weekly sampling results collected at the South Peel water intake). The Atherley data consist of two overlapping data sets: the Hwy#12 bridge samples were collected approximately monthly during 1971-1987, while the Blue Beacon Marina samples were collected about twice weekly since 1984 (plotted points are monthly means).

Total phosphorus

a) *Outflow*

Considerable year-to-year variability makes it difficult to detect long term trends in many of the other chemical variables. More work needs to be done to separate out weather effects on, for example, mixing depth which can influence the vertical distribution and concentration of several water quality variables.

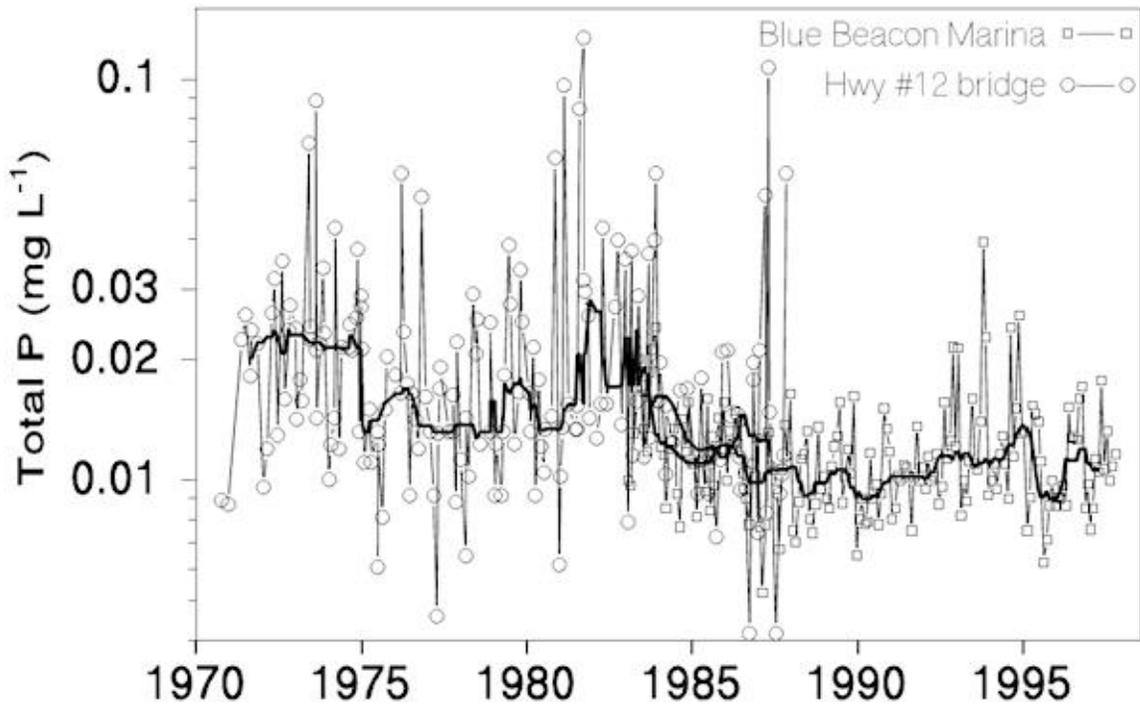


Fig. 3. Total phosphorus concentrations in the Lake Simcoe outflow at Atherley: the Hwy #12 bridge samples were collected approximately monthly during 1971-1987, while the Blue Beacon Marina samples were collected about twice weekly during 1984-1997 (plotted points are monthly means). The thick lines are the 12-month moving medians.

Generally, lower concentrations of total phosphorus (TP) have been measured in the Lake Simcoe outflow during the 1990's than in the 1980's (Fig. 3). There was a major decline in outflow TP (about -40%) in the mid-1970's coinciding with the implementation of legislation controlling the phosphate content of laundry detergent (Federal legislation in 1973 limited the content (as P₂O₅) to 5%, by weight). Concentrations rose again during the early 1980's but then declined rapidly from annual medians of about 0.02 mg P L⁻¹ to concentrations of about 0.01 mg P L⁻¹ by the late 1980's and early 1990's (Fig. 3). Some of this decline in outflow TP concentrations over the past decade probably reflects upgrading of the Orillia sewage treatment plant to achieve improved phosphorus removal and correction of bypassing problems related to hydraulic overloading. Recent declines in 1996 and 1997 may reflect water column removal by zebra mussel filtration.

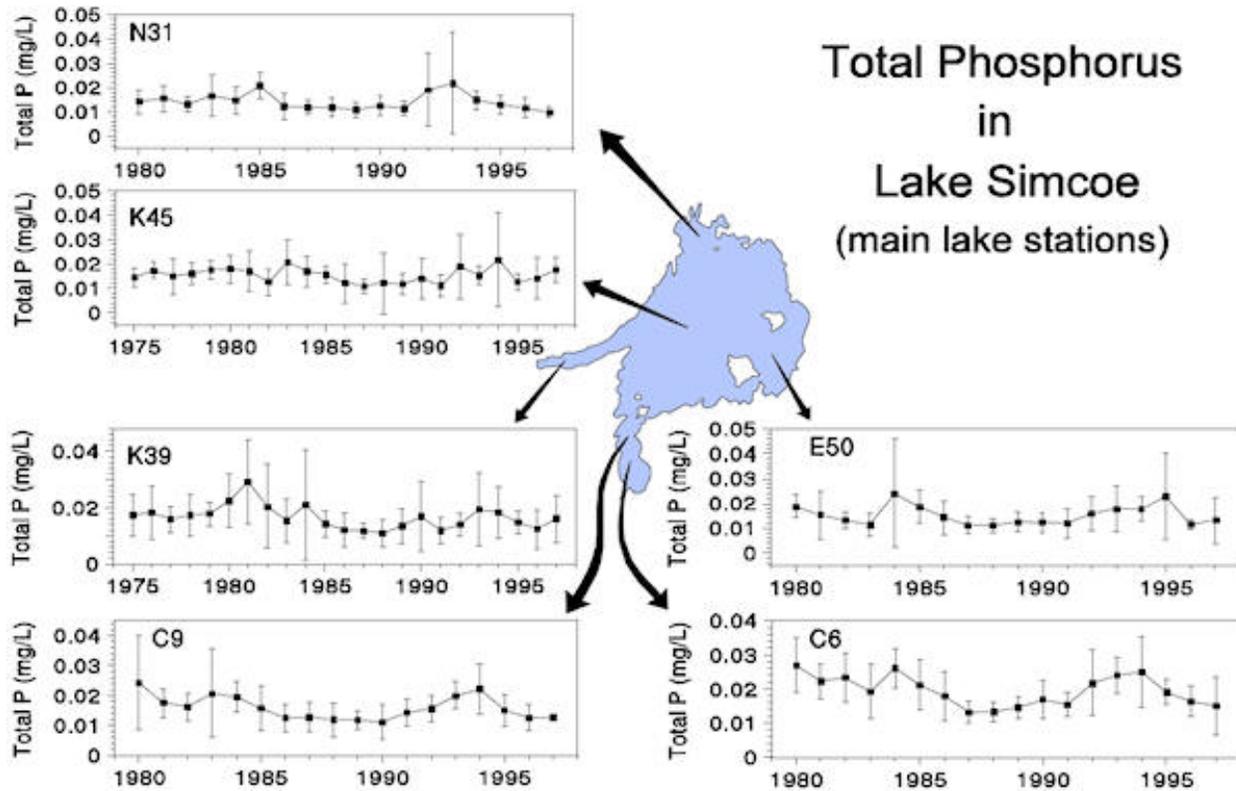


Fig. 4. Total phosphorus concentrations at six of the main lake sampling stations (May-Oct means ± 1 St. Dev.). Excluded in the calculated means are two anomalously high values at Station C9 (0.119 and 0.198 mg P/L recorded in July and August 1994, respectively) and at Station K45 (0.086 and 0.140 mg P/L in July and August of 1996). The 1975-79 samples from Stations K39 and K45 were collected from the epilimnion, while all other data reported here are from samples collected as euphotic zone composites Note also the slight differences in Y-axis scales.

b) *Main Lake Stations*

Patterns in the long term change of total phosphorus at several main lake stations are emerging, although the magnitude of change has not been as great as that seen in the outflow data. Generally, highest concentrations were seen during the early 1980's; levels declined through the late 1980's, rose during the early 1990's, then declined again after 1994 (Fig. 4). Recent declines in phosphorus concentrations in 1995-97 may have resulted from the invasion of the lake by zebra mussels which began about 1992 (but dense populations did not develop until 1995). Still, total phosphorus concentrations in 1995-97 at many sites were not significantly different from those measured in the late 1980's, so the early zebra mussel impact appears much less dramatic than that recorded for Lake Erie,

where declines of 30-50% in summer total phosphorus concentrations were attributed to zebra mussels. Inter-annual variation in stream flow is likely responsible for some of the short term variability in Lake Simcoe phosphorus, but a thorough evaluation of weather and climate effects on phosphorus trends has not been done.

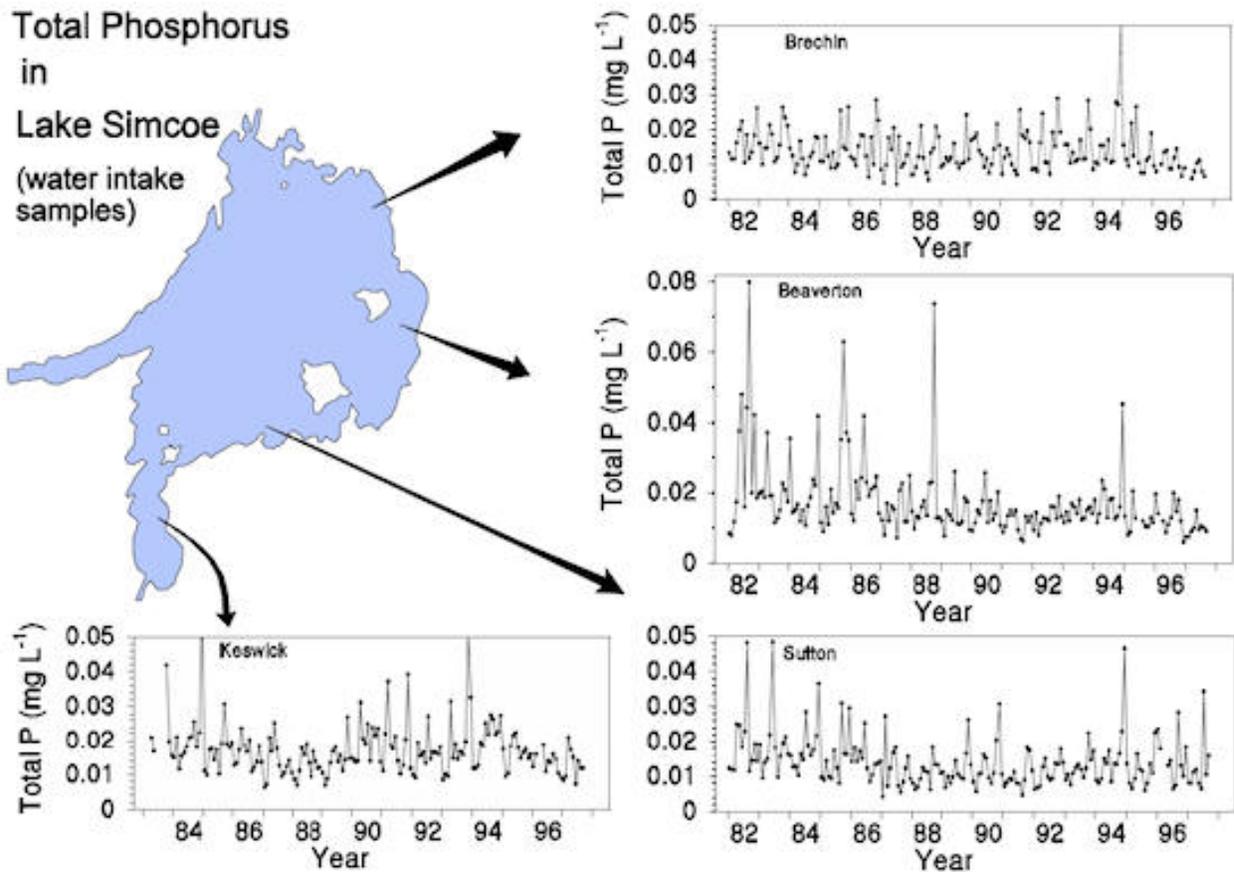


Fig. 5. Monthly mean total phosphorus concentrations in “raw” (untreated) water samples from four municipal water supply intakes in Lake Simcoe.

c) *Water Intake Samples*

Long term trends in total phosphorus are not as clearly defined in samples collected over the 16-year period for which we have data from the four municipal water supply intakes (Fig. 5). The greatest short term rate of decline in total phosphorus ($0.0023 \text{ mg P L}^{-1} \text{ yr}^{-1}$) was for the four-year period 1994-1997 at Keswick (Table 1). A significant rate of decline ($0.0022 \text{ mg P L}^{-1} \text{ yr}^{-1}$) was also measured in the Keswick intake samples for the period 1983-1988, but no statistically significant change was detected for the entire 16-year period (Table 1). Other significant short term declines were measured at Sutton for the 16-year

period (Table 1). Other significant short term declines were measured at Sutton for the 1982-1988 period and at Beaverton for the 1982-1991 period (Fig. 5; Table 1). At the Beaverton and Brechin locations, there was some evidence of a zebra mussel effect in 1997 when phosphorus concentrations were the lowest recorded (Fig. 5).

Table 1. Rate of decline of total phosphorus in samples collected from the Brechin, Beaverton, Sutton and Keswick water intakes, 1982-1997.

LOCATION	TIME PERIOD	RATE OF DECLINE (mg L ⁻¹ yr ⁻¹)	SIGNIFICANCE LEVEL ^a
Brechin	1982-1997	0.0001	0.04
	1982-1994	-	ns
Beaverton	1982-1997	0.0008	0.05
	1982-1989	-	ns
	1982-1991	0.0014	0.05
	1992-1997	0.0005	0.05
Sutton	1982-1997	0.0001	0.04
	1982-1988	0.0014	0.01
	1989-1997	-	ns
Keswick	1983-1997	-	ns
	1983-1988	0.0022	0.02
	1989-1997	-	ns
	1994-1997	0.0023	0.01

Footnote:

^a ns = no statistically significant trend; statistical tests after Cluis *et al.* (1989).

Water Clarity

Some of the highest water clarity measurements ever recorded in Lake Simcoe were made in 1996 and 1997 and extends the longer term trend toward improved water clarity in the lake. At all sampling locations, the May-October average Secchi disc visibility during the period 1988-1994 was higher than the average recorded for the 1980-1987 period, and May-October average Secchi disc the water column. The regions showing the greatest improvements in water clarity were the eastern one-third of the lake and the northern outlet

basin, where improvements ranged from 43% to 73%. Sampling Station E50, located in the shallow water (10 metres deep) between Georgina Island and Thorah Island had a May to October average water clarity of 3.3 metres during the 1988-1994 period. This increased to 5.9 m in 1996 and 7.0 m in 1997. The least improvement (13%) was seen in the deep (35 m) main lake region.

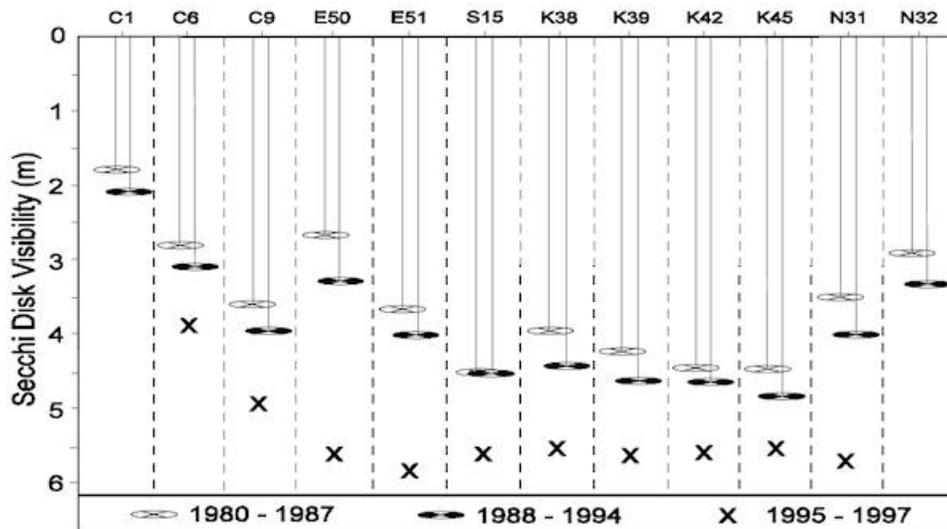


Fig. 6. Secchi disc visibilities at each of the 12 Lake Simcoe sampling stations grouped into three time periods: 1980-87, 1988-94 and 1995-97. The 1995-97 data for Stations C1 and N32 are not included because several measurements showed the Secchi disc on the lake bottom (a meaningless measurement).

Some evidence for a zebra mussel-related cause of the recently improved water clarity lies in the magnitude of the water clarity change relative to station depth. Zebra mussels clear the water by filtration of particles from the surrounding water. It is to be expected that this impact (clearer water) will be greater at near-shore shallow stations owing to a higher ratio of zebra mussel substrate area-to-overlying water volume. The shallow water stations (E50, E51, S15, N31 and N32) all showed greater recent proportional increases in water clarity (compared with the 1980-87 vs 1988-94 change) than did the deep water stations, K38, K39, K42 and K45 (Fig. 6). Thus-far, an apparent zebra mussel effect at the K-series lake sampling stations is no more significant than the increases in water clarity that occurred prior to the zebra mussel invasion (although they may have occurred more quickly).

Other possible effects of the recent zebra mussel invasion are even less clear, but may include altered species composition and biomass of the plankton (required to support the fish community) and benthic communities. Also, in the past two years, there has been

an apparent altered species composition and biomass of the plankton (required to support the fish community) and benthic communities. Also, in the past two years, there has been an apparent increase in the number of inquiries and complaints about taste and odour in Lake Simcoe. This duplicates the situation in Lake Erie and Lake Ontario of the past five years and is likely related to the zebra mussel invasion. Important effects of these bottom dwelling animals include an accelerated clearing of the water, so that benthic algae are now able to grow at deeper depths (higher illumination and nutrients from zebra mussel faeces, pseudofeces and dead zebra mussels). The altered lake bottom environment is conducive to colonization by odour producing blue-green algae (especially species of *Lyngbia* and *Oscillatoria* that produce musty odours as natural products of their growth). Additionally, the abundance of organic material promotes growth of aquatic actinomycetes (fungal-like bacteria), also known for their production of similar musty odours. Activated carbon ("charcoal") filtration is effective in removing these odours from drinking water supplies. A few more years of data are needed to define more clearly the zebra mussel impact in Lake Simcoe.

Dissolved Oxygen

Dissolved oxygen concentrations in the deep water zone of the lake continued to show the typical summertime decline in recent years. In 1995 and 1996, concentrations declined to about 2 mg L⁻¹ by early October (Fig. 7), as has been typical for most recent years. This has serious consequences for cold-water fish species which require higher dissolved oxygen levels, but cannot tolerate the higher temperatures of the more shallow strata in the lake where higher oxygen levels are found.

The decline in deep water dissolved oxygen was mirrored by a rise in temperature and both variables are best summarized as lake volume-weighted values (an integrating procedure that divides the total mass of oxygen (or heat content for temperature) by the total volume of the deep water zone). The June-August deep water volume-weighted temperature during 1994 averaged about 2-4°C higher than in 1995 and 1996 and was a factor contributing to lower end-of-summer oxygen concentrations in 1994 than in 1995 and 1996 (Fig. 8), because oxygen depletion is controlled (in part) by temperature. Factors other than temperature that control the end-of-summer deep water oxygen concentration include the initial early summer oxygen concentration in the deep water zone, the store of oxidizable material in the lake sediments and the rate of supply of fresh organic material from the water column (mainly

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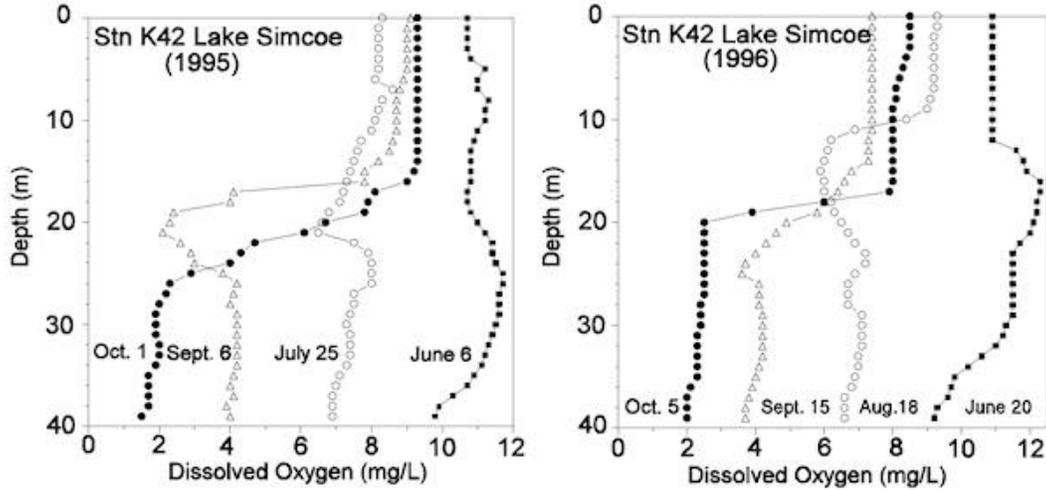


Fig. 7. Loss of dissolved oxygen in Lake Simcoe during the summer-fall periods of 1995 and 1996.

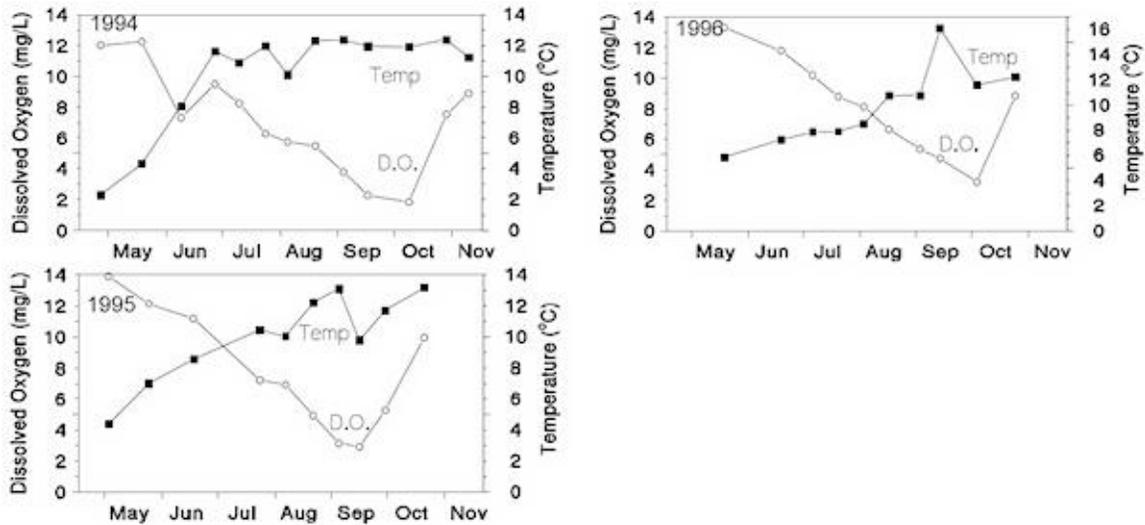


Fig. 8. Lake volume-weighted temperature and dissolved oxygen concentrations in the 18m-bottom zone of Lake Simcoe (Station K42) during the open water seasons of 1994-1996.

record, all rates for the deep water zone (18m-bottom) have been normalized to a rate at 4°C. The 4°C depletion rate rose steadily over the period 1980-1991 (Fig. 9). More recently, there has been a return to lower oxygen depletion rates and perhaps reflects the expected delayed response to lower total phosphorus concentrations in the water column of the lake.

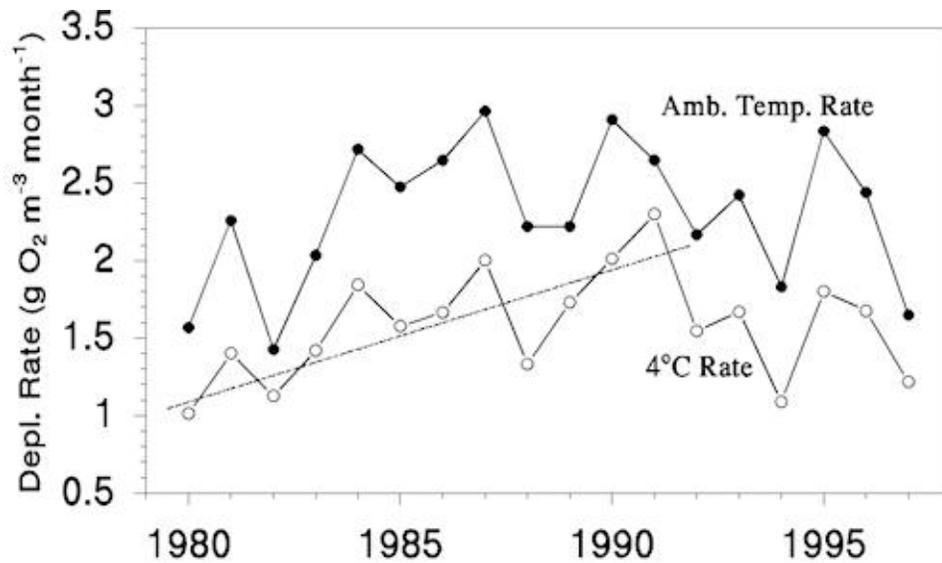


Figure 9. Lake volume-weighted dissolved oxygen depletion rate in the 18m-bottom zone of Lake Simcoe for mid-June to mid-September periods of years 1980-1997. Amb. Temp. Rate = depletion rate at ambient temperatures; 4°C Rate = rate after normalization to a rate at 4° C.

Holland River-Cook's Bay - Main Lake Gradient

The Holland River has been identified as a major source of phosphorus for Cook's Bay of Lake Simcoe (Peat and Walters, 1994). Water quality in the lower Holland River was expected to improve after the 1984 diversion out of the Lake Simcoe basin (to the York-Durham trunk line for discharge to Lake Ontario) of the treated sewage effluents from Aurora and Newmarket. There is some evidence (Fig. 10) for an immediate reduction in phosphorus concentrations in the East Branch of the river (Station H4, downstream of Newmarket) after 1984, but further improvements after 1984 are less easily demonstrated (Table 2). Statistical tests show significant step trends for both filtered reactive phosphorus (FRP) and total phosphorus (TP) at all three Holland river stations, with pre-step (1982-83) global FRP means of 0.152, 0.161 and 0.117 mg P L⁻¹ and post-step (1984-1997) global FRP means of 0.049, 0.042 and 0.033 mg P L⁻¹ at Stations H3, H4 and H6, respectively (Table 2). Similarly, pre- and post-step TP means were 0.289 and 0.183 mg P L⁻¹ at H3, 0.373 and 0.204 mg P L⁻¹ at H4, and 0.231 and 0.145 mg P L⁻¹ at H6. Statistically significant (but of much lower magnitude) step trends were also detected at Station H8 in Cook's Bay, near the mouth of the Holland River (Table 2). The reductions in phosphorus at H3 in the West Branch of the Holland River are likely related to flow reversal effects in this section of the

river. During summer stagnation, occasionally strong northerly winds that sometimes accompany summer storms drive Lake Simcoe water up the Holland River, causing an upstream movement of water. Water below the confluence of the two branches containing a phosphorus load contributed by the East Branch of the river is then pushed back up both branches, thus resulting in an east branch influence on the west branch.

The mid-summer stagnation of the lower Holland River is associated with the highest phosphorus concentrations. At Stations H3, H4 and H6, mid-summer peak concentrations have averaged 2-3 times higher than those measured in May (Fig. 11) and July-August values in the 0.2-0.4 mg P L⁻¹ range are similar to those achieved in the treated final effluent from sewage treatment plants in the Lake Simcoe basin. Earlier experimental work by Ministry staff showed that at least some of these high phosphorus levels could be attributed to a sediment feedback condition exacerbated by warm summer water temperatures. The sediments of the lower Holland River store high concentrations of phosphorus, some of which is released to the overlying water as a result of microbiological and redox-related chemical transformations. This condition is an unfortunate consequence of historically high phosphorus loading rates from urban areas on the East Branch (Aurora, Newmarket and Holland Landing) and urban (Bradford) and agricultural (Holland Marsh) areas on the West Branch.

The process of sediment burial by “cleaner” sediments will help to lessen the sediment feedback phenomenon, but based on the post sewage diversion data (1984-1997) reported here, this is likely to be a very slow process. At H4 in the East Branch of the river, the statistically significant monotonic trend had a slope of -0.004 (i.e. an annual reduction rate of 0.004 mg P⁻¹ yr⁻¹). Similarly, the annual rate of decline in total phosphorus at this site was only 0.005 mg P⁻¹ yr⁻¹ for the 1984-1997 period (Table 2). At this rate, it will take approximately 35 years to reduce concentrations to 0.03 mg P L⁻¹, levels above which the Ontario Ministry of the Environment has deemed undesirable for rivers (Ontario Ministry of Environment and Energy, 1994). Although constituting only about 3% of the total land area in the Lake Simcoe basin, urbanized areas are contributing 25-30% of the total phosphorus loading to the lake in urban runoff, excluding sewage treatment plant discharges (LSEMS, 1995). Therefore, there is no assurance that the rate of phosphorus decline in the Holland River over the past 1.5 decades (likely attributable to the York-Durham sewage diversion) will continue into the future as long as the human population growth in the Holland River basin continues its rapid increase.

Chlorophyll and Secchi disk visibility data from the Holland River-Cook's Bay-main

lake transect show patterns that are largely predictable from the phosphorus data. Generally, the years with high phosphorus levels also had high chlorophyll concentrations (Fig. 12) and low water clarity (Fig. 13). The south to north gradients in these variables is striking. The Holland River stations had chlorophyll a concentrations averaging in the 40-60 $\mu\text{g L}^{-1}$ range, with highest levels in the East Branch at H4 (Fig. 12). Concentrations decreased rapidly in the river mouth area and at Station H8, approximately 300 m N of the river mouth, the 14-year average was only 8.1 $\mu\text{g L}^{-1}$. Chlorophyll concentrations further declined northward, with 1980-1997 averages of 5.9, 4.0, 3.0 and 2.2 $\mu\text{g L}^{-1}$ measured at Stations C1, C6, C9 and K45, respectively (Fig. 12). At Station H4, the highest chlorophyll levels were measured in 1982 and 1983 (104 and 92 $\mu\text{g L}^{-1}$, May-October averages), prior to the sewage diversion from Aurora and Newmarket. At Station H3 in the West Branch of the river, the highest May-October averages were 88.6 and 89.9 $\mu\text{g L}^{-1}$ in 1988 and 1991 (Fig. 12).

Water clarity in Cook's Bay and the main lake was much lower than average in 1991, a year with higher than average total phosphorus and chlorophyll at the Holland River stations, and was extremely poor at the Holland River sites in all years. Water clarity in the main lake was about an order of magnitude higher on average than in the Holland River. The May-October average Secchi disk visibility at Station H4 was only 0.28 m during the 1982-1997 period (Fig. 13). Again, as for TP and chlorophyll, the Cook's Bay stations were intermediate along the south-to-north water clarity gradient (Fig. 13). The lake stations demonstrated an apparent zebra mussel effect with markedly clearer water in 1996 and 1997 at most locations (but not in the river).

There are three likely contributing sources to the poor water clarity of the Holland River: 1) resuspension from the river bottom by boat traffic and wind, 2) runoff of silt and clay colloids from agriculture and urban construction activities, and 3) suspended algae growing in the lower river in response to phosphorus loading to the river from upstream sources. Of these, the last (suspended algae) is apparently the dominant contributor to the high river turbidity. The Holland River data fit reasonably well into phosphorus-chlorophyll-Secchi disk models developed for other eutrophic lakes; thus the excessive turbidity of the Holland River is apparently largely contributed by chlorophyll-bearing particles (algae) and therefore is related directly to the phosphorus enrichment problem.

Conclusions

Although there is no evidence for a recent worsening of the phosphorus enrichment status of Lake Simcoe, neither has there been any major progress made in achieving lower phosphorus concentrations in the Lake. The Holland River showed a major reduction in phosphorus and chlorophyll immediately following the diversion of the Aurora/Newmarket sewage effluent out of the basin in 1984; however, declines in recent years have been much less dramatic. At the present rate of decline, it will take approximately 35 years to achieve the Ministry of the Environment's guideline of 0.03 mg P L^{-1} for Ontario rivers. This assumes that this rate of decline can be maintained despite an expanding urban population over the next 35 years - a questionable assumption. Even after the 1984 diversion, the lower Holland River had some of the highest phosphorus and chlorophyll levels and the poorest water clarity ever measured in Ontario. A successful "cleanup" of Lake Simcoe will depend in large part on controlling phosphorus inputs from the Holland River.

A trend to higher deep-water summer dissolved oxygen depletion rates through the 1980's appears to have been broken in recent years, with rates in 1994 and 1997 in particular among the lowest measured since 1980. Some of this apparent "improvement" may be attributed to the establishment of zebra mussels in the lake by the mid-1990's.

Acknowledgments

Joyce Clark, Janet Humber, Ted Sheldon, Ron Taylor, Mark Ledlie and Vanessa Ledlie did most of the sampling and measurements of temperature, dissolved oxygen and Secchi disk visibility. Staff of the Laboratory Services Branch, Ministry of the Environment performed the chemical analyses. Steve Maude (Central Region, MOE) provided helpful suggestions on the first draft of this report.

Table 2. Non-parametric test statistics for detection of monotonic and step trends (Cluis *et al.*, 1989) in filtered reactive phosphorus (FRP) and total phosphorus (TP) concentrations at Stations H3, H4 and H6 in the lower Holland River and at Station H8 in S Cook's Bay, using monthly means (May to October), 1982-1997.

STATION (and variable)	TIME PERIOD (and trend type)	STATISTICAL TEST	SLOPE ± ST. DEV. (mg/L/Y)	SIGNIF. LEVEL	PRE-STEP GLOBAL MEAN ± ST. DEV.	POST-STEP GLOBAL MEAN ± ST. DEV.
H3 (FRP)	1982-97(monotonic)	Hirsch & Slack	-0.006 ±0.001	0.009 (yes)	NA	NA
H3 (FRP)	1982-83 <u>vs.</u> 1984-97 (step)	Mann-Whitney seas/ Lettenmaier	NA	0.009 (yes)	0.152 ± 0.104	0.049 ± 0.038
H3 (FRP)	1984-97(monotonic)	Hirsch & Slack	NA	0.077 (no)	NA	NA
H4 (FRP)	1982-97(monotonic)	Spearman/ Lettenmaier	-0.008 ±0.001	yes ¹	NA	NA
H4 (FRP)	1982-83 <u>vs.</u> 1984-97 (step)	Mann-Whitney seas/ Lettenmaier	NA	0.014 (yes)	0.161 ± 0.09	0.042 ± 0.034
H4 (FRP)	1984-97(monotonic)	Spearman/ Lettenmaier	-0.004 ±0.001	yes ¹	NA	NA
H6 (FRP)	1982-97(monotonic)	Hirsch & Slack	-0.005 ±0.001	0.002 (yes)	NA	NA
H6 (FRP)	1982-83 <u>vs.</u> 1984-97 (step)	Mann-Whitney seas/Lettenmaier	NA	0.007 (yes)	0.117 ± 0.079	0.033 ± 0.025
H6 (FRP)	1984-97(monotonic)	Hirsch & Slack	-0.003 ±0.001	0.018 (yes)	NA	NA
H8 (FRP)	1983-97(monotonic)	Kendall	-0.0005 <±0.001	0.016 (yes)	NA	NA
H8 (FRP)	1983 <u>vs.</u> 1984-97 (step)	Mann-Whitney	NA	0.014 (yes)	0.014 ± 0.013	0.005 ± 0.008

Table 2 cont'd

H8 (FRP)	1984-97(monotonic)	Kendall	NA	0.095 (no)	NA	NA
H3 (TP)	1982-97(monotonic)	Hirsch & Slack	-0.005 ±0.002	0.027 (yes)	NA	NA
H3 (TP)	1982-83 <u>vs.</u> 1984-97 (step)	Mann-Whitney seas/Lettenmaier	NA	0.032 (yes)	0.289 ± 0.139	0.183 ± 0.058
H3 (TP)	1984-97(monotonic)	Hirsch & Slack	NA	0.225 (no)	NA	NA
H4 (TP)	1982-97(monotonic)	Hirsch & Slack	-0.010 ±0.002	0.001 (yes)	NA	NA
H4 (TP)	1982-83 <u>vs.</u> 1984-97 (step)	Mann-Whitney seas/Lettenmaier	NA	0.014 (yes)	0.373 ± 0.158	0.204 ± 0.057
H4 (TP)	1984-97(monotonic)	Hirsch & Slack	-0.005 ±0.001	0.008 (yes)	NA	NA
H6 (TP)	1982-97(monotonic)	Hirsch & Slack	-0.005 ±0.001	<0.001 (yes)	NA	NA
H6 (TP)	1982-83 <u>vs.</u> 1984-97 (step)	Mann-Whitney seas/Lettenmaier	NA	0.021 (yes)	0.231 ± 0.111	0.145 ± 0.038
H6 (TP)	1984-97(monotonic)	Hirsch & Slack	-0.003 ±0.001	0.002 (yes)	NA	NA
H8 (TP)	1983-97(monotonic)	Kendall	NA	0.123 (no)	NA	NA
H8 (TP)	1983 <u>vs.</u> 1984-97 (step)	Mann-Whitney	NA	0.049 (yes)	0.046 ± 0.02	0.034 ± 0.018
H8 (TP)	1984-97(monotonic)	Kendall	NA	0.304 (no)	NA	NA

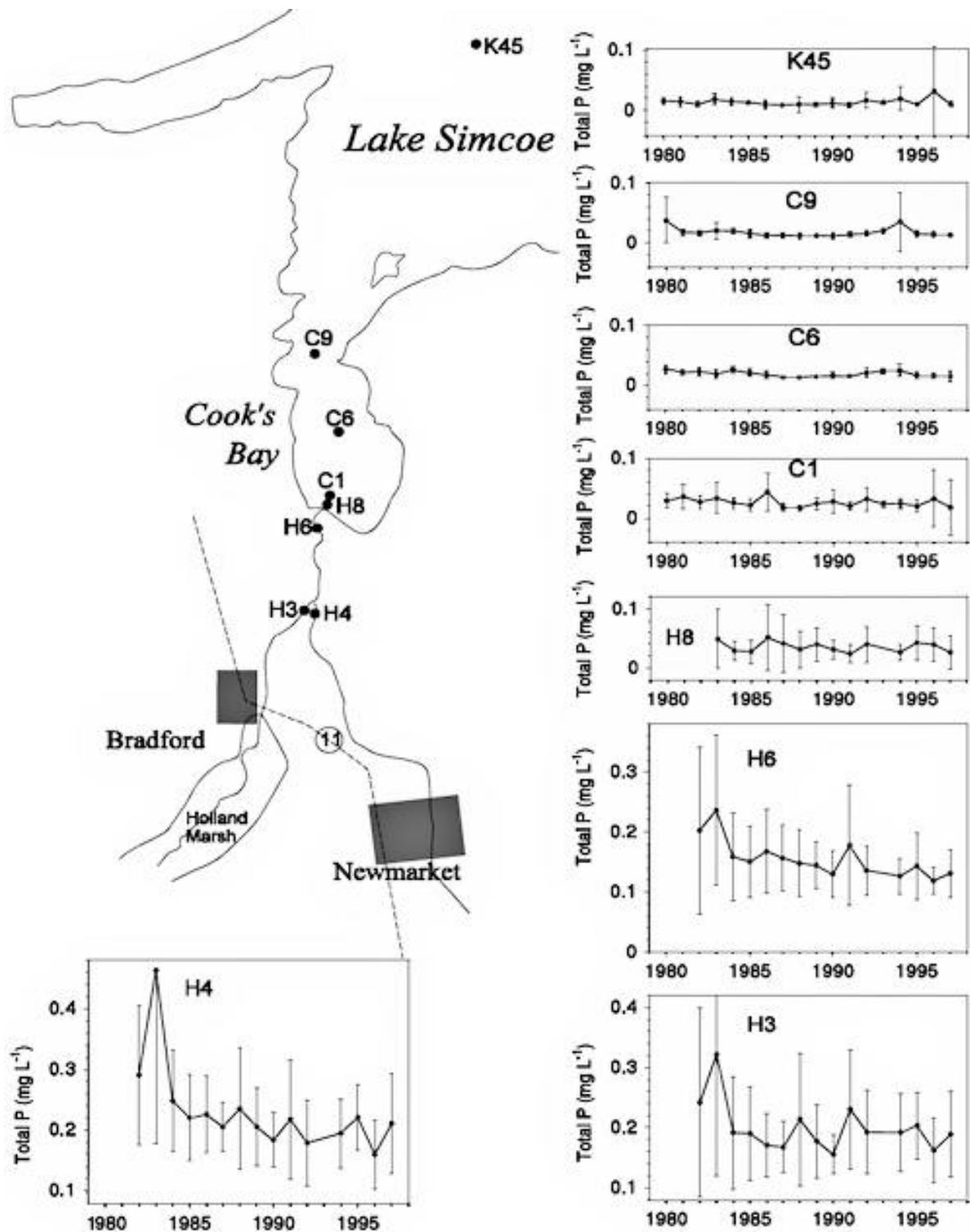


Fig. 10. May to October mean total phosphorus concentrations (± 1 St. Dev.) At sampling stations along a gradient from the lower Holland River to the middle of Lake Simcoe, 1980 - 1997.

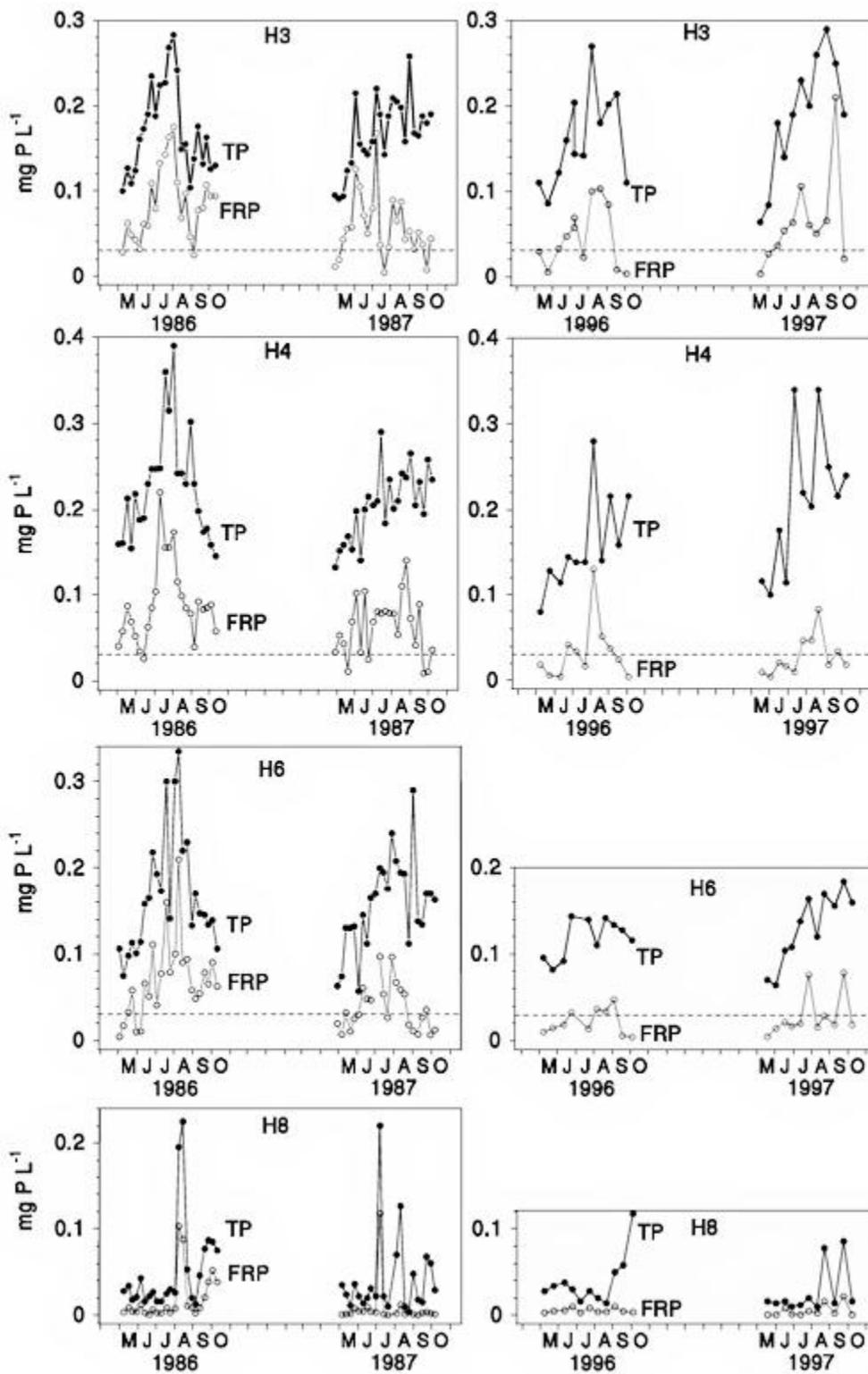


Fig. 11. Total phosphorus (TP) and filtered reactive phosphorus (FRP) concentrations at Stations H3, H4 and H6 in the lower Holland River and at Station H8 in S Cook's Bay during the May to October periods of 1986-87 and 1996-97. The dashed line at the river stations represents the Ontario Ministry of the Environment's interim TP guideline for Ontario rivers (levels above 0.03 mg L^{-1} are considered undesirable).

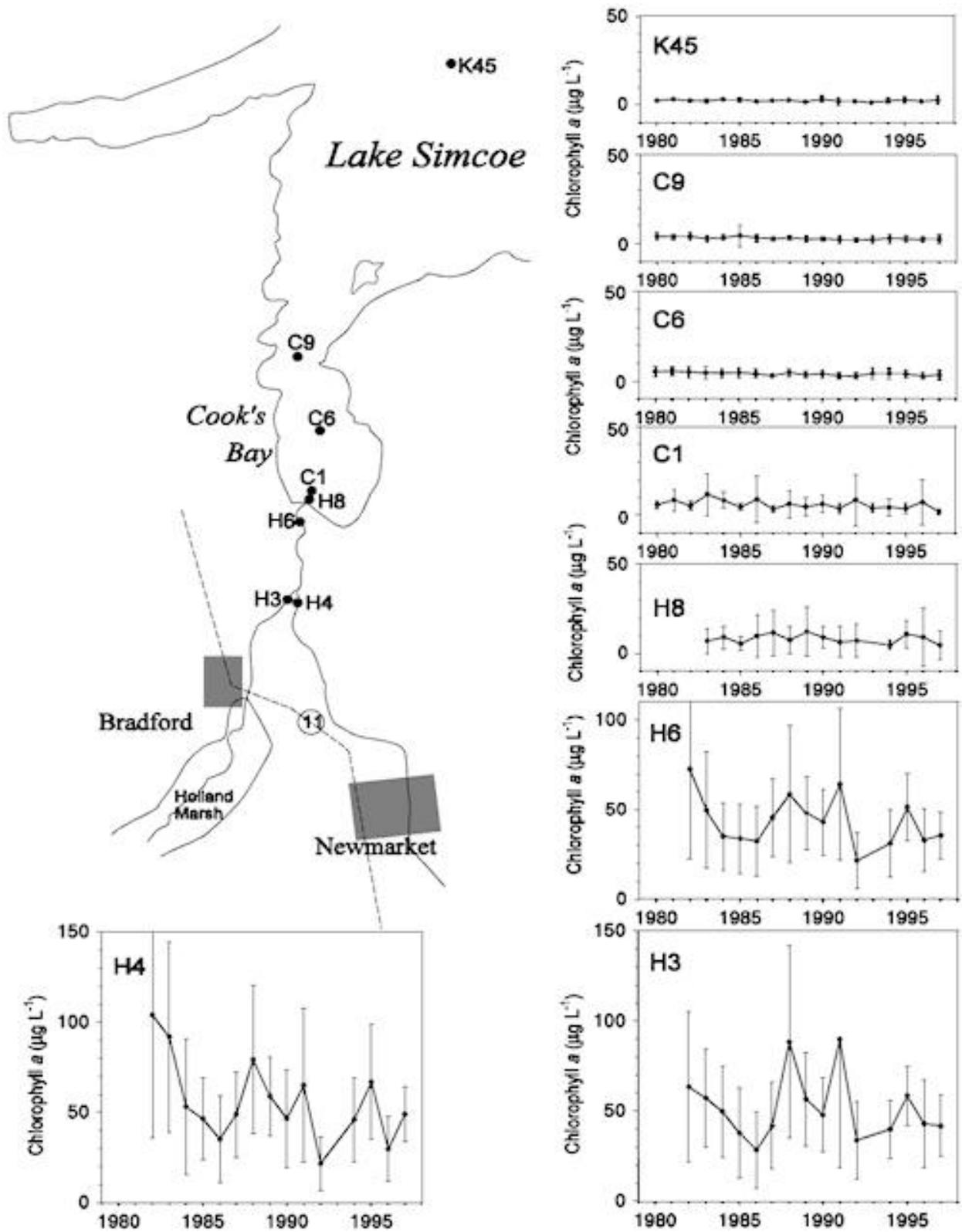


Fig. 12. May to October mean total chlorophyll concentrations (± 1 St. Dev.) at sampling stations along a gradient from the lower Holland River to the middle of Lake Simcoe, 1980-1997.

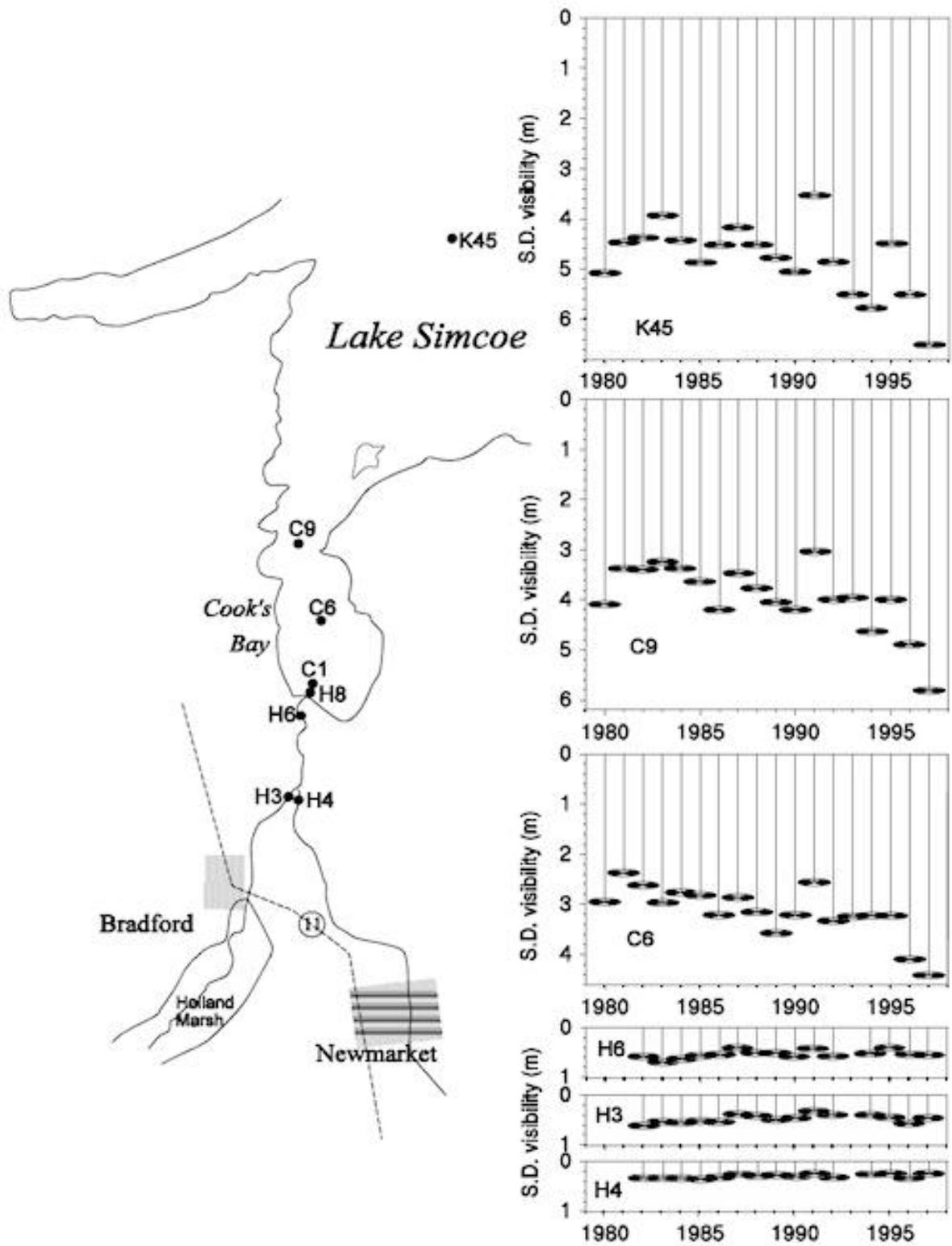


Fig. 13. May to October mean Secchi disk visibility (metres) at sampling stations along a gradient from the lower Holland River to the middle of Lake Simcoe, 1980-1997.

References

- Cluis, D., Langlois, C., Van Coillie, R., and Laberge, C. 1989. Development of a software package for trend detection in temporal series: application to water and industrial effluent quality data for the St. Lawrence River. *Environ. Monit. and Assessment*. 12: 429-441.
- Jackson, M.B. 1985. The red alga *Bangia* in Lake Simcoe. *J. Great Lakes Res.* 11: 179-181.
- LSEMS. 1995. Lake Simcoe - Our Waters, Our Heritage. Lake Simcoe Environmental Management Strategy Implementation Program. Summary of Phase I Progress and Recommendations for Phase II. Lake Simcoe Region Conservation Authority. Newmarket, Ontario. 109 p.
- Ministry of Environment and Energy. 1994. Water Management; Policies, Guidelines, Provincial Water Quality Objectives. Ministry of the Environment, Toronto.
- Nicholls, K.H. 1995. Some recent water quality trends in Lake Simcoe, Ontario: Implications for basin planning and limnological research. *Can. Water Res. J.* 20(4):213-226.
- Nicholls, K.H. 1997. A limnological basis for a Lake Simcoe phosphorus loading objective. *J. Lake and Reserv. Manage.* 13: 189-198.
- Peat, G. and Walters, M. 1994. *Lake Simcoe Tributary Monitoring Data Report*. LSEMS Report # Imp. A.2. Lake Simcoe Region Conservation Authority. Lake Simcoe Region Conservation Authority, Newmarket.