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Commentary on the Possible Effects of Phosphorus Loading Reductions on Oxygen Depletion In Lake Simcoe

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COMMENTARY ON THE POSSIBLE EFFECTS OF PHOSPHORUS LOADING REDUCTIONS ON OXYGEN DEPLETION IN LAKE SIMCOE

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M.N. Charlton and L.L. Janus

National Water Research Institute
867 Lakeshore Road
Burlington, Ontario, Canada L7R 4A6

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INTRODUCTION

As in many other lakes, eutrophication has been a concern in Lake Simcoe for some time. Due to the diversity of nutrient sources, control of large portions of total phosphorus loadings is difficult. Nevertheless, significant loading reductions have occurred and further reductions are proposed.

The fishery in Lake Simcoe is apparently impacted by eutrophication through the oxygen depletion process which occurs in the cold bottom water during summer. Under current conditions, the cold water fish are restricted to a narrow band of water which is the only suitable habitat existing by the end of summer. Thus, although surface water quality is important, there is interest in whether further phosphorus controls will ameliorate oxygen depletion and thereby allow greater utilization of the aquatic habitat by the fish.

COMMENTS ON MOE RESULTS

I. Phosphorus Loading - Lake Concentration Relationship

The following section is based on figures in Tables 1 and 2. The observed average lake concentration for Lake Simcoe during the late 1970s is reported at approximately 19 $mg.m^{-3}$. The average inflow concentration $[P_j]$, as estimated from the total phosphorus load (103 $tons.y^{-1}$) and annual hydraulic load ($7.7x10^8 m^3.y^{-1}$) is 133.7 $mg.m^{-3}$. The ratio $(P_\lambda P_j)$=0.142 indicating that Simcoe has a high assimilation capacity for phosphorus. Assuming that these lake and inflow concentrations are reasonably close to steady-state (which appears to be justified since 1974 and 1980 data are not much different), then a sedimentation coefficient (σ) of 0.381 y^{-1} can be estimated. This is somewhat higher than the 'global' statistical observation that $\sigma \sim 1/\sqrt{\tau_\omega}$ (i.e. 0.250 for Simcoe with τ_ω=16 y).

Table 1. Morphometric and Hydrological Data of Lake Simcoe

As	=	725 km^2
$\bar{z}$	=	17 m Z_{max} = 44 m
V	=	12.3×10^7 m^3
τ_ω	=	16 y therefore ρ = .063 y^{-1}
Q^ω	=	7.7×10^8 $m^3.y^{-1}$
$[P_\omega]$	=	21 $mg.m^{-3}$ (1974) = $167.17x10^3$ $kg.y^{-1}$ outlet loss
$[\bar{P}_\lambda]$	=	19 $mg.m^{-3}$ (1974)
L_p	=	103×10^3 kg $P.y^{-1}$
$[P_j]$	=	$\frac{103x10^9 \ mg.y^{-1}}{7.7x10^9 \ m^3.y^{-1}}$ = 133.7 $mg.m^{-3}$
(P_λ/P_j)	=	0.142 = $\rho/\rho+\sigma$, therefore σ = 0.381 y^{-1}; $\sigma \sim 1/\sqrt{\tau_\omega}$ = 0.250 therefore OECD model will overestimate P_λ slightly).

Table 2. Lake Simcoe Nutrients and Trophic Indicators as Reported by the MOE, 1980.

Sta	Sta z max	1980 min DO $mg.L^{-1}$	$[P]_{TOT}$ (range)	TKN	NH_3	NO_3	Chl a (range)	SD (range)
K39	35	0.4 Oct.	21	390	25	25	2.6	4.9
			(15-43)	356-420			1.4-4.5	3.5-7.6
K42	40	0.0 Oct.	22	410	25	17	2.1	4.6
			(14-38)	330-460			1.5-3.7	3.5-6.3
K45	35	2.0 Sept.	17	360	26	11	1.7	5.1
			(11-28)	70-430			10-2.8	3.2-7.0
E50	10	7.1 Jul.	17	370	16	6	2.0	2.8
			(13-26)	350-390			1.1-3.1	1.5-4.5
E51	13	3.0 Aug.	16	380	17	6	2.0	4.4
			(12-29)	320-450			1.1-3.0	1.8-7.5
N31	11	5.3 Jul.	16	370	19	6	2.0	4.5
			(12-20)	340-400			0.2-3.4	2.7-6.1
C9	19		36	410	32	8	3.1	3.9
			(14-119)	370-490			1.2-5.9	3.1-5.8
C6	12	3.5 Sept.	40	450	37	6	4.5	3.0
			(28-119)	350-520			1.2-7.2	1.8-5.0
C1	3		29	460	23	8	3.8	1.9
			(16-53)	370-450				1.6-2.6
1.0-2.9 HRl				195		136	101	
			(111-423)					

Projections:

The observed mean outflow concentration of 21 $mg.m^{-3}$ is not much different from the average lake concentration of 19 $mg.m^{-3}$ and it is therefore reasonable to assume that $P_\omega = P_\lambda$ for model projections. However, Vollenweider's flushing corrected inflow standard would slightly overestimate lake concentrations expected for given loadings since σ would be underestimated at 0.25 y^{-1}. Instead, using the observed σ=0.381, ρ=0.063, and the relationship:

$$[P_\lambda] = [P_j] \left(\frac{\rho}{\rho + \sigma}\right)$$

the lake concentrations resulting from different loadings may be estimated. These estimated lake concentrations (Table 3) show that the loading decrease from 138 $tons.y^{-1}$ to 103 $tons.y^{-1}$ in 1976 should have resulted in a concentration decrease of approximatley 5 $mg.m^{-3}$. If the proposed loading reduction to 87 $tons.y^{-1}$ is reached, one would expect the resultant lake concentration to be approximately 16 $mg.m^{-3}$. These projections are made assuming σ is constant, however, data on other lakes indicates that σ decreases over long periods of increasing loading. This means that lakes tend to lose their resilience and therefore a future projection of 23 $mg.m^{-3}$ for a loading of 125 $tons.y^{-1}$ may be too optimistic. Nutrient budgets should be maintained in order to follow changes in σ. At the present, Simcoe is still a strong sink for phosphorus.

Table 3. Projected [P] and [Chl] Values for Lake Simcoe

Year	P Load 10^3 $kg.y^{-1}$	$[P_j]$ $mg.m^{-3}$ Assume qs= $7.7x10^8$ $m^3.y^{-1}$	$[P_\lambda]^{expected}$ $mg.m^{-3}$*	$[Chl]^{+}$**
1972	138	179.22	25.43	6.45
1976	103	133.7	18.97	4.87
2000	125	162.3	23.03	5.87
Proposed Reduction:	87	112.99	16.0	4.13

*$[P_\lambda]$expected = $[P_j]$ $(\rho/\rho+\sigma)$; assumes σ does not change
σ = 0.381 in 1974
ρ = 0.063 if τ_ω = 16 y

**OECD standard relationship $[Chl] = 0.287\ [P_\lambda]^{.962}$

II. Phosphorus Concentration - Chlorophyll Relationship

Chlorophyll concentrations reported for the 9 stations in Simcoe were plotted against the mean phosphorus concentrations for the same stations (cf. Fig. 1). All chlorophyll values were substantially lower than would be expected on the basis of the OECD relationship (for approximately 90 temperate lakes). Figure 2 depicting the position of many lakes throughout Canada is included for comparison. Low Chlorophyll values are even more exaggerated when maximum values are plotted against total P (cf. Fig. 3). There are two possible explanations for this; either 1) Chl is limited by a factor other than phosphorus or 2) Chl values have been underestimated. Some judgement of which is more probable may be made by using the Secchi disk information. The Secchi depth (SD) plotted against Chl (Fig. 4) shows that the SD readings are consistently more shallow than one would expect on the basis of the Chl levels. However, SD values are very close to the OECD expectation on the basis of average phosphorus concentrations (cf. Fig. 5). Therefore it appears that Chl values have been underestimated.

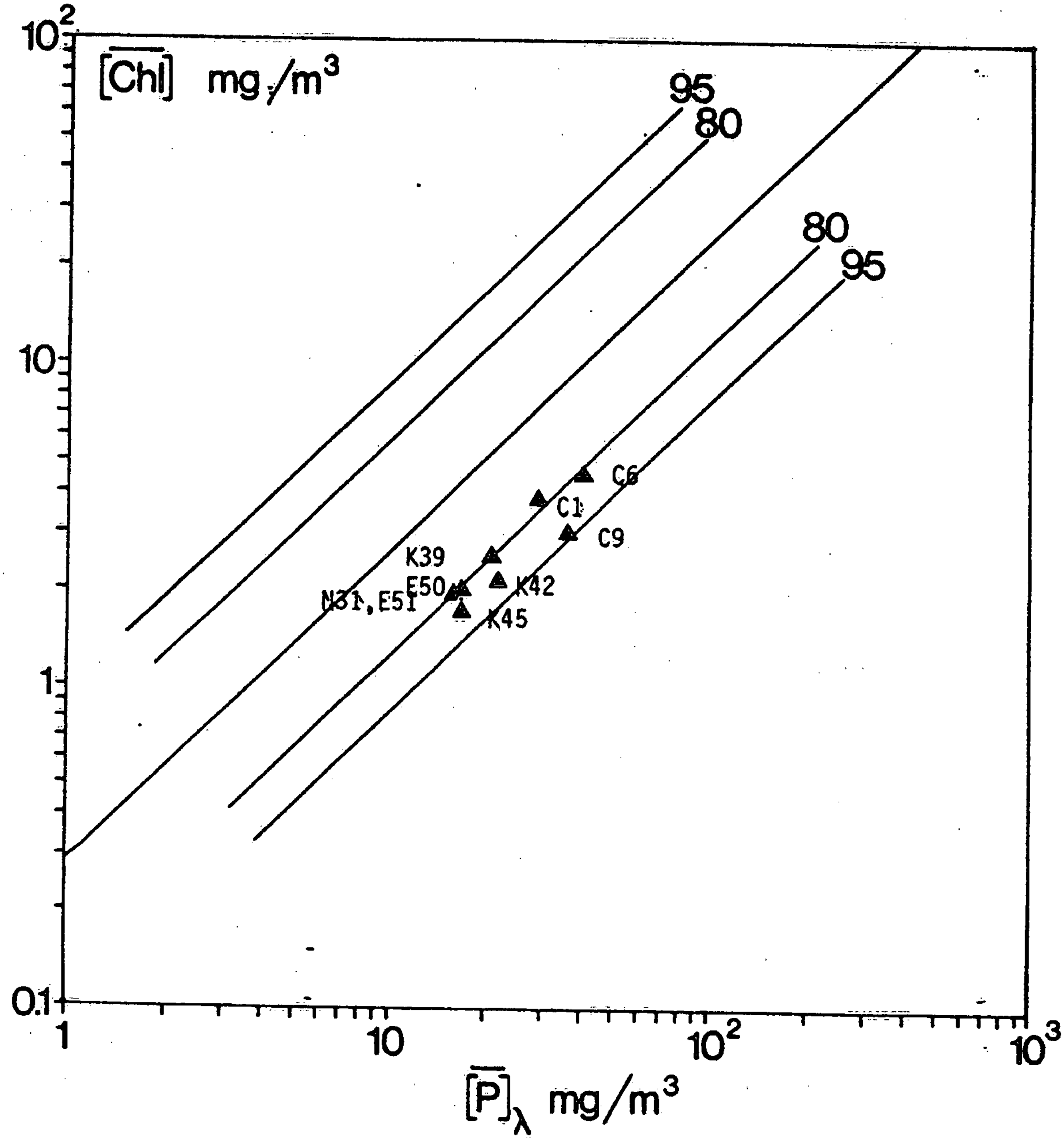

[Chl] mg/m3
95
80
80
95
C6
C1
C9
K39
E50
K42
N31, E51
K45
10^2
10
1
0.1
1
10
10^2
10^3
[P]λ mg/m3

Figure 1

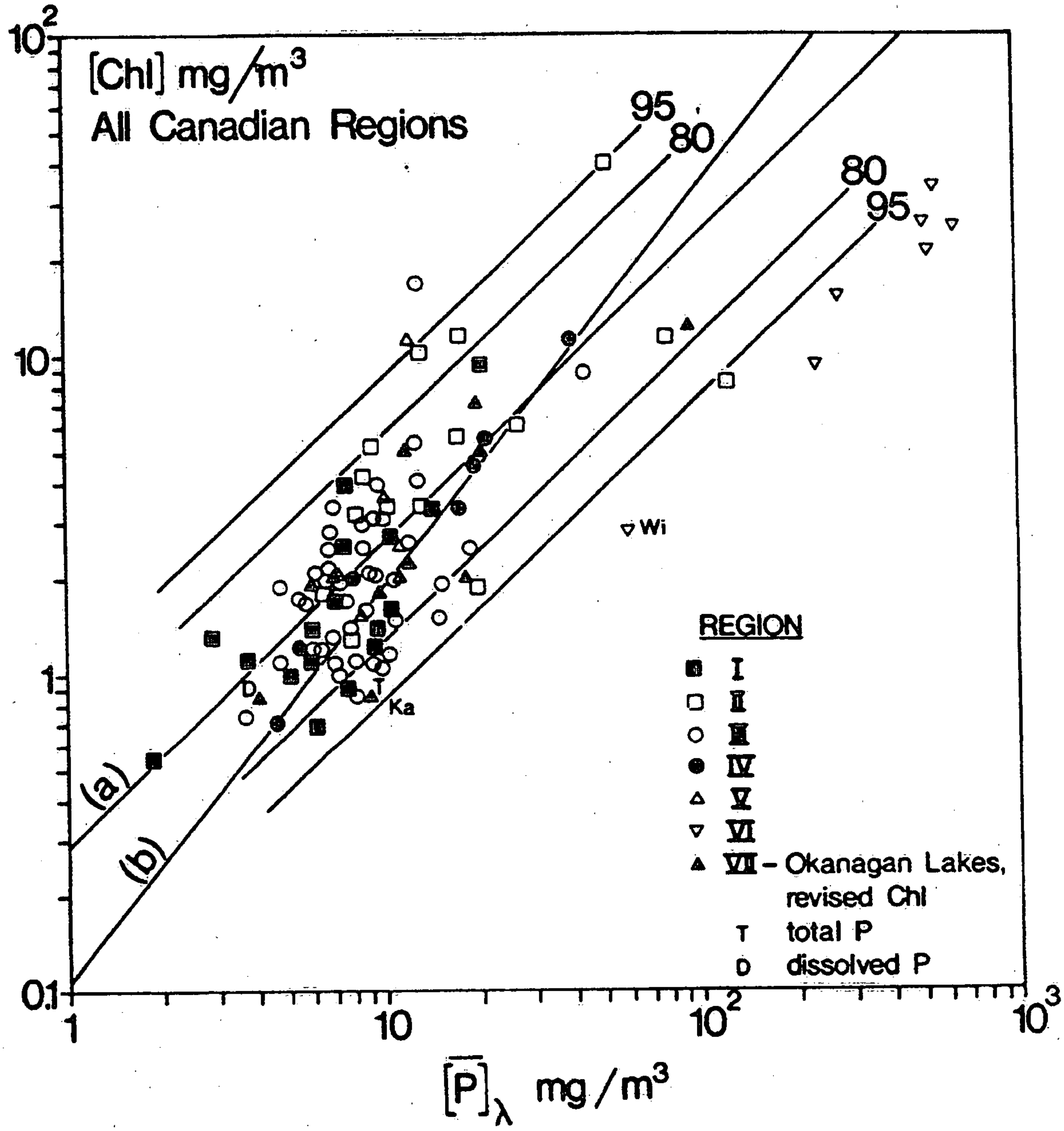
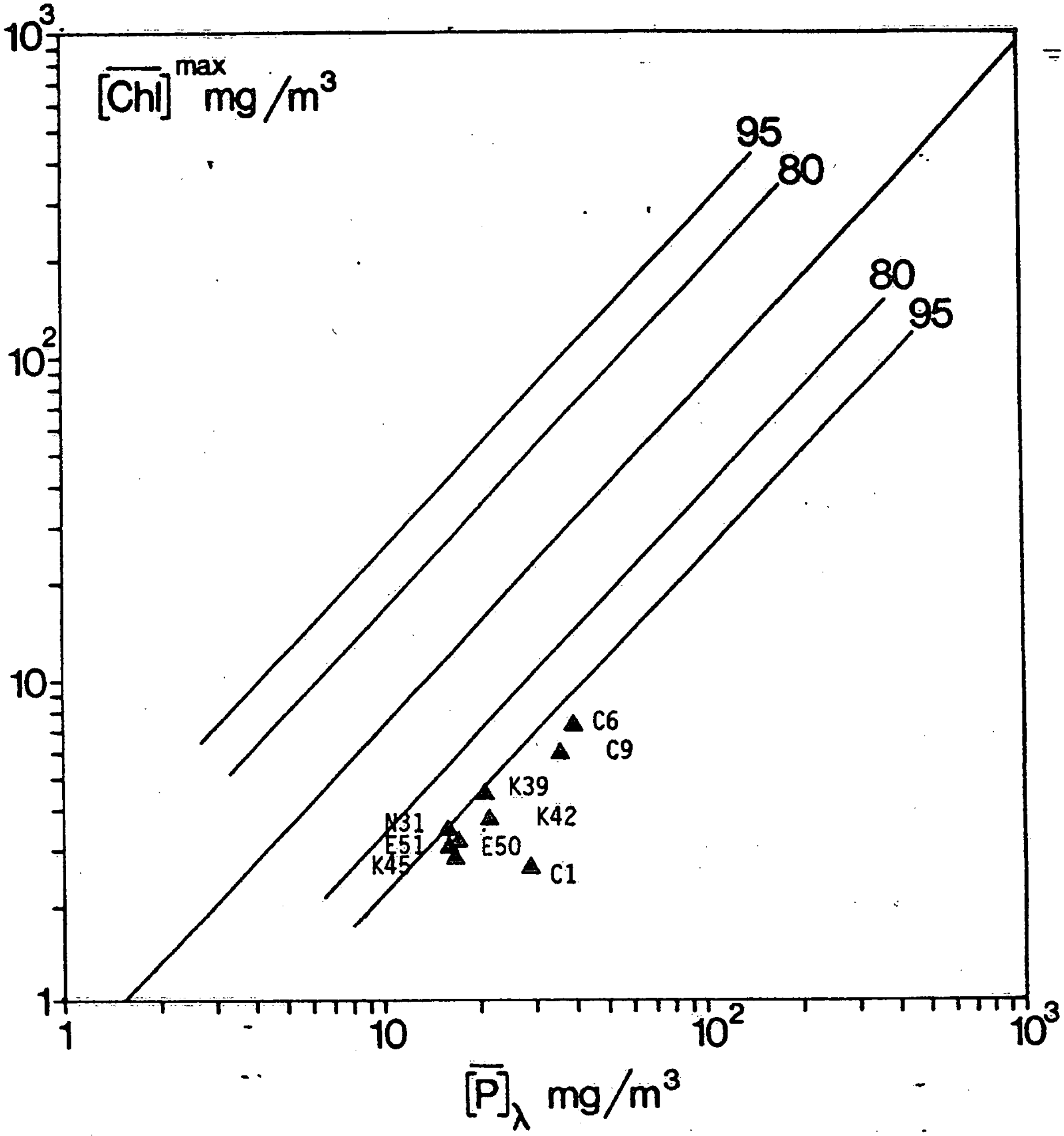

[Chl] mg/m3
All Canadian Regions
95
80
80
95
(a)
(b)
Wi
Ka
D
T
REGION
I
II
III
IV
V
VI
VII - Okanagan Lakes, revised Chl
T total P
D dissolved P
0.1
1
10
10^2
1
10
10^2
10^3
[P]λ mg/m3

Figure 2



$\overline{[Chl]}^{max}$ mg/m^3
95
80
80
95
C6
C9
K39
K42
N31
E51
E50
K45
C1
10^3
10^2
10
1
1
10
10^2
10^3
$\overline{[P]}_\lambda$ mg/m^3

Figure 3

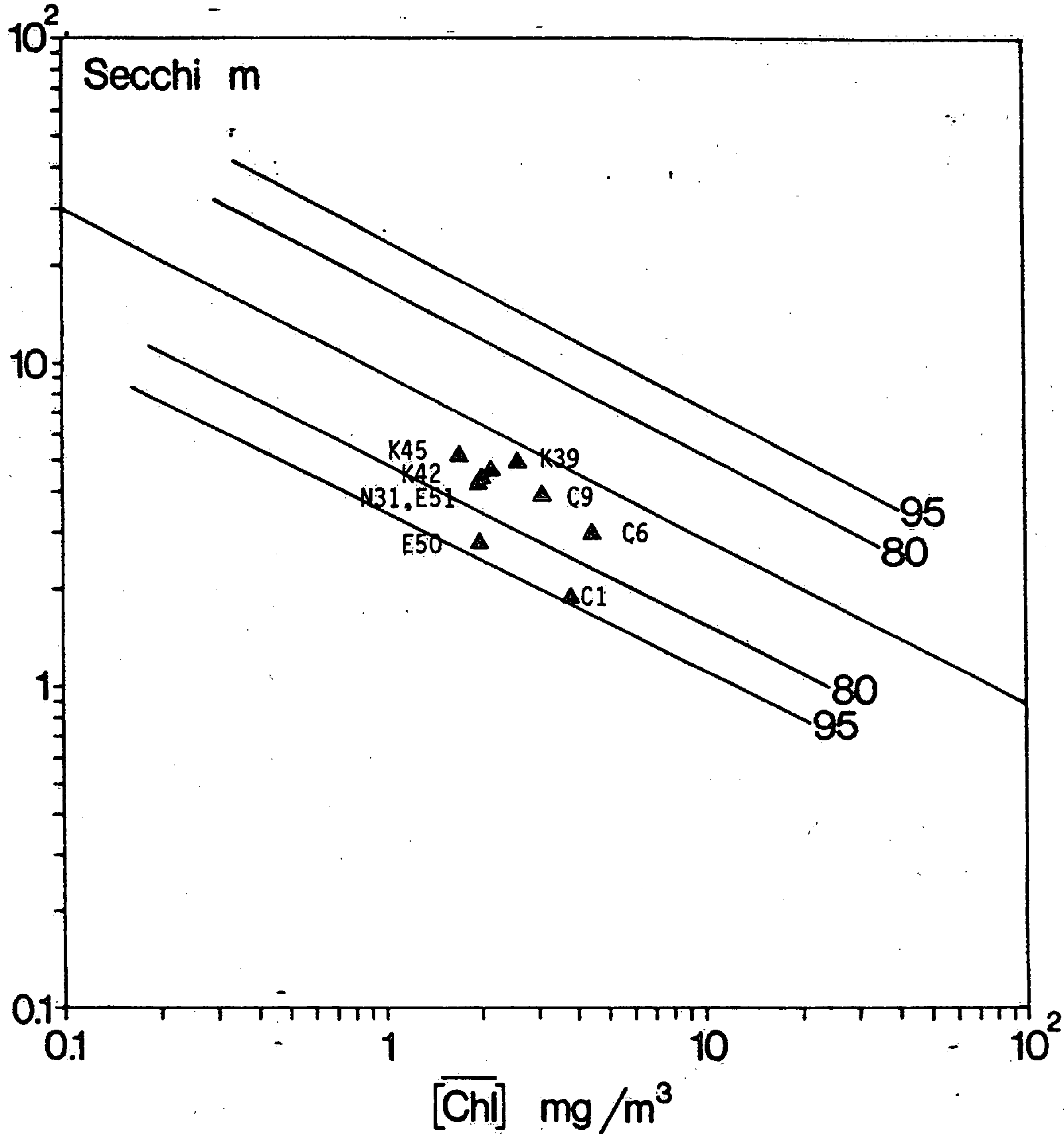
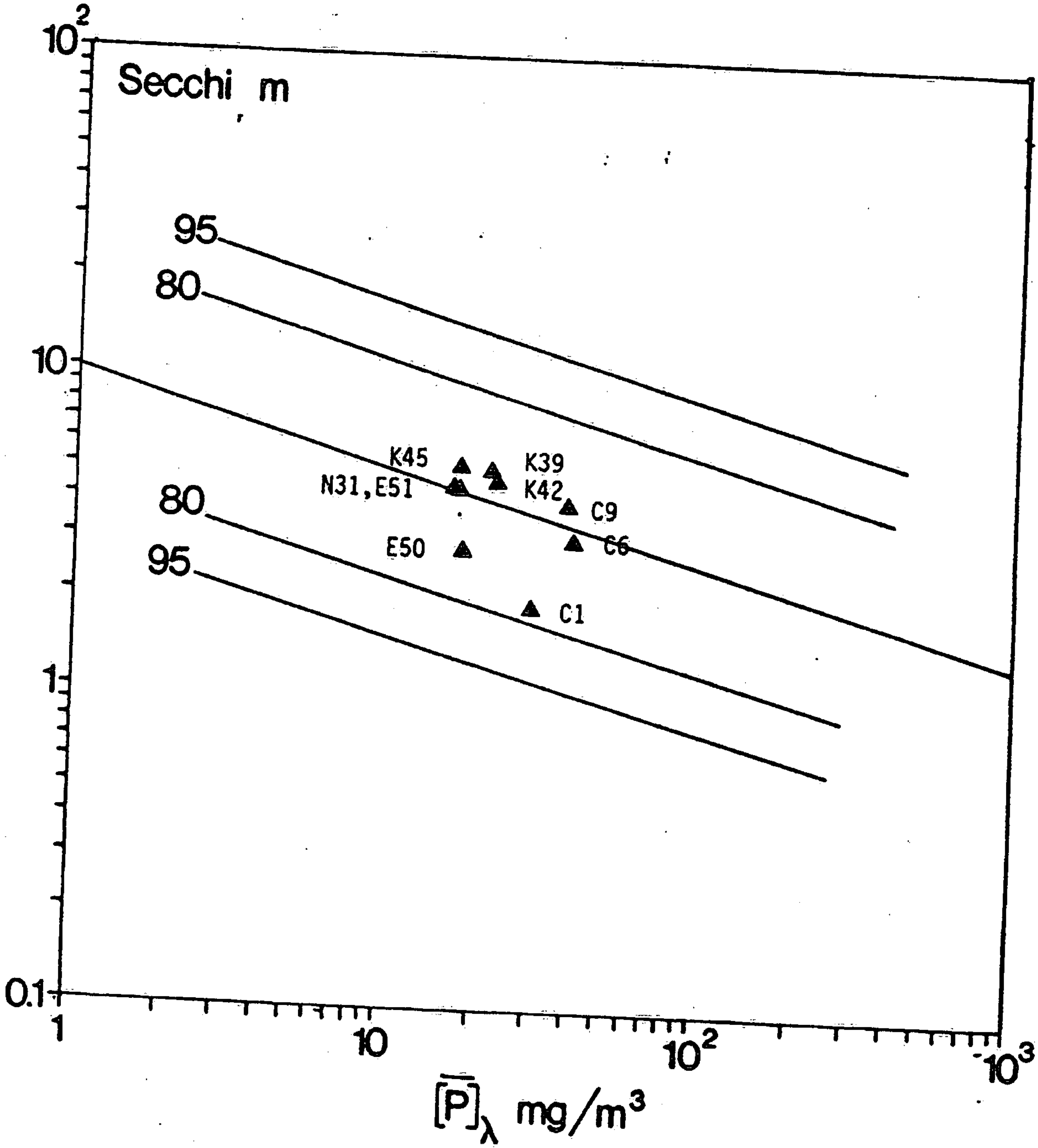

Secchi m
10²
10
1
0.1
K45
K42
N31,E51
K39
C9
C6
E50
C1
95
80
80
95
0.1
1
10
10²
[Chl] mg/m³

Figure 4



Secchi m
95
80
80
95
K45
K39
N31,E51
K42
C9
E50
C6
C1
10^2
10
1
0.1
1
10
10^2
10^3
$[\bar{P}]_\lambda$ mg/m^3

Figure 5

Some expected Chl values for given phosphorus loads are listed in Table 3. If the loading reduction to 87 tons.y^{-1} is reached, an average Chl concentration of approximately 4 mg.m^{-3} or maximum of 12 mg.m^{-3} is expected. This average Chl would equate to a Secchi depth of 7 to 8 m. If loading in the year 2000 were 125 tons.y^{-1}, Chl and SD would be projected at approximately 6 mg.m^{-3} and 6 m, respectively.

III. Nitrogen - Chlorophyll Relationship

Despite the fact that Chl values may be underestimates, they appear to be independent of mean nitrogen concentrations (cf. Fig. 6). Considering the trend of the Chl vs P plot and high N/P ratios (~20), it appears that the lake is phosphorus controlled, rather than nitrogen controlled.

IV. Expected Oxygen Changes

The equation describing the relationship between oxygen depletion, hypolimnion thickness, temperature and chlorophyll was solved for various conditions applicable to Lake Simcoe (Charlton 1980). The predicted oxygen depletion in Table 4 is lower than expected given the observed chlorophyll concentration of 2ug/L, lower thermocline depth of 20M, and a temperature of 10°C. OME and MNR reports show that a normal oxygen depletion rate for recent years is about 0.06 mg/L/day and this is twice the depletion predicted in Table 4.

Predictions from Charlton's (1980) equation are more consistent with a productivity/chlorophyll effect equivalent to chlorophyll concentrations closer to 4ug/L. As was shown in an earlier section, higher than reported chlorophyll levels are expected from the nutrient concentrations. Also, the funnel shape of Lake Simcoe's basin may exaggerate the effect of lake productivity on oxygen depletion.

A graphical presentation of Charlton's (1980) equation is shown in Fig. 7. Assuming that recent chlorophyll levels have been 4ug/L, a 25% reduction in chlorophyll and phosphorus would result in an improvement of about 1 mg/L if the lake responds according to the equation. A 37% difference (138 to 87 tonnes P) would represent a change in O_2 of 1.5 mg/L after 100 days of stratification.

Using the chlorophyll concentrations expected from loadings in Table 1, the following oxygen depletions are predicted after 100 days:

P Load (tonnes)	O_2 Depleted (mg/L)
138	7.7
103	6.7
87	6.1

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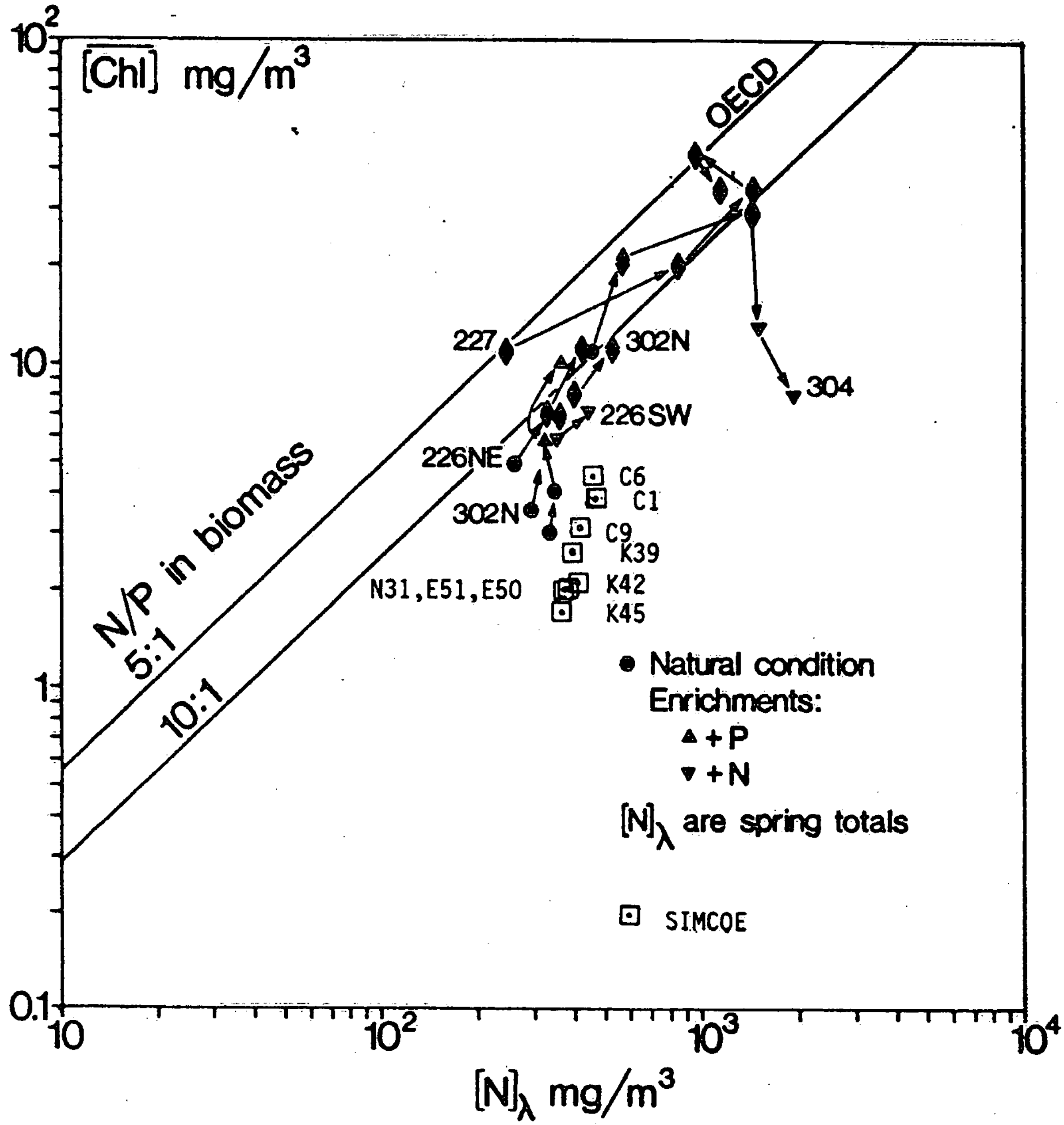


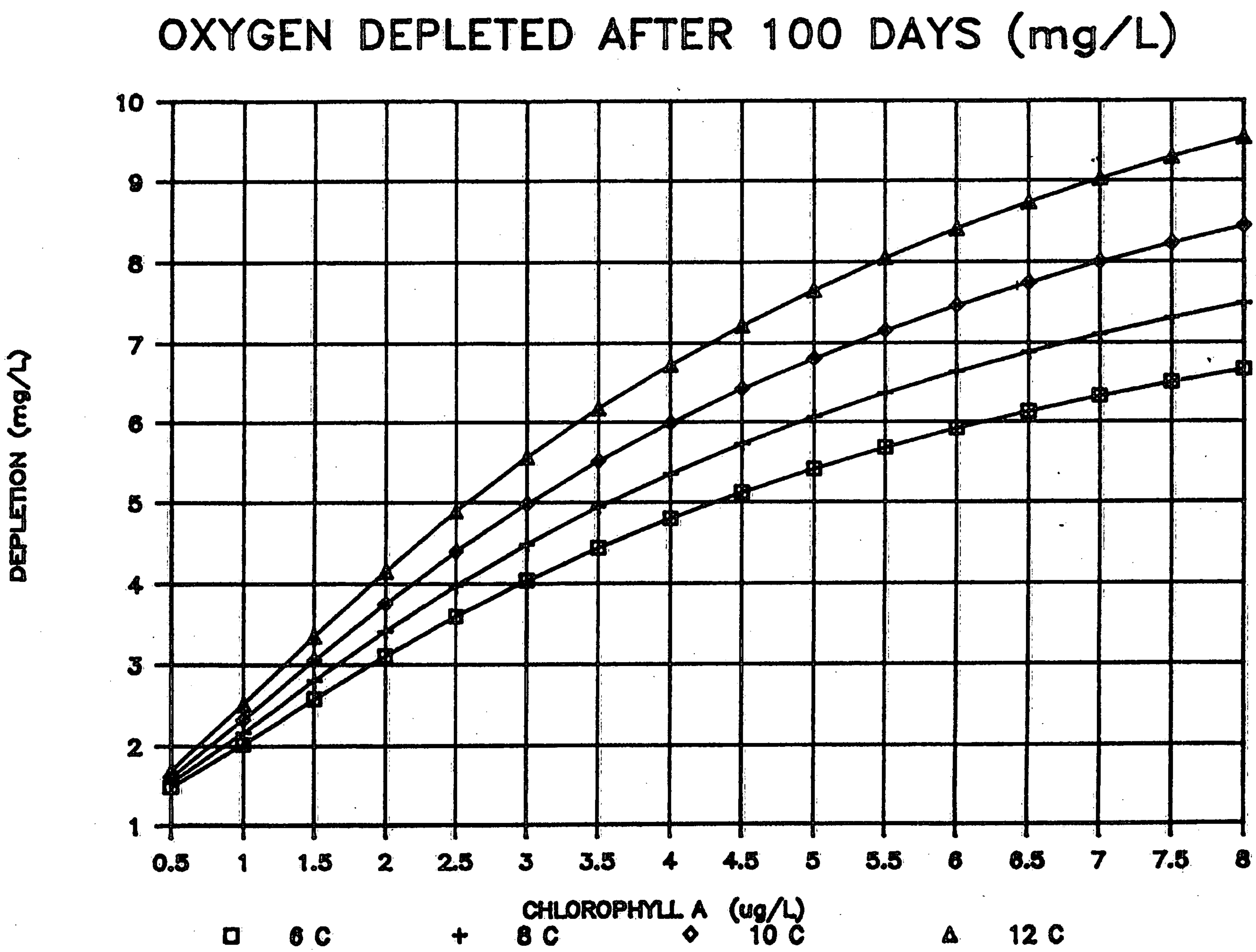
Figure 6

Table 4. Lake Simcoe

Depth (M)	% Area	Volume m^3x10^9	
20-25	15	271.875	Area of Hypo 275.5 Km^2
25-30	17	924.375	Area of Lake 725 Km^2
30-35	5	453.125	Mean Thickness Hypo 6.45 M
35-40	1	126.875	

CHLA	Oxygen depleted after 100 days				
	6	8	10	12	T°C
0.5	1.49	1.55	1.62	1.70	
1	2.03	2.17	2.33	2.52	
1.5	2.58	2.80	3.06	3.35	
2	3.11	3.41	3.76	4.15	
2.5	3.60	3.97	4.40	4.89	
3	4.04	4.48	4.99	5.57	
3.5	4.44	4.94	5.52	6.17	
4	4.80	5.36	5.99	6.72	
4.5	5.13	5.73	6.42	7.21	
5	5.42	6.06	6.80	7.66	
5.5	5.68	6.37	7.15	8.05	
6	5.92	6.64	7.46	8.41	
6.5	6.13	6.88	7.75	8.74	
7	6.33	7.11	8.00	9.03	
7.5	6.50	7.31	8.23	9.30	
8	6.66	7.49	8.44	9.54	

FIG. 7


OXYGEN DEPLETED AFTER 100 DAYS (mg/L)
DEPLETION (mg/L)
10
9
8
7
6
5
4
3
2
1
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
CHLOROPHYLL A (ug/L)
□ 6 C
+ 8 C
◇ 10 C
Δ 12 C

Thus, the degree of change likely in the late summer oxygen concentrations would be about 1-1.6 mg/L assuming that the global equation of Charlton (1980) applies and the lake productivity would vary according to the global phosphorus - chlorophyll relationship. Similar results are obtained by applying the relative loading changes (% change) to the chlorophyll axis regardless of the original position on the axis.

If the oxygen response to P loading changes lags behind the water quality response, then an improvement in O_2 of 1 mg/L may remain to be seen due to the initial reduction in loading. Further reductions to 87 tonnes annually may result in an eventual improvement of a further 0.6 mg/L. While the total improvement of 1.6 mg/L may seem small it may have some significance to fish populations.

The reasons for the relatively small improvements in O_2 are the basin depth, temperature, and original background oxygen depletion. In 1928, a concentration of 4.1 mg/L was found (Evans, 1978). In 1980, concentrations were 0-2 mg/L. Although the early data are insufficient to establish a trend, for the sake of argument we could assume that the eutrophication effect, since 1928, on O_2 has been minus 2-4 mg/L. This means that the maximum improvement to be obtained by eliminating all the eutrophication increases since 1928 would be 2-4 mg/L. Reducing the eutrophication effect by about 40% would then result in an improvement of about 0.8-1.6 mg/L which is similar to the solution of Charlton's equation. Of course, this depends on the original nutrient loadings and the rate at which the loadings increased.

The global relationship approach to predicting oxygen depletion is able to roughly estimate conditions in lakes although not all morphometric or other physical effects are accounted for. Predicting the response of lakes is even more uncertain for a secondary effect of nutrients such as oxygen since there is little knowledge of response delays. When the expected changes in oxygen are small, there seems to be an uncertainty of plus or minus 100%. Therefore, only the scale of change is indicated not the exact amount. In the case of Lake Simcoe, the small improvements predicted in O_2 seem reasonable and are likely to improve fish habitat. The question of whether these improvements might be significant is best left to fisheries biologists.

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National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada

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