Evaluation of empirical relationships used to derive the phosphorus loading target for Lake Simcoe with 1996 to 2004 data

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BACKGROUND

Nicholls (1995 and 1997) quantified the relationship between total phosphorus (TP) loading rate and hypolimnetic dissolved oxygen (DO) depletion rate so than an objective phosphorus loading rate could be set for Lake Simcoe that would improve conditions for cold water fish. This was accomplished through statistical relationships between:

1) flushing-corrected TP loading rate and lake water TP concentration,
2) lake water TP and chlorophyll concentrations, and
3) chlorophyll, and temperature-corrected dissolved oxygen depletion rate.

These relationships permitted the estimation of annual total phosphorus loading rates of 89, 73 or 58 metric T/yr required to achieve end-of-summer volume weighted average DO concentrations of 4, 5 or 6 mg/L in the 18-m to bottom zone of Lake Simcoe (assuming a present-day TP loading rate of 100 metric T/yr). These results are in good agreement with an independently developed deterministic model based on the mechanics of the production and decay of organic matter as related to phosphorus loading (Snodgrass and Holubeshen, 1993). As they were in such close agreement, phosphorus loading-oxygen prediction curves were plotted for the two models for application to Lake Simcoe. An equation was fitted to points positioned mid-way between the two curves that can be used to predict the phosphorus loading rate required to achieve a given end-of-summer DO concentration (Nicholls, 1997). This led to the proposed target reduction of annual TP load from 100 metric T/yr to 75 metric T/yr (a 25 % reduction) which is predicted to generate a lake volume-weighted springtime (mixed water column) TP concentration of 9 to 10 µg/L.

OBJECTIVE

These models were developed using data collected up to 1993. Zebra mussels became established in the lake in 1995 and since that time there have been significant increases in water clarity and reductions in algal biovolume (Eimers and Winter, 2005). Mean annual total phosphorus concentration also showed a significant declining trend at several lake stations and there was a significant increase in minimum deepwater DO concentration over time. The purpose of this evaluation was to assess the empirical relationships developed by Nicholls (1995 and 1997) using data collected post-zebra mussel invasion and establishment, over the period from 1996 to 2004. The equations presented are outlined in Nicholls' publications.

EVALUATION

1) Relationship between chlorophyll *a* versus total phosphorus concentration

The relationship developed between chlorophyll *a* (Chl *a*) and TP from all 12 main Lake Simcoe stations for 1990-1992, and including data from several other Ontario lakes was:

$$\text{Log Chl a} = 1.465 * \text{Log [TP]} - 1.22 \qquad (1)$$

Where Chl *a* is euphotic zone, ice-free period concentration of Chl *a* in µg/L and [TP] is spring (mixed water column) TP in µg/L ($r = 0.899$).

Mean 1996 to 2004 TP data collected at 8 Lake Simcoe open-lake stations were used in this equation to predict Chl *a*. Predicted versus measured Chl *a* values were then compared.

Concordance analysis (Lin, 1989) was used to evaluate the fit of the predicted versus observed Log Chl *a* data around a 1:1 line. Perfect fit around the 1:1 line (or concordance) indicates perfect agreement between the measured and predicted values. The concordance correlation coefficient (r_c) was 0.89 indicating almost perfect concordance (using the scale developed by Landis and Koch, 1977) and the confidence intervals do not include zero. Overall the results indicate a good fit to a 1:1 line and therefore good agreement between Chl *a* concentrations predicted using equation (1) and those measured.

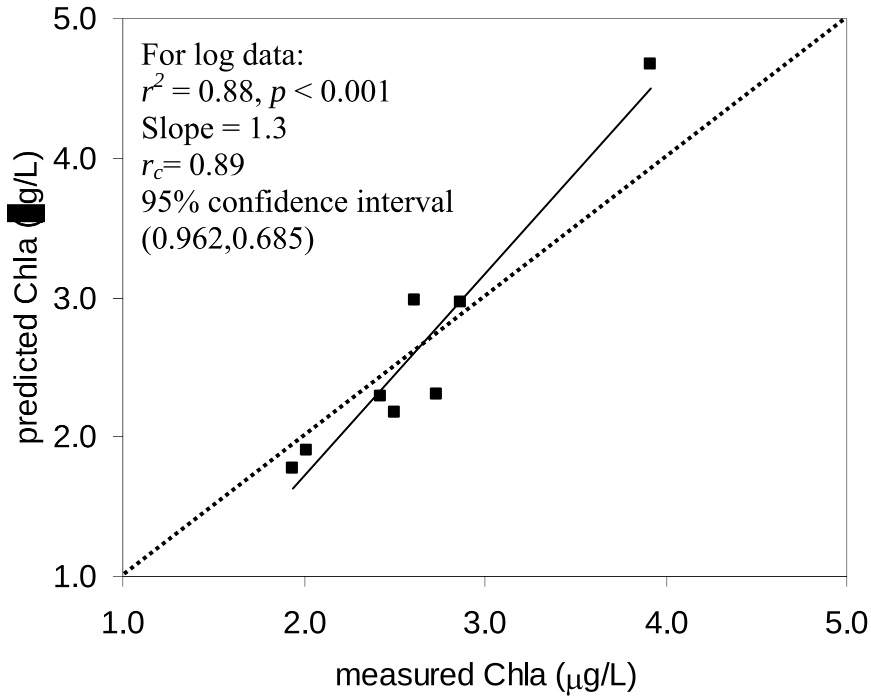

Figure 1. The relationship between predicted chlorophyll *a* concentrations based on equation (5) in Nicholls (1997) and 1996 to 2004 mean ice-free, euphotic zone chlorophyll *a* concentrations measured at 8 Lake Simcoe open-lake monitoring stations.

2) Relationship between hypolimnetic dissolved oxygen depletion rate and chlorophyll *a*

Nicholls (1997) applied 1989 to 1993 average Lake Simcoe euphotic zone, ice-free Chl *a* data to the Vollenweider-Janus model using the following equation:

$$\Delta DO = -0.218 + 0.741 * [(\text{Chl } a) * (V_e/V_h)]^{1/2} \quad (2)$$

Where ΔDO = dissolved oxygen depletion rate, V_e = trophogenic zone volume (0-12 m) and V_h = tropholytic zone volume (18 m-bottom).

The model demonstrated such a high level of agreement between measured and predicted depletion rates in Lake Simcoe that only a small calibration factor was required (predicted = 0.96 x measured).

Based on average 1996 to 2004 open lake data, using the same equation (all rates are normalized to 4°C):

Predicted DO depletion rate = 1.74 g/m^3/month

Measured DO depletion rate = 1.42 g/m^3/month

Observed DO depletion rate was thus 23 % lower than that predicted, and the calibration factor for these data is: predicted = 1.225 x measured.

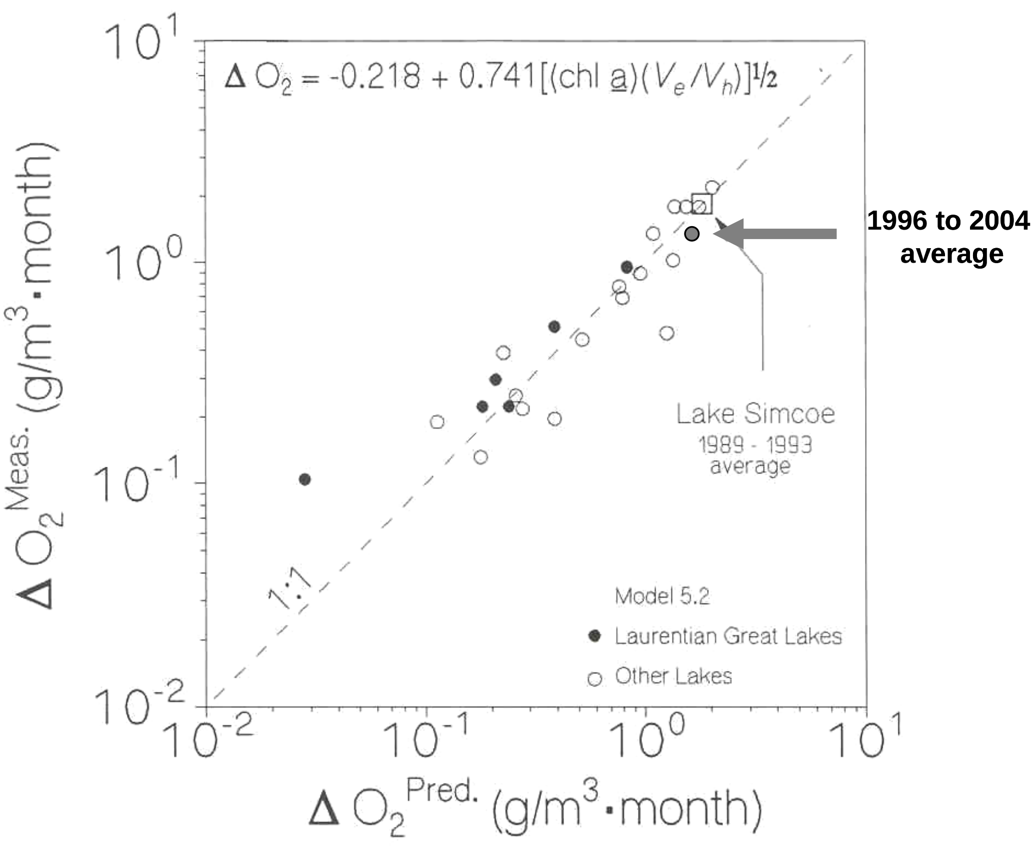

Figure 2. From Nicholls (1997). The relationship between measured and predicted rates of change of volume-weighted tropholytic zone (18-m to bottom) dissolved oxygen in Lake Simcoe (Station K42, 1989-1993 average) relative to several other lakes using the Vollenweider-Janus model. The 1996-2004 average Lake Simcoe point (K42) has been superimposed on the graph.

However, when the point is superimposed on the graph presented in Nicholls (1997) as in Fig. 2, it falls close to the 1:1 line for predicted versus observed DO depletion for the full model, and is well within the spread of the data points. The fit of the 1996 to 2004 data point relative to the full model is therefore reasonably good.

3) Relationship between dissolved oxygen and phosphorus loading rate

The final relationship presented by Nicholls (1997) is the relationship between end-of-summer volume-weighted hypolimnetic DO concentrations in the deep water zone (18 m to bottom) and annual total phosphorus loading rate. Changes in DO at different TP loading rates (P_L, metric T/yr) are predicted using the equation:

$$DO = 10.73 - 0.94 * P_L + 0.0002 * P_L^2 \quad (3)$$

This equation is the basis for the TP loading target of 75 metric T/yr for Lake Simcoe.

Based on the average 1996 to 2004 loading rate, using equation (3):

Predicted DO = 4.6 mg/L

Measured DO = 4.3 mg/L

Measured and predicted DO are within -6 % (-5.7 %) based on 1996 to 2004 loading rates.

CONCLUSIONS

Based on this evaluation, it can be concluded that the empirical relationships used to derive the 75 metric T/yr loading target for Lake Simcoe hold for the 1996 to 2004 data. The empirical model as developed by Nicholls (1995 and 1997) therefore continues to provide a sound limnological basis for the phosphorus loading objective. However, should a new dissolved oxygen target concentration be considered, a phosphorus loading target will have to be determined based on current loading rates.

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