Relationship between Summer Mean and Maximum Chlorophyll *a* Concentrations in Lakes

R. Anne Jones, Walter Rast, and G. Fred Lee[1]

Department of Civil Engineering, Environmental Engineering Program,
Colorado State University, Fort Collins, CO

● Based on literature values from approximately 50 water bodies, an empirical relationship has been developed between the summer mean and summer maximum chlorophyll *a* levels in water bodies. Where chlorophyll is expressed in micro grams/liter, this relationship is: maximum = 1.7 (mean) + 0.2

Chlorophyll concentration has long been used as a general indicator of the trophic status of a water body. Sakamoto (1), NAS–NAE (2), Dobson *et al.* (3), U.S. EPA (4), and Rast and Lee (5) have suggested mean chlorophyll *a* levels which are indicative of oligotrophic, mesotrophic, and eutrophic waters. A :summary of these levels is presented in Table 1. Examination of this table shows that while there is considerable overlap of values, oligotrophic water bodies tend to have chlorophyll concentrations of about 5 µg/L or less, whereas water bodies classified as eutrophic tend to have chlorophyll concentrations of greater than 6 µg/L.

Based on data from a number of European and North American water bodies, Vollenweider (6) described a relationship between mean summer epilimnetic chlorophyll *a* concentration and phosphorus load normalized by mean depth and hydraulic residence time, Rast and Lee (5) have found that this relationship is applicable to a wide variety of water bodies throughout the U.S. Further, Rast and Lee (5) have found a relationship between mean summer chlorophyll *a* concentration and mean summer Secchi depth. Using these relationships, they formulated a mathematical model to relate phosphorus load to mean summer Secchi depth in water bodies with low inorganic turbidity and color.

These various phosphorus load response relationships have, in general, been based on mean summer epilimnetic chlorophyll *a* concentrations. In addition to the overall mean chlorophyll concentration of a water body, there is also interest in the maximum chlorophyll *a* concentration since, in general, the public tends to respond to (and remember) the maximum greenness (chlorophyll), i.e. the extreme bloom conditions. Therefore, it is of value to be able to relate the phosphorus load of a water body to the maximum summer chlorophyll *a* concentration in that water body. This paper presents the results of a study to determine the relationship between the mean and maximum summer epilimnetic chlorophyll concentrations in a water body. This relationship, coupled with those discussed above, will enable water quality managers to predict the impact of altering the phosphorus load to a water body on not only the mean summer chlorophyll concentration, but also the maximum summer chlorophyll concentration.

Procedure

Chlorophyll data sets for approximately 50 lakes in North America and Western Europe were obtained from the literature. Since algal blooms are usually relatively rapid events normally lasting from several days to a week, data sets were chosen mainly for water bodies which had been sampled at least weekly during the summer growing season (approximately June to mid-September). However, in several instances when such data were lacking, biweekly sampling data were utilized; interpolation between data points was used to obtain weekly values in those water bodies. In general, the approach used for determining the mean chlorophyll concentration was to take the arithmetic mean of all epilimnion chlorophyll *a* concentration values presented by the investigator for the summer growing season. This was the general approach used by Vollenweider (6) and Rast. and Lee (5) in evaluating the relationship between the phosphorus load to a water body and its planktonic algal chlorophyll concentration. The maximum summer growing season chlorophyll concentration was selected from each data set.

Results

Approximately 90 mean maximum chlorophyll data sets, representing about 50 lakes or portions of lakes, are presented graphically in Figure 1. Simple linear regression using the method of least squares was initially used to obtain the equation for the line of best fit through the data sets. However, during the regression analysis it was noted that, although the F ratio indicated a highly significant relationship, the variance ("scatter") around the line of best fit was not constant but rather tended to increase at higher mean chlorophyll *a* values. Consequently, the regression analysis was repeated, using a weighted least-squares regression method. This latter method assigns more weight in the regression procedure to those data sets showing the more constant variance, while giving less weight to those data sets exhibiting the greater scatter.

The resulting equation for the line of best fit, using weighted least-squares regression, is as follows (the unit for chlorophyll *a* in these and subsequent equations is µg/L):

max summer Chl *a* concn,
=1.7(mean summer surface Chl *a* concn) + 0.2 (1)

This relationship, with the 95% confidence intervals, is shown in Figure 1. The correlation coefficient, r, is equal to 0.76. In the test for significance, the F ratio indicated a highly significant relationship.

As noted above, the variance in this regression was rot constant. Rather, at high mean chlorophyll *a* concentrations (characteristic of eutrophic water bodies). it increased as the mean summer chlorophyll *a* concentration increased. This was not surprising since water bodies at this level of eutrophication are often characterized

[1] Current affiliation: G. Fred Lee & Associates, El Macero, CA, (530)753-9630, gfredlee@aol.com, www.gfredlee.com

Table I. Trophic Boundary Mean Chlorophyll *a* Concentrations in Water Bodies (μg/L) [a]

trophic condition	ref *1*	ref *2*	ref *3*	ref *4*	ref *5*
oligotrophic	0.3–2.5	0–4	0–4.3	<7	0–2
mesotrophic	1–15	4–10	4.3–8.8	7–12	2–6
eutrophic	5–140	>10	>8.8	>12	>6

[a] Taken from ref *4* and *5*.

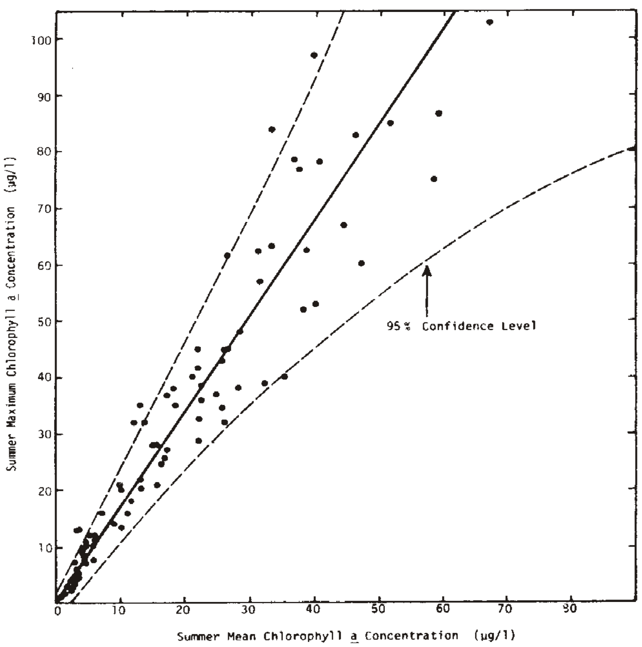

Figure 1. Relationship between mean and maximum summer chlorophyll *a* concentrations in lakes

by rapid fluctuations in chlorophyll concentrations associated with the series of algal blooms that normally occur. The chlorophyll *a* obtained at a particular sampling (and upon which the mean and maximum data sets in this analysis are based) is, therefore, a function of the bloom status of the water body at that time. Also, high concentrations of dead algal cells could produce erroneously high measured chlorophyll *a* values unless such determinations were corrected for phaeophytin. It was not possible in all cases to check the reported chlorophyll *a* data sets for such corrections. Consequently, a wide scattering of data in the upper mean chlorophyll *a* is not unexpected.

Discussion

Using Equation 1 and the relationship developed by Vollenweider (6) and evaluated by Rast and Lee (5) for U.S. OECD water bodies, it is possible to relate the summer maximum chlorophyll *a* concentration to the phosphorus load of a water body. The Rast and Lee relationship between phosphorus load and mean summer surface chlorophyll *a* concentration (μg/L) is as follows:

$$\log [\text{Chl } a]=0.76 \log [(L(P)/q_s)/(1 + (z/q_s)^{1/2}] - 0.259 \quad (2)$$

where L(P) = areal mean phosphorus load (mg of P/m^2/yr), z = mean depth (m), τ_ω = hydraulic residence time (yr) = volume (m^3)/annual in-flow volume (m^3/yr), and $q_s = z/\tau_\omega$ = hydraulic load (m/yr).

The phosphorus loading term, $(L(P)/q_s)/(1 + (z/q_s)^{1/2})$ is equivalent to the predicted in-lake steady-state total phosphorus concentration. Rast and Lee (5) have also determined that chlorophyll *a* (μg/L) and Secchi depth (m) are related as follows:

$$\log \text{Secchi depth} = - 0.473 \log [\text{Chl } a] + 0.803 \quad (3)$$

(Additional information on the development of these phosphorus load response equations can he obtained from Rast and Lee (5)). By substituting the mean chlorophyll *a* concentration calculated from the phosphorus loading term of Secchi depth (Equation 2 or 3) into Equation 1, a prediction of maximum summer chlorophyll *a* concentration can be made.

Acknowledgment

The statistical assistance of John L. Clark is greatly appreciated..

Literature Cited

(1) Sakamoto, M., *Arch. Hydrobiol.*, **62**, 1-28 (1966).
(2) National Academy of Science and National Academy of Engineering "Water Quality Criteria 1972", A Report of the Committee on Water Quality Criteria. EPA R73-033, Washington, DC (1973).
(3) Dobson, H. F. H, Gilberton, M., Sly, P. G., *J. Fish. Res Board Can,* **31**, 731-8 (1974).
(4)Environmental Protection Agency, "The Relationships of Phosphorus and Nitrogen to the Trophic State of Northeast and North Central Lakes and Reservoirs" National Eutrophication survey Working Paper No. 23, US EPA Pacific Northwest Environmental Protection Agency Laboratory, Corvallis, OR (1974), 28 pp
(5) Rast, W., Lee G. F. Summary Analysis of the North American (US Portion) Eutrophication Project: Nutrient Loading-Lake Response Relationships and Trophic State Indices, US EPA, EPA-600/3-78-008, Corvallis Environmental Research Laboratory, Corvallis, OR (1978), 454 pp.
(6) Vollenweider, R. A. .Mem. 1st. Ital. Idrobiol. Dott. Marco deMarchi, **33,** 53-83 (1976).