Prog. Wat. Tech. Vol.12, Norway, pp.81-88. IAWPR/Pergamon Press Ltd.1980. Printed in Great Britain.

APPLICATION OF US OECD EUTROPHICATION STUDY RESULTS TO DEEP LAKES

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ABSTRACT

The U.S.A. OECD nutrient load-eutrophication response models have been found to be applicable to Lake Mjøsa, a deep Norwegian lake. This lake, as well as other deep lakes, shows the same normalized phosphorus load-planktonic algal chlorophyll relationships as a variety of shallow lakes and impoundments located in the U.S.A. and other parts of the world. The phosphorus load normalizing factor developed by Vollenweider, which includes waterbody mean depth and water residence time, is appropriate for use in relating P load to planktonic algal growth in deep waterbodies. The OECD eutrophication modeling approach can be used to predict the magnitude of eutrophication-related water quality improvement that will result from reducing the phosphorus load to deep, as well as shallower lakes and impoundments.

KEYWORDS

Eutrophication; deep lakes; phosphorus; nutrient load-waterbody response modeling.

INTRODUCTION

Approximately five years ago the Organization for Economic Cooperation and Development (OECD) initiated a study to define the relationship between the nutrient load to a waterbody and the eutrophication-related response of the waterbody to that load. Approximately 200 lakes and impoundments in 22 countries are being investigated as part of this study. Primary emphasis is being given to the impact of the flux of nitrogen and especially phosphorus compounds on water quality as measured by chlorophyll, Secchi depth and hypolimnetic oxygen depletion rate.

The US portion of the OECD eutrophication study, which included approximately 40 waterbodies, was recently completed. The results of the US OECD study have been published by the US EPA (Rast and Lee, 1978) and a summary of these results, by Lee et al. (1978). They showed that the Vollenweider approach of using phosphorus load normalized by mean depth and hydraulic residence time to predict the planktonic algal chlorophyll in the waterbody is valid for a wide variety of waterbodies. Rast and Lee (1978) also showed that the normalized phosphorus load can be used to predict the Secchi depth and hypolimnetic oxygen depletion in many waterbodies.

The US waterbodies investigated in the OECD studies represented a highly heterogeneous group based on their morphological, climatological, geological, and hydrological characteristics. As expected, due to the highly heterogeneous character of the group, there was considerable scatter about the lines of best fit between the normalized nutrient loads and the response parameters. It is possible that a less scattered or somewhat altered relationship would be found for a more homogeneous group of waterbodies such as a group of deep lakes. It is of interest to determine whether or not the nutrient load-response relationship for the deeper US waterbodies included in the OECD studies tended to be consistently different from the average for all the US waterbodies studied. Further, because of the importance of the eutrophication problems of Lake Mjøsa, it is of interest to see how the nutrient load-response relationships for this waterbody compare to those found by Rast and Lee for US waterbodies. These two topics are addressed in this paper. For further information on the approaches used in this discussion, consult Rast and Lee (1978) and Lee et al. (1978).

NUTRIENT LOAD-EUTROPHICATION RESPONSE RELATIONSHIPS FOR US OECD DEEP LAKES

In order to determine if the Vollenweider approach properly normalizes deep lakes for their mean depth and hydraulic residence time characteristics, i.e., if the relationships for deep lakes are consistently different from the norm, those US OECD waterbodies with mean depths greater than 10 meters were singled out on the US OECD P loading characteristic-eutrophication response plots (Figs. 1 and 2). Figure 1, the phosphorus loading characteristic for the US OECD waterbodies vs their mean chlorophyll a concentrations, shows that all of the deep lakes, except for Lake Washington, plot below the line of best fit for the US OECD waterbodies. These lakes are, however, within the general variability about the line of best fit found for the US OECD waterbodies as a whole. Similarly, most of the US OECD deep lakes plot above the line of best fit between mean Secchi depth and the P loading characteristic (Fig. 2), indicating as expected that the deep lakes are somewhat clearer than shallower ones. Examination of Fig. 2 also shows that these lakes are within the general variability found about the line of best fit for the US OECD waterbodies. Therefore, based on the US OECD eutrophication studies, while it appears that there is a tendency for the deeper lakes to be different from the rest of the lakes, the magnitude of this difference is not sufficient to clearly place these lakes in a separate group within the Vollenweider relationship. It is possible, however, that the examination of the data for a larger number of deeper lakes (i.e., mean depth greater than 30 m) might show that this group of lakes would tend to have somewhat different nutrient load-eutrophication response relationships than found by Rast and Lee for the US OECD eutrophication study waterbodies. The data base from the complete OECD eutrophication study should indicate whether or not this is the case.

NUTRIENT LOAD-EUTROPHICATION RESPONSE RELATIONSHIPS FOR LAKE MJØSA

Considerable concern and controversy has been expressed about the eutrophication of Lake Mjøsa. This lake is one of the most important lakes in Norway. It is the largest lake in the country, an important recreational waterbody for the Oslo area of Norway and is a major water supply source. Considerable attention has therefore been given to the development of control programs for stopping and, where possible, reversing the trend of increasing fertility that has been observed in this lake in recent years. It is clear from the papers included in this book, as well as other work, that the primary cause of the excessive fertility of this lake is the introduction of excessive amounts of available phosphorus. Based on work that has been done in several parts of the world, the approach that holds the greatest promise for controlling excessive algal growth in waterbodies is the control of the phosphorus input. In the opinion of the authors, the approach that has been adopted

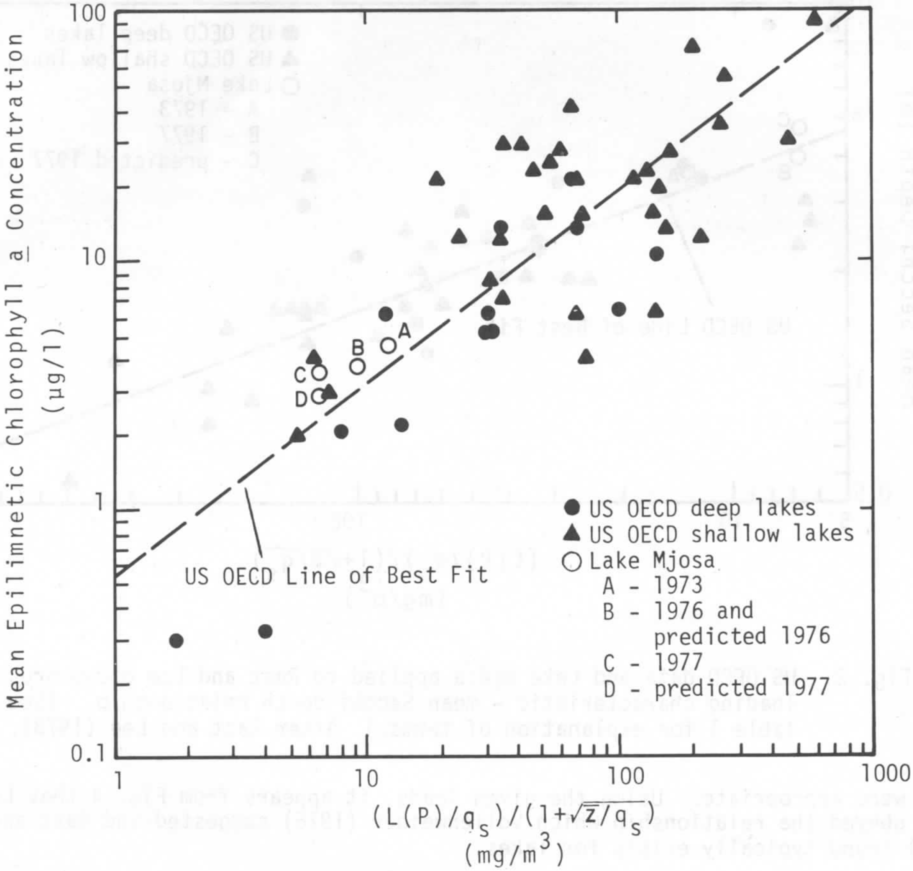

Fig. 1. US OECD data and Lake Mjøsa applied to Vollenweider phosphorus loading characteristic - mean chlorophyll a relationship. (See Table 1 for explanation of terms.) After Rast and Lee (1978).

by the water pollution control regulatory authorities responsible for Lake Mjøsa, i.e., reducing the phosphorus input from domestic wastewaters by the use of chemical treatment for P removal at the sewage treatment plants, is one of the procedures, and possibly the primary one, which should be used to control the excessive growth of algae in Lake Mjøsa. As discussed by Holton (1978b), this approach has significantly reduced the phosphorus input to this lake during the past few years. It is of interest to examine the water quality that Lake Mjøsa will attain under the equilibrium conditions that will prevail when the lake adjusts to these new phosphorus loads. This can be estimated from the results of the US OECD eutrophication study.

The first step in the application of this approach is to determine how well Lake Mjøsa fits the Vollenweider and Rast and Lee nutrient load-lake response relationships. H. Holton (1978b) provided a discussion of the characteristics of Lake Mjøsa. Information pertinent to this study is summarized in Table 1. First, it appears from Fig. 3 that the phosphorus loads provided by Holton and used in this

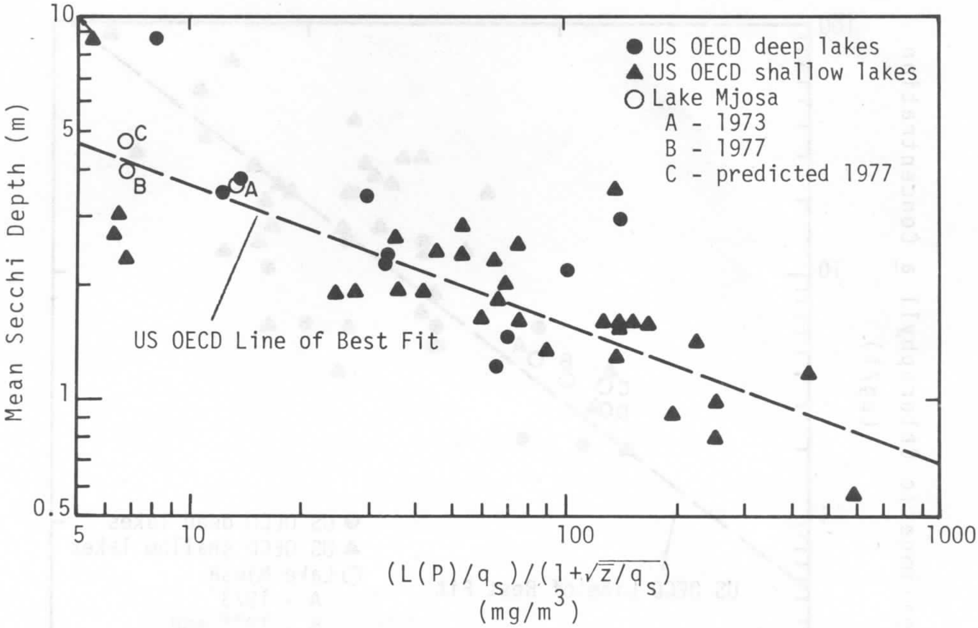

Fig. 2. US OECD data and Lake Mjøsa applied to Rast and Lee phosphorus loading characteristic - mean Secchi depth relationship. (See Table 1 for explanation of terms.) After Rast and Lee (1978).

study were appropriate. Using the given loads, it appears from Fig. 4 that Lake Mjøsa obeyed the relationship which Vollenweider (1976) suggested and Rast and Lee (1978) found typically exists for lakes.

Second, the results for Lake Mjøsa have been plotted in P load-eutrophication response relationships developed by Vollenweider (1976) and Rast and Lee (1978) (Figs. 1, 2 and 4). Figure 4 shows that during the period 1973 to 1977, Lake Mjøsa plots in the area where US OECD lakes classified as mesotrophic typically plotted. This is consistent with the way this lake has been classified.

As seen in Fig. 1, the chlorophyll a concentrations found in Lake Mjøsa in 1973, 1976 and 1977 are essentially what would be predicted by the US OECD line of best fit between chlorophyll and the P load normalized by mean depth and hydraulic residence time for a waterbody with Lake Mjøsa's P load, morphological and hydrological characteristics. The same is true for Lake Mjøsa for the Secchi depth as seen in Fig. 2. This indicates that Lake Mjøsa closely obeys the nutrient load-eutrophication response relationships developed by Vollenweider and extended by Rast and Lee to include Secchi depth.

The eutrophication-related response of Lake Mjøsa to altered P loads can be predicted using the OECD eutrophication modeling approach. There were two major P load reductions that took place during the period 1973 to 1977; one occurred between 1973 and 1974 and the other, between 1976 and 1977. It takes on the order of three times the phosphorus residence time for a lake to come to a new equilibrium after a change in P load (Sonzogni et al., 1976). Since for the period 1973 to 1977 the P residence time of Lake Mjøsa was estimated to be 1.3 to 2.4 years, the lake should have come close to equilibrium with the altered 1973 load by 1976-1977. Therefore,

TABLE 1 Characteristics of Lake Mjøsa, Norway*

Parameter	1973	1976	1977
Surface Area of Lake (km^2)	365	365	365
Mean depth (m)	153	153	153
Total P load (tons/yr)	396.8	294.7	218.9
Chlorophyll a (μg/l)	4.5	3.7	3.3
Secchi depth (m)**	3.5	-	4
τ_ω (hrs)	6	6	6
Inflow P (mg P/l)**	0.039	-	0.022
In lake P (mg P/l)**	0.009-0.01	-	0.009-0.01
τ_p (yrs)***	1.3	-	2.4
$(L(P)/q_s)/(1+\sqrt{\tau_\omega})$ (mg P/m^3)	12.4	9.2	6.8

Definition of symbols used in Table 1 and Figures

τ_ω	hydraulic residence time
τ_p	phosphorus residence time
L(P)	areal phosphorus load
q_s	mean depth/hydraulic residence time ($\bar{Z}/\tau_\omega$)
[P]	average in-lake P concentration
$[\bar{P}]$	average inflow P concentration

* Data from Holton (1978b) unless otherwise noted.

** Personal communication with H. Holton (1978a).

*** Calculated.

the intersection of a line drawn through the 1973 position on Figs. 1 and 2 parallel to the US OECD line of best fit with a vertical line drawn through the 1976 P load should represent the 1976 position of Lake Mjøsa and should correspond to the 1976 measured chlorophyll a and Secchi depth values. The actual chlorophyll values for 1976 and 1977 (3.7 and 3.3 mg/l, respectively) are what would be predicted (3.7 and 2.8 mg/l, respectively) based on the 1976 and 1977 P loads. Similarly, the 1977 Secchi depth would be predicted to be 4.7 m; the actual value for 1977 was 4 m.

DISCUSSION

The results of this investigation have shown that Lake Mjøsa fits the phosphorus load-eutrophication response relationships developed by Rast and Lee (1978) for a group of US waterbodies. It is also evident that Lake Mjøsa, as well as a number of other deep lakes which have been examined, show about the same P load-response relationships as many shallow lakes and impoundments. It can be concluded from these results that the OECD eutrophication modeling approach and the nutrient load-eutrophication response relationships developed by Vollenweider and expanded by

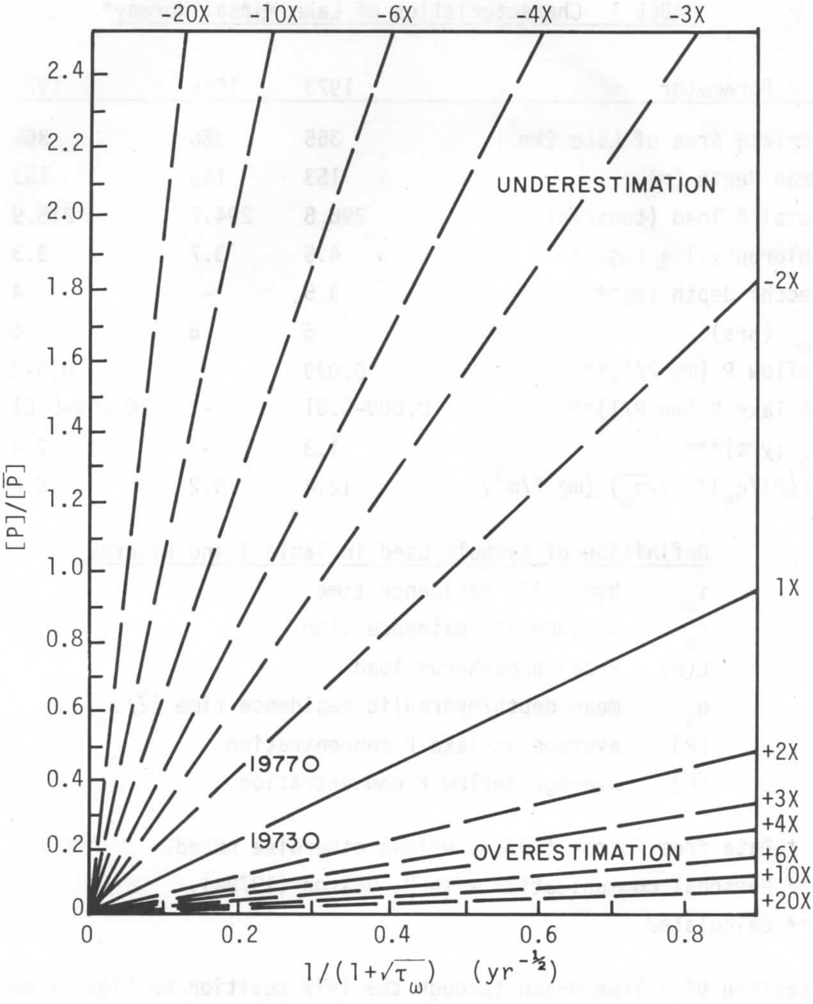

Fig. 3. Evaluation of estimates of Lake Mjøsa phosphorus loadings: Vollenweider mean phosphorus/influent phosphorus-hydraulic residence time relationship. (See Table 1 for explanation of terms.) After Rast and Lee (1978).

Rast and Lee together represent a powerful tool that can be readily used by water quality managers to assess the impact of eutrophication control programs. Water quality managers now have the ability to predict, with a high degree of reliability, the changes in water quality that will occur as a result of reducing the phosphorus input to a waterbody by a certain magnitude. In making predictions of this type, it is important to consider the phosphorus residence time of the waterbody since, for lakes in which the algal growth is limited by phosphorus, it will generally take on the order of three times the phosphorus residence time for the water to achieve the predicted-new equilibrium eutrophication-related water quality characteristics.

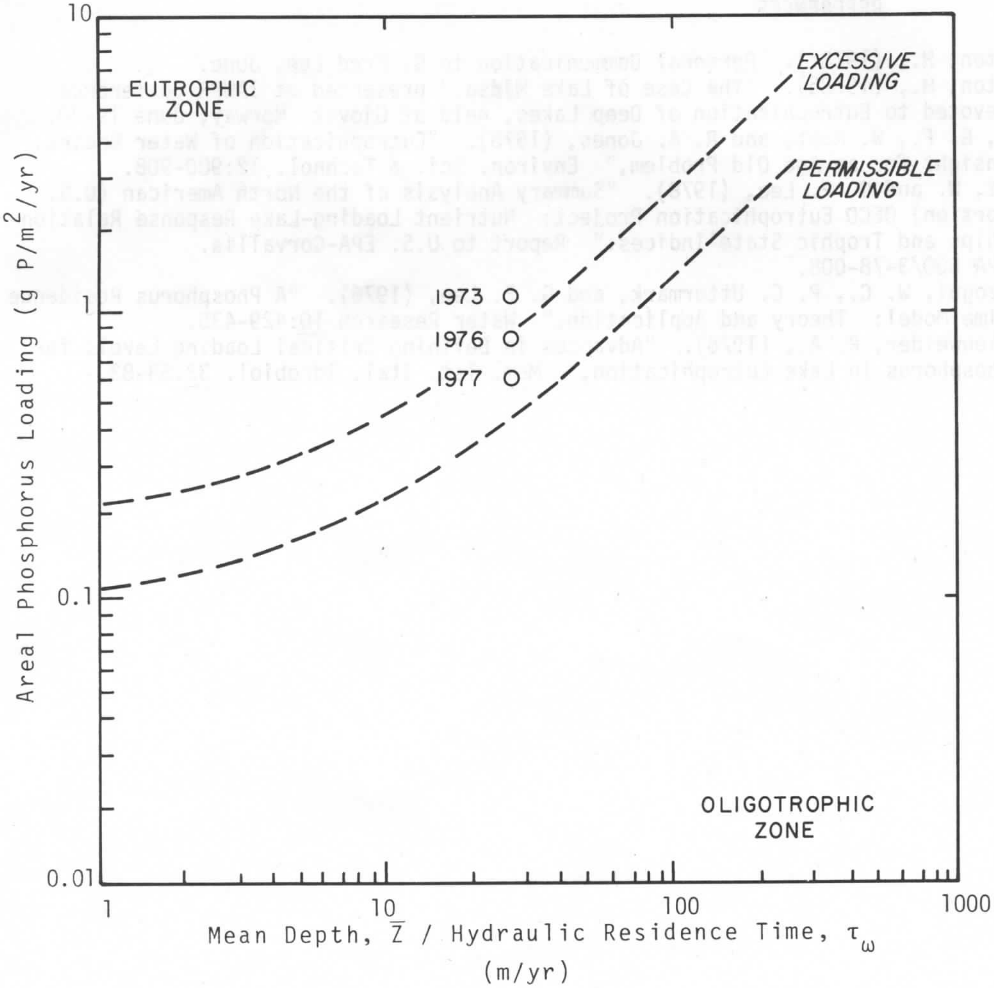

Fig. 4. Lake Mjøsa applied to modified Vollenweider phosphorus loading-mean depth/hydraulic residence time relationship. (See Table 1 for explanation of terms.) After Vollenweider (1976).

ACKNOWLEDGMENT

Support for the preparation of this paper was derived from the Department of Civil Engineering, Colorado State University, Fort Collins, Colorado; and EnviroQual Consultants and Laboratories, Fort Collins, Colorado.

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