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Summary of US OECD Eutrophication Study. Results and their application to water quality management

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With 2 figures in the text

Introduction

In the early 1970's, under the auspices of the Organization for Economic Cooperation and Development (OECD), a Cooperative Programme on Eutrophication was initiated to quantify relationships between nutrient loads to waterbodies and their eutrophication-related water quality responses. This project included a five-year study of about 200 lakes and impoundments in Australia, Japan, and 16 countries in Western Europe and North America. These waterbodies were divided into three regional projects (Nordic, Alpine, and North American) and one catch-all project (Shallow Lakes and Reservoirs), with the latter being composed of lakes and reservoirs which did not fit within the geographic regional designations. The North American project was divided into two distinct projects; one representing Canadian lakes and reservoirs and the other representing lakes and reservoirs in the United States. This paper briefly summarizes the results of the USA OECD Eutrophication Study Program (US OECD-ESP) and follow-on studies conducted in this area by the authors. It also discusses the application of these results to the management of excessive fertilization in lakes and reservoirs.

Summary of US OECD-ESP results

As a result of the fact that during the 1960's, there was considerable eutrophication study support available within the USA, the USA approach to the OECD-ESP was somewhat different than that followed by many of the other participating countries. While most of the countries involved in the OECD-ESP had done some studies to determine eutrophication-related characteristics of lakes and reservoirs, there were few or no data on the nutrient loads to these waterbodies. As a result, it was necessary to conduct simultaneous measurements of nutrient loads and eutrophication responses. On the other hand, in the USA, there had been a number of nutrient load-eutrophication response studies on a wide variety of lakes and reservoirs. Therefore, rather than conducting additional studies of this type, the US OECD-ESP consisted of having each of the investigators who had previously studied waterbodies in detail, prepare a report presenting their data in a standardized form. Approximately 20 USA investigators prepared such reports on 34 lakes, reservoirs, and an estuarine system. These data reports were compiled by the US Environmental Protection Agency (EPA) (SEYB & RANDOLPH 1977). The senior author of this paper (LEE) had the contract with the US EPA to develop a synthesis report based on the summary reports prepared by each of the US OECD-ESP investigators. The synthesis report was completed in 1976 and was published by the US EPA in 1978 (RAST & LEE 1978). A feature article summarizing the key aspects of this study was published in *Environmental Science and Technology* (LEE et al. 1978).

Subsequent to the completion of the US OECD-ESP report in the mid-1970's, the authors and their associates have been active in conducting nutrient load-eutrophication response studies of this type on a wide variety of waterbodies in the USA and other countries. They have approximately doubled the number of USA lakes and reservoirs evaluated using the OECD nutrient load-eutrophication response modeling approach and have also evaluated another approximately 50 waterbodies outside the US. JONES & LEE (1982) summarized the results of their additional studies on US waterbodies and updated the normalized P load-response regressions developed for the US OECD waterbodies by RAST & LEE, to include the additional US waterbodies. They found

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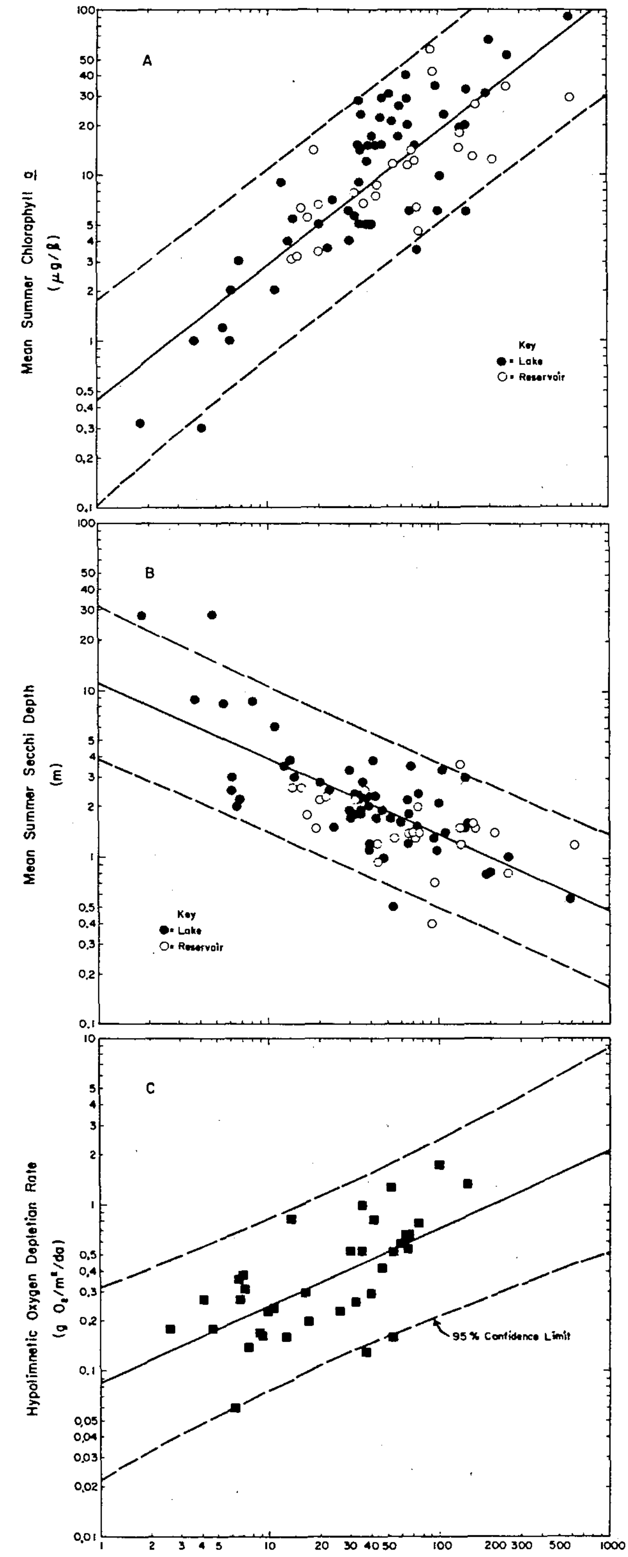
A
Mean Summer Chlorophyll a
(μg/ℓ)
Key
● = Lake
○ = Reservoir
B
Mean Summer Secchi Depth
(m)
Key
● = Lake
○ = Reservoir
C
Hypolimnetic Oxygen Depletion Rate
(g O2/m²/da)
95 % Confidence Limit
(L(P)/qs)/(1+√τω)
Normalized Annual Areal Phosphorus Loading (mg P/m²)

that while the added waterbodies covered geographic areas of the US not represented by the US OECD waterbodies, their addition to the data base did not significantly alter the load-response regressions. They also found non-US waterbodies followed the same load-response relationships as the US waterbodies. Fig. 1 shows the updated US waterbody relationships. Furthermore, the P load-chlorophyll regression line found by RAST & LEE (1978) and JONES & LEE (1982) is essentially the same as the regression line originally developed by VOLLENWEIDER (1976) which served as a basis for the OECD-ESP data review.

In setting up the original OECD-ESP, an advisory board (Technical Bureau) was established with representatives from each of the regional projects. It was agreed by the Technical Bureau that the regional project coordinators would examine how well the data base developed in the regional projects, conformed to the approach formulated by VOLLENWEIDER for relating P loads to waterbodies to the waterbodies' planktonic algal chlorophyll. Those responsible for regional data work-up were to have complete freedom to investigate any other relationships that they felt might be applicable to the data gathered. The RAST & LEE data work-up of the USA data was completed several years ahead of the other regional projects' data review as a result of the fact that no new field studies were undertaken. RAST & LEE, in developing the synthesis report for the USA data, found that VOLLENWEIDER's (1976) normalized P load-chlorophyll relationship was a reliable method for correlating one of the primary eutrophication responses of lakes and reservoirs to a given phosphorus load. Subsequently, the additional data developed in the other regional projects as well as the overall synthesis report (OECD 1982) have further confirmed the validity of VOLLENWEIDER's proposed approach for normalizing P load data for lakes and reservoirs. All of the subsequent work conducted by the authors, the regional reports, and the overall synthesis report have confirmed that the normalized P load-chlorophyll relationship developed by VOLLENWEIDER and confirmed on the US OECD data base by RAST & LEE (1978), are applicable to lakes and reservoirs in many other countries. In fact, it is appropriate now to conclude based on the authors' experience, that a waterbody that does not fit the OECD Eutrophication Study results relating its normalized P load to its planktonic algal chlorophyll is an atypical waterbody. Well over 300 lakes and reservoirs located in various parts of the world have been found to fit these relationships.

RAST & LEE (1978) expanded VOLLENWEIDER's load-response concept to include planktonic algal-related SECCHI depth, and hypolimnetic oxygen depletion rate. These additional correlations are of importance since they are measures of the consequences of eutrophication that are of importance to the public. The updated additional relationship developed by JONES & LEE based on the RAST & LEE approach are shown in the lower two graphs of Fig. 1. While the data available for developing lines of best fit for the hypolimnetic oxygen depletion rate were somewhat more sparse than those for chlorophyll and SECCHI depth, it is still clear, as would be expected, that there is a strong correlation between a waterbody's hypolimnetic oxygen depletion rate and its normalized P load. In their recent discussion of the mechanisms of hypolimnetic oxygen depletion for lakes and reservoirs, LEE & JONES (1983) highlighted the primary role that the bacterial decomposition of planktonic algae grown in a waterbody plays in the rate of hypolimnetic oxygen depletion. It follows that for those waters in which the oxygen depletion rate is controlled by planktonic algal BOD, the OECD P load-areal hypolimnetic oxygen depletion rate relationship should be applicable. In those rather unusual conditions where abiotic oxygen demand of a waterbody's sediments is significant in the oxygen depletion rate, this approach would not be expected to be directly applicable.

While not officially part of the OECD program, LEE & JONES (1983 b) have expanded the normalized P load correlation approach and have developed a correlation between normalized P load and waterbody fish yield. This relationship is shown in Fig. 2. Recently HANSON & LEGGETT (1982) have developed similar relationships from a completely independent data set indicating that, as would be expected, the correlation approach developed by VOLLENWEIDER is useful to predict not only planktonic algal biomass but also the level of biomass of higher trophic level organisms.

Fig. 1. Normalized P loading-eutrophication-related response for US waterbodies (after JONES & LEE 1982). L(P) = areal annual P load (mg P/m^2/yr); q_s = mean depth ÷ hydraulic residence time = $\bar{z}/\tau_\omega$ (m/yr); τ_ω = hydraulic residence time (yr).

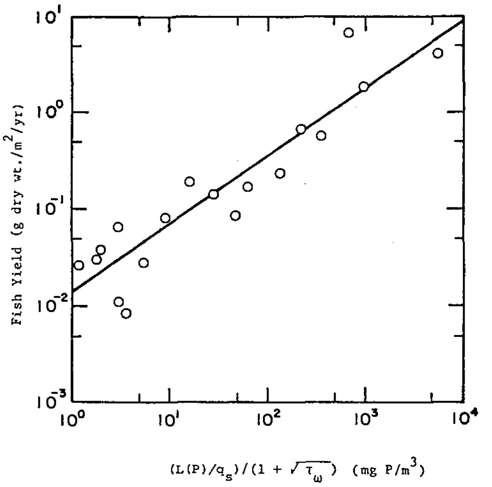

Fig. 2. Relationship between normalized P load and fish yield (after LEE & JONES 1983 b).

Utilization of US OECD-ESP results for water quality management

The primary factor that motivated the initiation of the OECD-ESP was the development of a management tool that could be widely used to predict the impact of altering P loads to waterbodies on the waterbodies' eutrophication-related water quality. Prior to completion of these studies, those responsible for management decisions were unable to reliably estimate the degree of impact that altering P loads to a waterbody would have on its water quality. Some attempts were made to develop deterministic models for this purpose. It was found, however, that such models have little or no predictive capabilities and required a massive field study on the waterbody to fulfill the data input requirements of the model. It is now generally agreed that such deterministic models should be used primarily as research tools and not as a basic for public policy formulation. In contrast, the OECD-ESP modeling approach has been found to have a high degree of predictive capability (RAST et al. 1983). Further and most importantly, generally only a relatively small data base is needed to apply this approach to a particular waterbody. LEE & JONES (1983 c) have described a minimum sampling program necessary to, in most cases, gather sufficient data to properly use the US OECD-ESP load-response models.

In the half-dozen years since RAST & LEE synthesized the US OECD Eutrophication Study results, the authors have had the opportunity to apply this approach to a wide variety of water quality management problems of lakes and reservoirs located in the USA and several other countries. Generally, the problem area of concern is excessive planktonic algal growth. The specific problems of concern range from domestic water supply water quality, low dissolved oxygen below hydropower releases from reservoirs, agricultural irrigational water quality, and impaired recreational use of waterbodies. In undertaking such evaluations, a more or less consistent pattern of analysis was developed; the first phase of the project is typically devoted to determining how well a particular waterbody's normalized P loads can be used to estimate the planktonic algal chlorophyll concentration in the waterbody. This evaluation is made by comparing the normalized P load-chlorophyll relationships for the waterbody to the load-response relationships developed based on the US OECD-ESP results. Often one or more of the factors needed to make this comparison are not readily available. This creates a need to estimate either P loads to the waterbody and/or its eutrophication-related water quality characteristics.

Procedures for estimating USA waterbody nutrient loads have been described by RAST & LEE (1983). If it is found that the normalized P loads for the waterbody closely predict the waterbody's planktonic algal chlorophyll based on the US OECD Eutrophication Study results, then there is considerable confidence that the change in chlorophyll concentration that would occur as a result of altering the P loads to that waterbody by a certain amount can be predicted. The predicted chlorophyll concentration is found by first drawing a line parallel to the P load-chlorophyll regression line through the existing load-response coordinate; the intersection of this line with a vertical line through the new (altered) normalized P loading will correspond to the predicted chlorophyll line. As discussed by RAST et al. (1983), this approach has been proven to be sufficiently reliable to enable decisions to be made on whether from a eutrophication-related water quality improvement point of view, a particular P removal program should be undertaken.

There are some who have the mistaken idea that the reliability of these predictions is the width of the 95 % confidence interval shown on Fig. 1. This is certainly not the case. These confidence intervals were developed to describe the area within which 95 % of the points plotted. Their only relevance is for the situation in which no waterbody response information is available for a waterbody, and the response must be estimated based on load and the regression line. However, the 95 % confidence intervals have nothing whatever to do with predicting the chlorophyll level (or SECCHI depth or hypolimnetic oxygen depletion rate) that will result from a change in P loading if an initial P load-chlorophyll coupling (point) for the water body can be determined. As shown by RAST et al. (1983), the load-response relationships for a waterbody will track parallel to the lines of best fit when the P load is changed. Whatever causes a waterbody's point to plot above or below the "norm", i. e., the lines of best fit, appears to be a log constant when the loading term is changed. The confidence intervals have no bearing on the reliability of those predictions under the conditions described above.

Some of those who are critical of the use of this approach do not have a good understanding of the sensitivity of a decision on nutrient removal relative to the precision of the estimated impact of such removal. As discussed by RAST et al. (1983), there will be few instances where the above-mentioned approach is not sufficiently reliable to yield an appropriate guidance on whether to implement a P control program or not based on eutrophication-related water quality considerations.

There are certain kinds of waterbodies and situations that require special attention in applying the OECD Eutrophication Study results. These are discussed in detail by JONES & LEE (1982) and RAST et al. (1983) and briefly summarized here. If a waterbody is elongate, or has arms or bays having restricted exchange with the main body of water, and if these areas receive a significant nutrient load, the P load to the main body may need to be adjusted to reflect the nutrient removal that typically occurs in such areas. It is not uncommon for the upper reaches of an elongate reservoir, or arm or bay areas to remove to the sediments 75 % or more of the nutrients they receive. It would be inappropriate to try to correlate the response in the main body with the load received by the waterbody as a whole under these circumstances. It is important to clearly focus on that area of the waterbody that is of concern. If the hydraulic residence time of the waterbody is less than about two weeks, there may be insufficient time for the algae to grow to the extent expected based on the P loading. Where this occurs, the impact of this factor on the load-response couplings should be examined. The authors have encountered situations in which adjustments could be made in the value for the residence time to more properly reflect the residence time encountered during the growing season, allowing the model to apply to the data. The presence of large amounts of inorganic turbidity, color, or aquatic macrophytes can alter the load-response couplings for waterbodies; the regressions were developed for waterbodies having "average" amounts of inorganic turbidity and free from significant developments of aquatic macrophytes and non-planktonic algae.

This modeling approach is a powerful tool for eutrophication-related water quality evaluation/management. It has demonstrated predictive capability and applicability to a wide variety of lakes, reservoirs, and to a lesser extent, estuarine systems, around the world — from Antarctica to Texas, USA; from small shallow lakes to Lake Superior, USA and Lake Mjosa, Norway; lakes and reservoirs, alike. Therefore, before a waterbody is judged "not to fit" or the model judged "not to work", careful consideration should be given to characteristics of the system which cause the waterbody to behave differently. This should include a detailed review of the reliability of the input data used, both measured and estimated. This approach was not designed to be used mechanically, without consideration given to each individual waterbody's characteristics.

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