Eutrophication of water bodies: Insights for an age-old problem

New information enables water quality managers to predict reliably water quality changes that result from various phosphate control management practices

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The significance of phosphate as a cause of excessive fertilization problems in fresh and marine waters has been a subject of considerable controversy for many years. Large amounts of research funding have been devoted to this topic. As a result, a good understanding of the relationship between phosphorus input to a water body and its effect on eutrophication-related water quality problems is gradually being achieved.

This report reviews the current state of information on the significance of phosphate as a water pollutant and the relationship between phosphorus loads and water quality responses in water bodies, and discusses areas that need additional research. It represents a condensation of a more extensive report by the authors that is available upon request.

The concern over phosphate with respect to water quality stems primarily from its ability to stimulate algae and other aquatic plant growths. It has been recognized for many years that phosphate may be the controlling nutrient for planktonic and attached algae and macrophytes. This concern is a result of the fact that the amounts of the biologically available forms of phosphorus, relative to other required nutrients in the surface waters (assuming there is sufficient light to promote photosynthesis), is small compared to the quantity of phosphate needed by the aquatic plants for optimum growth.

The aqueous environmental chemistry of phosphate involves a wide variety of reactions and several transport processes that tend to make phosphorus unavailable for aquatic plant growth. One of the most important of these processes is the transport of phosphorus to the sediment by chemical and biological activity. While there is some recycling of phosphorus from sediments to the overlying waters, this return is usually relatively small, with the result that the sediments serve as a sink for phosphorus.

Key to the control of excessive fertilization is the control of available phosphorus from external sources

About 10 to 15 years ago, there was considerable controversy over the relative significance of internal (recycling from sediments) versus external (inputs from land and the atmosphere) phosphate loads, but it has now been well established that for many water bodies the internal phosphorus loading is small. Consequently, the key to the control of excessive fertilization in waters in which P is or can be made to be the limiting aquatic plant nutrient, is the control of available P from external sources.

This control has been demonstrated in several water bodies, such as Lake Washington in Seattle, where reducing the external P load resulted in reduced algal growth in the lake to levels proportional to the resulting external P load.

In addition to phosphorus, carbon and nitrogen are also sometimes cited as controlling aquatic plant growth. In the late 1960's, there was considerable controversy over the relative significance of carbon and phosphorus in controlling aquatic plant growth in natural waters.

Algae typically need 106 carbon atoms and 16 nitrogen atoms for each phosphorus atom for growth and reproduction. The relatively large algal demand for carbon, as compared to phosphorus, could lead one to speculate that carbon may be a key limiting element. However, it is the demand for carbon, compared to the rate of supply of its available forms (i.e., CO_2 and carbonate species) that is critical. Except under atypical, highly fertile conditions, it now appears that carbon rarely limits the total algal biomass in a water body.

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Nitrogen is also frequently cited as an element that could limit algal biomass in natural waters. The forms of nitrogen that are generally available for aquatic plant growth are nitrate and ammonia. In addition, certain algae and bacteria in natural waters can use dissolved nitrogen gas as a nitrogen source. While algae normally require almost ten times as much nitrogen for growth as phosphorus (on a mass basis), natural waters typically contain at least this relative quantity of algal-available nitrogen over phosphorus.

During the past 10 years, several techniques have been developed to assess the relative significance of nitrogen versus phosphorus as growth-limiting elements for algae in natural waters. These include algal assay procedures and examination of changes in concentrations of available nutrient forms during algal blooms.

In general, these procedures have shown that freshwater lakes and impoundments tend to frequently be phosphorus-limited. Marine waters, on the other hand, tend to be nitrogen-limited. There are exceptions to these generalizations, but, these exceptions are usually associated with gross pollution of the water body from the activities of man, such as from agricultural drainage and discharge of domestic wastewaters.

In many instances, although phosphorus may not be limiting algal growth because of large phosphorus inputs, from a eutrophication control point of view, the control of phosphorus inputs could decrease the available phosphorus concentration in a water body sufficiently to make phosphorus the limiting element in a water body.

In addition to nitrogen and phosphorus, other compounds and elements can limit algal growth. Iron and silicon are found to apparently be limiting in some waters, with the latter limiting only with respect to diatoms. Occasionally reference will be made to limitation by vitamins such as vitamin B12.

However, there is sufficient evidence today to conclude that, for most freshwater bodies, phosphorus is the key limiting-nutritive element for aquatic plant growth. Nitrogen would likely be ranked second. In the absence of gross pollution by man, nitrogen-limited lakes would tend to occur in regions in which the nitrate and ammonia content of rainfall is low, such as the West Coast of the U.S. Although nitrogen, and especially phosphorus, exert primary control over the total algal biomass in most surface waters, it is likely that trace elements, vitamins, and organic growth factors exert control over the types of algae present.

As noted above, for marine waters, the relative roles of nitrogen and phosphorus in the eutrophication process are usually reversed from those typically found in fresh water. While it is usually rare for classical eutrophication problems to occur in marine waters, under certain circumstances such as with conditions of restricted circulation and massive nutrient inputs, more or less classical eutrophication problems do occur.

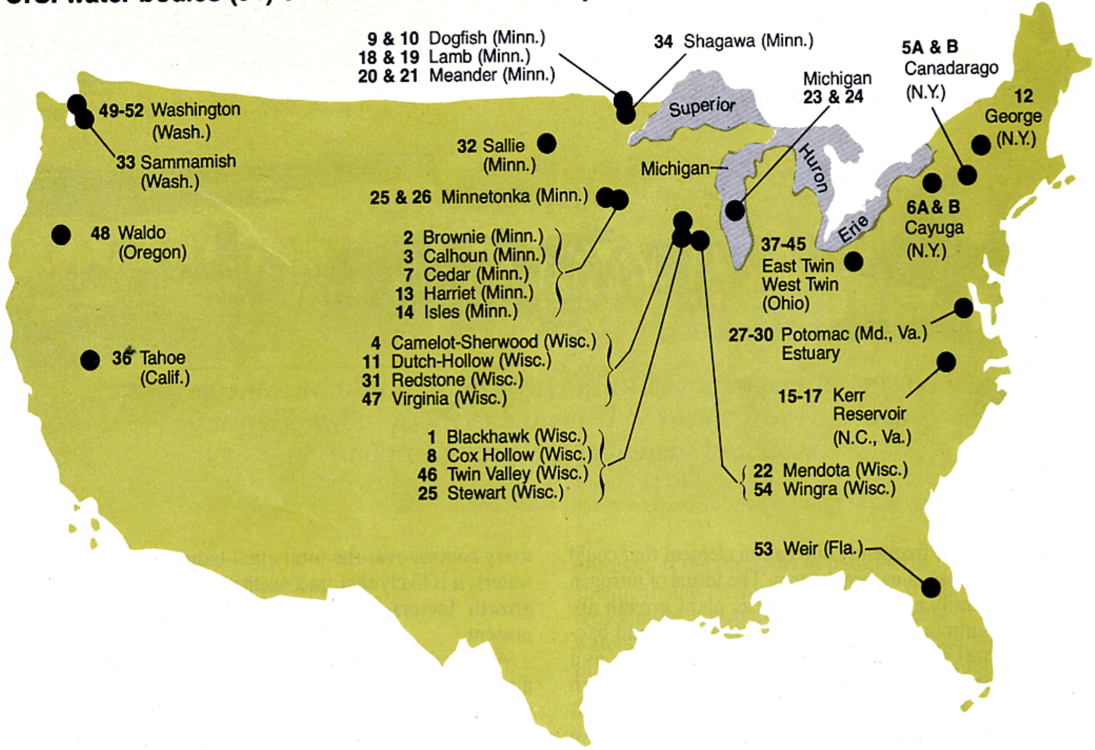
A recent example of this type of problem was the massive deoxygenation of the coastal waters of New York and New Jersey, which occurred in the summer of 1976. A combination of meteorological conditions caused restriction of the normal mixing of the nearshore and offshore waters. In association with this occurrence, there was a large growth of algae that died and subsequently settled through the thermocline.

The decomposition of these dead algae depleted the oxygen in the bottom waters in an area approximately 100 miles long and 20 miles wide along the New York-New Jersey coast. This dissolved oxygen (DO) depletion resulted in large-scale destruction of benthic organisms in this area, many of which are of great commercial importance, including lobster, crabs, flounder, and other flat fish. In this case nitrogen appeared to have been the limiting element.

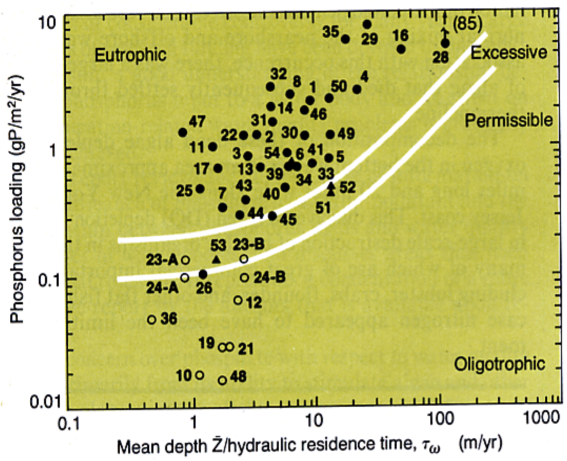
The lower Great Lakes are among the most significant eutrophication problem areas in the U.S. and Canada

The open waters of the Great Lakes are all phosphorus-limited. However, some nearshore areas and some bays, such as southern Green Bay, appear to be nitrogen-limited because of large phosphorus inputs into those areas.

U.S. water bodies (34) evaluated in OECD eutrophication study



Critical P loads for the Great Lakes can be determined according to the Vollenweider relationship of two parameters—areal P loading and ratio of mean depth/residence time



Investigator-indicated Trophic state:
- ● Eutrophic
- ▲ Mesotrophic
- ○ Oligotrophic

L(P) = Surface area total phosphorus loading (mg P/m^2/yr)

q_s = Hydraulic loading (m/yr) = $\bar{z}/\tau_\omega$

$\bar{z}$ = Mean depth (m) = water body volume (m^3)/surface area (m^2)

τ_ω = Hydraulic residence time (yr) = water body volume (m^3)/annual inflow volume (m^3/yr)

Eutrophication, some useful definitions

Eutrophication is the process of fertilization of natural waters.

Eutrophic water bodies receive large amounts of aquatic plant nutrients relative to their surface area and volume and have high production of aquatic plants.

Oligotrophic water bodies tend to be poorly fertilized and have low aquatic plant production.

Mesotrophic water bodies receive moderate amounts of aquatic plant nutrients.

Thermocline is the depth in a water body in which there is a rapid change in temperature with depth which results in the division of the water body into two layers with different densities. These are the **epilimnion,** the warmer, less dense surface waters; and the **hypolimnion,** the cooler, more dense bottom waters. The thermocline provides a barrier of mixing of water between these two layers and is normally present between early June through late October in temperate water bodies.

Hypolimnetic oxygen depletion rate — During periods of thermal stratification, the waters of the hypolimnion are isolated from the atmosphere by the thermocline and, therefore, cannot have their dissolved oxygen supplies replenished. Algae which have grown in the epilimnion settle and decompose in the hypolimnion, resulting in the reduction of the dissolved oxygen concentration in the bottom waters. The oxygen depletion rate is the rate at which this decrease proceeds. In many eutrophic water bodies, the rate of dissolved oxygen depletion is sufficient to cause anoxic conditions (zero dissolved oxygen) in the hypolimnion.

Some years ago, the U.S.-Canadian International Joint Commission for Great Lakes Water Quality (IJC) established a phosphorus control program for the domestic wastewaters entering the Great Lakes and their tributaries (U.S.-Canadian Water Quality Agreement of 1972). This agreement established a limit of 1 mg P/L in the effluent of domestic wastewater treatment plants with a discharge of 1 mgd or greater. Revised objectives are currently being formulated.

The IJC phosphorus discharge limit is typically being achieved by precipitation of phosphate with iron or aluminum salts or lime. The use of iron and aluminum salts for phosphate removal has several advantages in addition to phosphorus removal. Many other contaminants in domestic wastewaters are removed in hydrous oxide floc. In fact, in some parts of the U.S., in order to achieve the required BOD load based on Best Practicable Treatment and wasteload allocation for a "water quality-limited" stream or to control hazardous chemicals, the effluent is treated with iron or aluminum salts. Phosphate removal is a concomitant benefit of this treatment.

It is highly likely that, as the U.S. EPA 1976 *Quality Criteria for Water* are implemented into state water quality standards, and as the Best Available Treatment procedure provisions of P.L. 92-500, the 1972 amendments to the Federal Water Pollution Control Act, are implemented, there will be even greater emphasis on the use of iron and/or aluminum flocculation of wastewaters to achieve the new, much stricter water quality standards.

Phosphorus is derived from a wide variety of sources

A number of recent studies have shown that phosphorus, in the form of phosphate, is derived from a wide variety of sources. These sources include the atmosphere, agricultural and urban drainage, domestic and industrial wastewaters, and to a very limited extent, groundwater. Research conducted during the past 10 years has provided a considerable body of knowledge on the amounts of phosphorus derived from various types of land use.

Table 1 presents a compilation of the quantities of nitrogen and phosphorus derived from various types of land use. It is of interest to note that the conversion of land use from forest to agricultural, and from agricultural to urban, results in consecutive several fold increases in the quantity of phosphorus exported per unit area of land surface, with the largest increase occurring as one proceeds from forest to urban use.

One of the phosphate sources to natural waters of greatest concern is domestic wastewater. In regions that do not have a detergent phosphate ban in effect, approximately 35% of the phosphorus in domestic wastewaters is derived from phosphate-built detergents.

Since the early 1970's, the phosphorus content of domestic wastewaters in the U.S. has, in general, decreased by several mg P/L. This is largely the result of a reduced phosphorus content of detergents.

In the early 1970's the phosphorus content of detergents was on the order of 12%, which resulted in approximately 50% of domestic wastewater phosphorus being derived from detergents. By contrast, today it is typically on the order of 5% phosphorus, resulting in the lower P content of domestic wastewaters found today.

Another potential source of phosphorus that has received attention recently is the septic tank wastewater-disposal system. There is controversy concerning the relative importance of septic tank wastewater-disposal systems as phosphorus sources for surface waters. The authors have conducted a comprehensive review of this subject and concluded that the likelihood of sufficient phosphate being transported from such systems to surface waters, where it could result in a significant contribution to eutrophication problems, is small.

Most of the work on the effects of phosphorus in the eutrophication process is based on total phosphorus concentrations. However, it is well known that in some instances a substantial part of this total phosphorus is not in a chemical form that can readily be used to support algal growth. This is especially true for part of the organic and particulate phosphorus forms.

In some eutrophication studies, measurements are only made of soluble orthophosphate. While in most instances soluble orthophosphate is readily available for algal growth, measurement of only this phosphorus form will usually underestimate the total quantity of P that is likely to influence algal growth in a water body.

For most water bodies, the available phosphorus load is a quantity that lies between the soluble orthophosphate load and the total phosphate load. It has been found that the biologically available phosphorus is approximately equal to the soluble orthophosphate plus 0.2 times the difference between the total phosphorus and soluble orthophosphate. This formula makes allowance for any solubilization and mineralization reactions that may take place in a water body which would lead to the formation of soluble orthophosphate.

One of the areas that needs additional attention is determination of the quantity of available phosphorus present in domestic wastewater effluent that has been treated for phosphorus removal. It is reasonable to expect that a substantial part of the phosphorus remaining in domestic wastewater effluents treated with iron or aluminum salts will not be readily available to support algal growth in natural waters since these salts incorporate phosphorus into their hydrous oxide precipitates.

Several studies have indicated that a substantial part of the phosphorus in effluents of domestic wastewater treatment

TABLE 1
Watershed nutrient export coefficients based on U.S. OECD eutrophication study

Land use	Export coefficients ($g/m^2/y$) Total phosphorus	Total nitrogen
Urban	0.1	0.5 (0.25)[a]
Rural/agriculture	0.05	0.5 (0.2)[a]
Forest	0.01	0.3 (0.1)[a]
Other:		
rainfall	0.02	0.8
dry fallout	0.08	1.6

[a] Export coefficients used in calculating nitrogen loadings for water bodies in the western U.S.

Source: Rast and Lee (1978).

plants practicing phosphorus removal with iron or aluminum salts will be in a particulate form that can be readily removed by filtration. It has also been shown that aluminum and, to a lesser extent, iron, could keep the phosphorus in a form that is unavailable for algal growth.

It is, therefore, conceivable that the filtration of domestic wastewater treatment-plant effluents to reduce their total phosphorus content may have little or no impact on the quantity of available phosphorus in the effluents. This is a research area that needs further attention before large-scale filtration systems designed to control eutrophication by improving phosphorus removal are constructed.

The importance of developing an assessment methodology for determination of the biologically available forms of phosphorus cannot be over stressed. For water bodies in which a significant part of the phosphorus is derived from domestic wastewaters, the removal of the available fraction of the P load can usually be achieved by advanced waste-water treatment processes costing less than a cent per person per day for the population served.

It may take several years after initiation of an advanced wwt system before changes in water quality are visible

After initiation of an advanced wastewater treatment, several years may pass before an improvement is seen in receiving water quality. This time lag is because it is expected to take three times the phosphorus residence time of a water body, following a change in its P load, before anew equilibrium phosphorus concentration in the water body is achieved.

The phosphorus residence time is calculated by dividing the total mass of phosphorus present in a water body by its annual P load. For many lakes, particularly eutrophic ones, this value is on the order of one year or less, and is usually considerably shorter than the hydraulic residence time (i.e.,water filling time) of the water body.

For the lower Great Lakes, and many other lakes, the removal of phosphorus by advanced wastewater treatment to about 1 mg P/L in the treated effluent will not achieve a desirable water quality in the water bodies. Under these conditions, it is necessary to explore the possibility of additional phosphorus removal from the treated domestic wastewater effluents as well as the control of phosphorus from non-point sources such as the atmosphere, and urban and rural drainage.

As noted above, a substantial portion of the total phosphorus in treated domestic wastewater effluents is likely to be in chemical forms unavailable for the stimulation of algal growth. This is also the case for atmospheric, and urban and rural drainage inputs. Focusing only on total phosphorus contributions from these sources could result in a large expenditure of funds for eutrophication control with little or no resulting improvement in water quality. It is recommended that eutrophication control measures for these sources be directed toward controlling the available forms of phosphorus so that the best use can be made of the natural and financial resources available for water pollution control.

The emphasis on controlling available phosphorus must include both those forms that are immediately available and that portion of the phosphorus that may become available for algal assimilation in a water body over a period of time. Evaluation of this latter portion requires an understanding of the aqueous environmental chemistry of each of the phosphate forms in the particular water body of concern.

Attention should focus not only on the quantity of phosphorus from a particular source which, while not immediately available for algal assimilation, may become available in the water body, but also on the corollary situation in which phosphorus is available at its point of origin, but becomes unavailable in transit from its source to a lake. The latter is especially important for phosphorus inputs to rivers in which there is removal of phosphorus by sorption on sediments; coprecipitation with iron and aluminum oxides and calcium; and uptake by aquatic organisms.

A portion of phosphorus assimilated by organisms be-comes refractory, and is no longer available for stimulation of algal growth in downstream water bodies. All of these various reactions tend to convert available phosphorus to unavailable forms. The longer the transit time of the phosphorus, or the greater the primary productivity in the river or the greater the suspended sediment load in the river, the greater will be the conversion of initially available P to unavailable forms.

Further, should the river become impounded or flow through a lake, a significant portion of the phosphorus entering the lake or impoundment will be trapped within the water body, and will not be available for stimulation of algal growth in downstream waters. It is typically found that with hydraulic residence times

ALGAE IMPORTANT IN WATER SUPPLIES

of greater than a few months tend to be efficient phosphate traps. Usually, 80-90% of the phosphorus entering these water bodies is incorporated into their sediments.

The OECD project led to the classical report of Vollenweider (1968) on eutrophication of natural waters

In the mid-1960's the Organization for Economic Co-operation and Development initiated work on eutrophication effects and control. Subsequently, the Water Management Sector Group of the OECD initiated a 4-y multi-national cooperative study directed toward the development of quantitative nutrient load-eutrophication response relationships for lakes and impoundments.

This study was divided into four major regional projects:

- the Alpine Project (Swiss, German, French, Austrian, and Italian lakes)
- the Nordic project (Scandinavian lakes)
- the Shallow Lakes and Impoundments Project (German, Dutch, Belgian, English, Spanish, Japanese and Australian lakes and impoundments)
- the North American Project (U.S. and Canadian lakes and impoundments).

A total of approximately 200 lakes and impoundments is being studied. The program has consisted of a several-year data-gathering effort, including determination of nutrient loads and resultant eutrophication responses as expressed by a variety of chemical and biological parameters. The final year for data collection was 1976.

The data gathered in the Nordic, Alpine, and Shallow Lakes and Impoundments Projects, as well as the Canadian portion of the North American Project are currently being analyzed. A final report covering the U.S. portion of the North American Project has recently been published by the U.S. EPA.

The results of the U.S. OECD study strongly support the U.S. EPA's proposal to use the Vollenweider nutrient load-eutrophication response relationships as a basis for establishing nutrient load criteria for U.S. water bodies. This recommendation was published in July 1976 in the U.S. EPA *Quality Criteria for Water*. Further, this approach is also being used in their assessment of phosphorus loads for over 800 lakes and impoundments throughout the U.S., as part of the National Eutrophication Survey.

It is likely that the OECD eutrophication study approach will be instrumental in the implementation of Section 314-A of P.L. 92-500, and the 1977 amendments of this act, P.L. 95-217, which requires every state to classify its water bodies according to their degree of eutrophication. Each state must develop eutrophication control programs for those water bodies that are found to be excessively fertile. The OECD eutrophication project will provide both a data base and methodologies to allow states to classify their lakes and to determine the magnitude of phosphorus load reduction necessary in order to achieve a desired water quality in a given water body.

The approach developed by Vollenweider for determining critical phosphorus loading levels has been, and will likely continue to be, used by the International Joint Commission to establish critical phosphorus loads for the Great Lakes. Vollenweider developed a loading diagram that relates the phosphorus load to a water body to the ratio of the water body's mean depth and hydraulic residence time. The latter two parameters play dominant roles in determining the impact of a given phosphorus load on the fertility of a water body.

In order to produce a relationship more useful for water quality management purposes, Vollenweider extended the phosphorus loading concept to develop the relationship between P load and planktonic algal chlorophyll concentrations in water bodies. Rast and Lee have further extended the Vollenweider relationship to include the impact of P load on the Secchi depth (water clarity) and the hypolimnetic oxygen depletion rate.

The application of these relationships to the U.S. OECD eutrophication study water bodies is shown in the diagram. The phosphorus loading term

$$\frac{L(P)/q_s}{1 + (\tau\omega)^{1/2}}$$

is equivalent to the predicted steady-state mean-phosphorus concentration in a water body.

Several government organizations on the international, federal, and state levels have recently advocated a phosphate detergent ban in the U.S. states and the Canadian province bordering the Great Lakes. The originators of these bans indicated that this approach would result in a significant improvement in Great Lakes water quality. The OECD eutrophication project approaches have been used by Rast and Lee to estimate the expected changes in water quality in each of the Great Lakes that would result from advanced wastewater treatment for phosphorus removal (90% P removal), or a detergent phosphate ban in the Great Lakes Basin. The expected change in phosphorus load can be seen in the diagram. Examination of this diagram shows that no readily discernible impact on the 1975 phosphorus loads to Lake Superior or Huron will occur as a result of further detergent phosphate bans in the Great Lakes drainage basin or further achievement of a 90% phosphorus removal through advanced wastewater treatment in the Basin.

Selected important limnological measurement methods

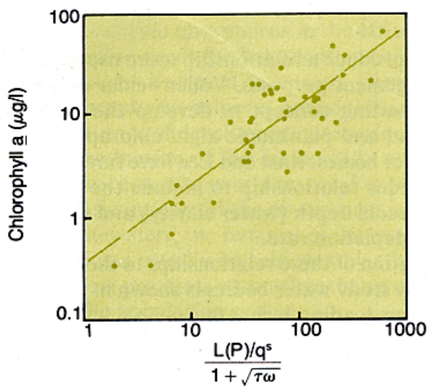
Chlorophyll – Water sample is filtered to remove the suspended algae. The materials collected on the filter are extracted with acetone. Spectrophotometric measurements arc made of the acetone extract to determine the amount of chlorophyll present in the algal cells of the water sample.

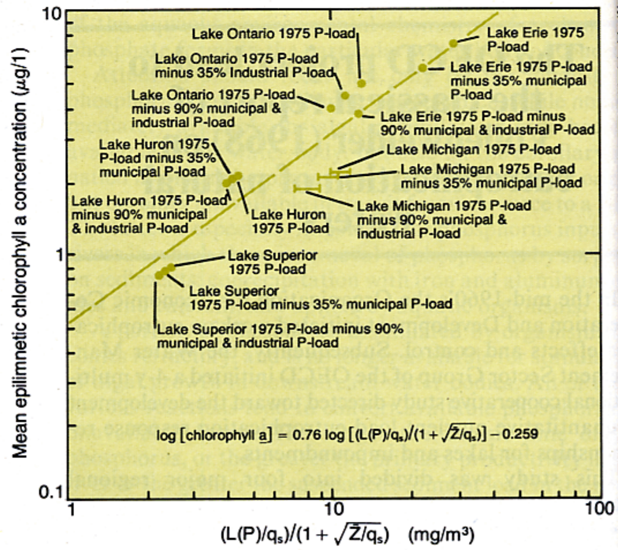
Secchi Depth – Secchi depth is a measure of water clarity that is made by lowering a 20 cm diameter disc suspended from a graduated line into the water until the disc is not clearly visible to the unaided eye.

Hypolimnetic oxygen depletion rate is measured by determining the dissolved oxygen content to the hypolimnion at periodic intervals during periods of thermal stratification.

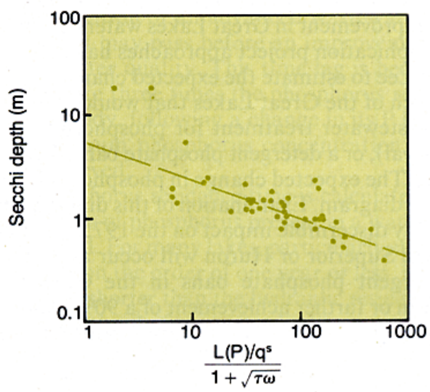
New OECD eutrophication study relationships: changing phosphorus loading affects these water quality parameters, as applied to the Great Lakes.

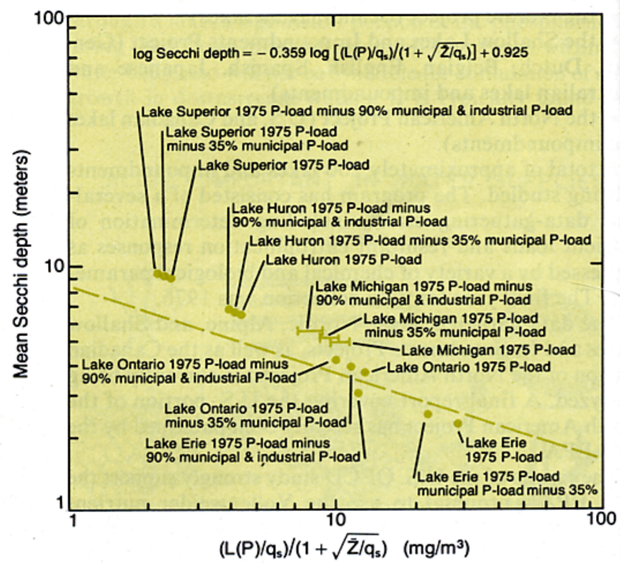
Chlorophyll concentration in water



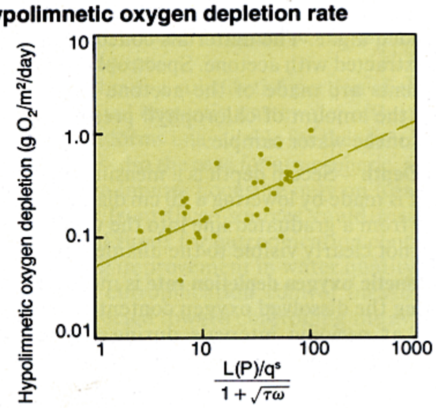


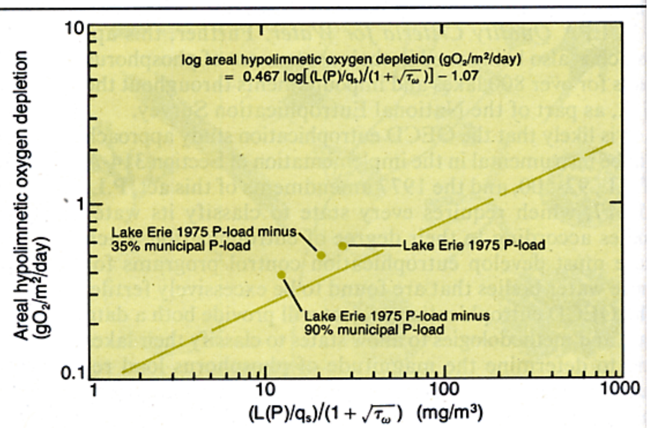
Secchi depth (water clarity)





Hypolimnetic oxygen depletion rate





In Lake Michigan, there is a small change in the phosphorus load resulting from both P reduction options. The range of values presented for Lake Michigan relates to the uncertainty of its estimated hydraulic residence time. LakeOntario shows a slightly larger P load reduction than that seen for the other lakes, excluding Lake Erie, resulting from both scenarios. Lake Erie shows a readily discernible P load decrease resulting from both advanced wastewater treatment and a detergent P ban, with most of the decrease associated with a reduced load from Detroit, Mich.

The changes in the chlorophyll, Secchi depth and hypolimnetic oxygen depletion rate were determined by moving the data point for a particular water body parallel to the line of best fit for the U.S. OECD eutrophication study bodies, in response to the allowed phosphorus loads from these two scenarios. The magnitude of change in the phosphorus loads to the Great Lakes that could be achieved with a detergent P ban in the Great Lakes Basin would have no readily discernible impact on the average summer surface chlorophyll a concentration or Secchi depth in the open waters of Lakes Superior, Michigan, Huron, or Ontario.

For Lake Erie, the average summer chlorophyll a would be reduced from approximately 7.2 µg/L to about 5.8 µg/L as the result of a basin-wide detergent P ban. The corresponding increase in Secchi depth would be about 0.2 meters. The hypolimnetic oxygen depletion rate would be reduced from about 0.6 g $0_2/m^2$/day to about 0.5 g $0_2/m^2$/day. The magnitude of these changes would likely be considered insignificant in terms of improved water quality by most investigators and would, in fact, not likely be discernible by the measurement techniques normally used today.

By contrast, a 90% point-source phosphorus removal would be expected to decrease the average summer surface chlorophyll a concentration in Lake Erie to 3.7 µg/L and increase the Secchi depth there from 2.2 m (1975 load) to about 3.0 m. The hypolimnetic oxygen depletion rate would decrease from about 0.56 g $0_2/m^2$/day to 0.37 g $0_2/m^2$/day. It is evident that a 90% point-source phosphorus removal could have a much greater impact on the water quality in Lake Erie than a detergent P ban.

All of the above estimates of improvements in water quality arising from further adoptions of detergent phosphate bans and/or additional advanced wastewater treatment are based on IJC 1975 estimated P loads to the Great Lakes.

Recently the authors have had the opportunity to examine the Lake Erie situation with respect to the 1978 P load from domestic wastewater treatment plants with discharge to the lake or its tributaries. It was found that there have been substantial improvements in the level of P removal attained by these plants since 1975.

Many of them are or will soon achieve the 1 mg/L P standard that has been established by the IJC. Therefore the adoption of a detergent P ban such as that recently adopted in the state of Michigan or proposed in the State of Ohio will cause little or no improvement in Lake Erie water quality.

The U.S. OECD eutrophication project has provided the methodologies needed to estimate the changes in water quality arising from changes in phosphorus loads. The application of these techniques must be done on a case-by-case basis, in which the estimated available phosphorus loads from each of the major sources is determined for a given water body.

As a result of these phosphorus load relationships, it is no longer necessary to speculate about the degree of improvement in water quality that can be expected to result from a particular water body management practice devoted to control of input phosphorus.

Such questions as what will be the impact of a detergent phosphate ban, 90% removal of phosphorus from domestic wastewaters by advanced wastewater treatment techniques, or control of phosphorus in agricultural or urban runoff, can now be answered with a high degree of reliability. This represents a significant achievement of the OECD eutrophication study. It is emphasized that these water quality relationships must be used with some caution since they possess several constraints that determine their applicability to various types of water bodies.

The U.S. OECD Summary Analysis Report by Rast and Lee (1978) should be consulted for an explanation of the appropriate applications of these project results for predicting water quality changes that will occur as a result of various phosphorus management practices.

An interesting application of the results of the U.S. OECD eutrophication project is in determining whether or not a lake behaves in a manner similar to that of other lakes. While there is good overall correlation between phosphorus loads and chlorophyll a, Secchi depth, and hypolimnetic oxygen depletion rate, there is also some scatter about the line of best fit in the diagram with three plots. This scatter is due to differing analytical methodologies, errors in investigator's measurements, differences in morphological and hydrological characteristics of the water bodies, and a variety of limnological and ecological factors relating to the effects of physical, chemical and biological characteristics of the water body on the growth of phytoplankton.

Another important factor that may cause scatter about these lines of best fit is that the relationships are based on total phosphorus loads. An appreciable part of the phosphorus from some sources is in unavailable forms. Considering all of the factors that are known to influence phytoplankton growth in water bodies, it is remarkable that the curve fit is as good as it is.

The Vollenweider and other loading relationships discussed in this report should be evaluated for many different types of water bodies. Those water bodies that show the greatest deviation from the U.S. OECD lines of best fit should receive additional attention to understand the reason for this deviation.

It is highly likely that additional studies along these lines would result in further refinement of these phosphorus load-eutrophication response relationships. In addition to hydraulic residence time and mean depth, other factors that play dominant roles in influencing the phosphorus load eutrophication response relationships in lakes and impoundments should be considered.

Another interesting aspect of the U.S. OECD eutrophication project results is that, in general, the water quality in lakes and impoundments is remarkably insensitive to small changes in phosphorus loads. All of the various relationships are double logarithmic plots, which indicates that large changes in phosphorus loads will produce relatively small changes in average chlorophyll levels, water clarity, or hypolimnetic oxygen depletion rates.

In summary, eutrophication research of the past 10-15 years has established phosphorus as one of the key elements controlling growth of planktonic algae in fresh water. In marine waters, nitrogen is generally the controlling element.

In the past, eutrophication control measures have been largely directed toward the control of phosphorus from point sources, such as domestic wastewaters. Phosphorus can be reduced to a concentration of approximately 1 mg P/L in domestic wastewater effluent, at a cost of a fraction of a cent/person/day for the population served. It is now clear that for many water bodies, including Lakes Erie and Ontario, phosphorus control from non-point sources will also have to be initiated if the water quality in these water bodies is to be restored to desirable levels. The control of phosphorus from non-point sources will require a much better understanding of the quantities of available phosphorus obtainable from each source and the cost controlling this available P.

Additional reading

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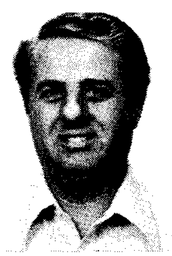

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