Assessing the Water Quality Impacts of Phosphorus in Runoff from Agricultural Lands: Expanded Discussion[1]

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The excessive fertilization of waterbodies is recognized as one of the major causes of the impairment of the beneficial uses of waters through the growth of excessive amounts of aquatic plants such as algae and water weeds. Agricultural land use is found to be an important source of N and P compounds leading to excessive fertilization of some waterbodies. Increasing attention is being given to controlling the water quality impacts of nitrogen and phosphorus compounds in stormwater runoff and irrigation tailwater discharges from agricultural lands. The US EPA is developing numeric chemically based nutrient criteria which will lead to increased efforts to restrict the discharge/release of N and P compounds from ag lands. This paper is the first of a two-part review of issues that should be considered in assessing/managing the impact of phosphorus added to a waterbody on its eutrophication-related water quality.

Introduction

Increasing attention is being given to controlling the water quality impacts associated with excessive fertilization (eutrophication) of waterbodies. This effort is leading to increased attention to the role of agricultural stormwater runoff and irrigation return water (tailwater) as a source of aquatic plant nutrients (nitrogen and phosphorus compounds) that cause excessive fertilization of waterbodies. The discussion presented herein is an overview of some of the issues that need to be considered by agricultural interests and those regulating agriculture in evaluating the water quality significance of nitrogen and phosphorus derived from ag land runoff/discharges. For a more detailed discussion of many of these issues, consult Jones-Lee and Lee (2001), Lee and Jones-Lee (2001a) and references cited therein.

Water Quality Impacts of Waterbody Excessive Fertilization

The excessive fertilization of waterbodies is a long-standing, well-recognized water quality problem throughout the US and other countries. It is manifested in excessive growths of planktonic (suspended) algae and attached algae, as well as macrophytes (water weeds), which can either be floating, such as water hyacinth or duckweed, or attached-emergent. The impacts of excessive fertilization-eutrophication on a waterbody=s water quality were discussed by Lee (1971). A brief summary of water quality problems caused by excessive fertilization is presented below.

Domestic Water Supplies. Planktonic algae can have a severe impact on domestic water supply water quality through shortened filter runs, the release of organic compounds that cause tastes and odors, and, in some instances, the production of trihalomethane (THM) precursors. The THMs

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Reference as Lee, G. F., and Jones-Lee, A., "Assessing the Water Quality Impacts of Phosphorus in Runoff from Agricultural Lands: Expanded Discussion," Report of G. Fred Lee & Associates, El Macero, CA (2001).

are chloroform and chloroform-like compounds which are formed during the disinfection of water supplies. They are regulated as human carcinogens. Water utilities experience increased cost of treatment if the raw water supply has excessive algae and some other aquatic plants.

Violations of Water Quality Standards. The excessive fertilization of waterbodies can lead to marked diel (night to day) changes in pH and dissolved oxygen concentrations. The diel photosynthesis/ respiratory changes are the result of algal removal of CO_2 from the water, which, by late afternoon, can cause the pH of the water to increase above the water quality standard. Accompanying algal growth, which occurs in light, there is production of oxygen. However, in the dark, the algae and other organisms in the water are only respiring, which results in the release of CO_2, lowering the pH, with a concomitant consumption of oxygen. The dissolved oxygen in a waterbody just before sunrise can be sufficiently low to violate water quality standards for protection of fish and other aquatic life. Richards (1965) has shown that one phosphorus atom, when converted to an algal cell which subsequently dies, can consume 276 oxygen atoms as part of the decay process.

While, ordinarily, the DO depletion issue is a near-bottom water issue, where there is thermal stratification which inhibits the surface water oxygen produced by planktonic algae and aeration from mixing to the bottom, there are situations where the algal-related oxygen demand can be sufficient (such as in the San Joaquin River Deep Water Ship Channel near Stockton, California) that there are DO depletion problems in the surface waters as well (see Lee and Jones-Lee, 2000; 2001b,c).

Figure 1 presents a diagram which shows the DO depletion issues in the San Joaquin River (SJR) Deep Water Ship Channel (DWSC). The SJR just upstream of the DWSC is eight to 10 feet deep and does not experience DO depletion problems. Upon entry into the 35-foot-deep DWSC, the oxygen demand in the form of algae and other constituents in the SJR begins to be exerted at a rate which greatly exceeds the oxygen production by the algae in the upper approximately one meter of water with sufficient light to support algal growth, as well as aeration from the atmosphere. This leads to significant DO depletion problems throughout the water column. The reactions involved are shown in Figure 2.

Toxic Algae. One of the major stimuli for increased US EPA attention to excessive fertilization is the *Pfiesteria* problem in Chesapeake Bay (2000a), where fish kills have occurred due to the presence of toxic algae. Fish kills associated with toxic algae are not new; they have been occurring in various waterbodies around the world for many years. Problems of this type have occurred off the west coast of Florida for many years. Further, blue-green algae at times excrete toxins which are known to kill livestock and other animals.

Impaired Recreation. Excessive growths of algae, both planktonic and attached, can affect the use of waterbodies for swimming, boating and fishing, through interference with water contact. They can also lead to severe odor problems due to decaying algae, algal scums, etc.

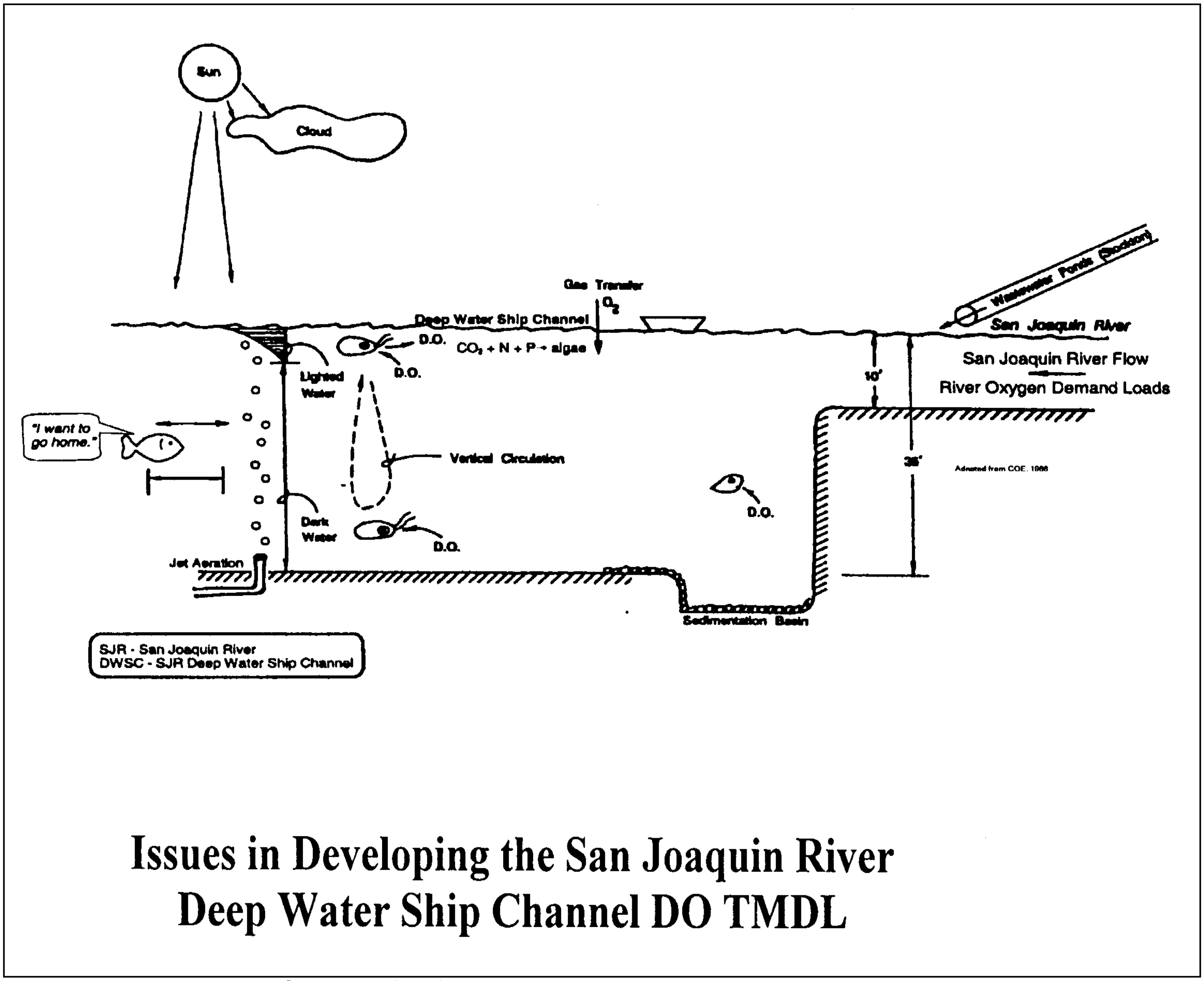


Figure 1. From Lee and Jones-Lee (2000).

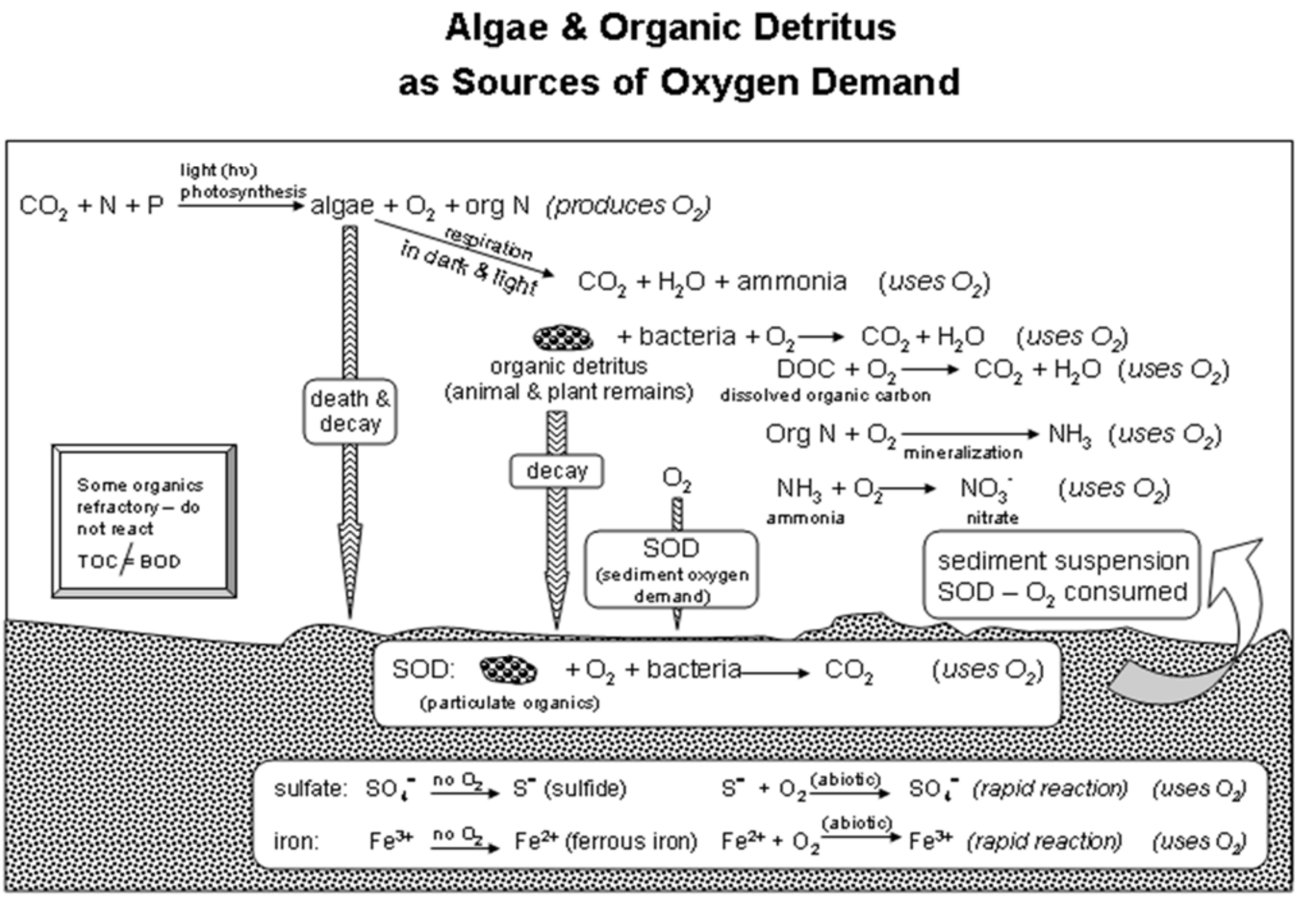
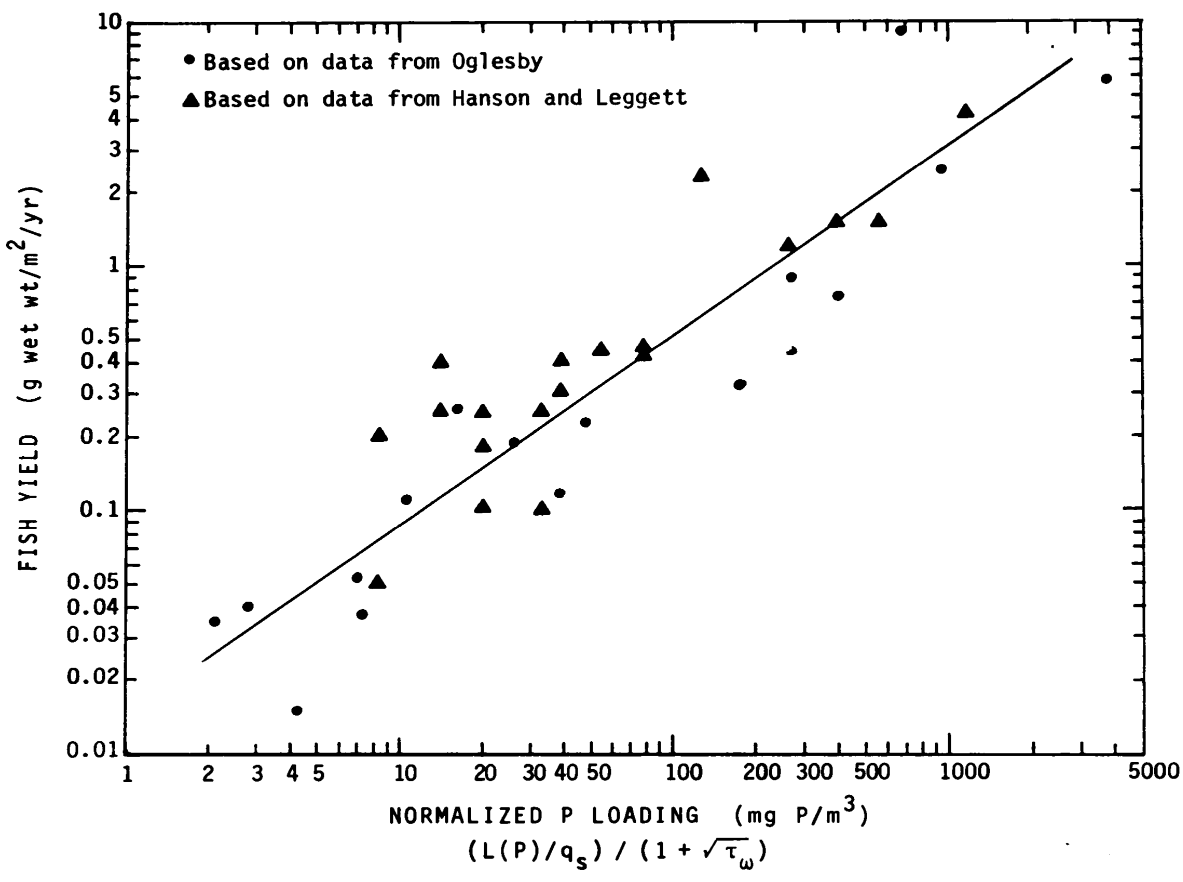


Figure 2. From Lee and Jones-Lee (2000).

Impact on Fisheries. Fertilization of waterbodies improves fish production in terms of total biomass; however, as Lee and Jones (1991) discuss, it can be adverse to production of desirable forms of fish, especially at high fertilization levels. In waterbodies that stratify, with a cold hypolimnion (bottom waters), oxygen demand created by the growth of algae in the surface waters which die and settle into the hypolimnion can be sufficient to deplete the oxygen. This is a characteristic of highly eutrophic waterbodies. This, in turn, means that, in temperate climates, the coldwater fish (such as the salmonids, trout, etc.) that normally inhabit the hypolimnion cannot survive because of a lack of oxygen. Further, with respect to the increased production in highly eutrophic waterbodies, the populations of rough fish, such as carp, which can tolerate lower dissolved oxygen (DO) levels, often dominate the increased production. These relationships are shown in Figure 3.



(The terminology used in the abscissa of Figure 3 is explained in the subsequent section of this paper.)

Figure 3. Relationship between Normalized P Load and Fish Yield. From Lee and Jones (2000).

Shallow Water Habitat. Emergent aquatic vegetation in the shallow waters of waterbodies provides important habitat for various forms of aquatic life. As discussed by Lee (1971), increased planktonic algal growth in a waterbody reduces light penetration which in turn inhibits the growth of emergent vegetation, resulting in loss of significant aquatic life habitat.

Overall Impacts. Excessive fertilization is one of the most important causes of water quality impairment of waterbodies. The US EPA (2000a), in its last National Water Quality Inventory, has listed nutrients as the leading cause of impaired lakes and reservoirs. Further, the Agency lists agriculture as the primary source of constituents (nutrients and sediments) that impair lakes. These relationships are shown in Figures 4 and 5.

Nutrients of Concern

The nutrients of primary concern are nitrogen and phosphorus compounds. While algae, like other forms of aquatic plants, require a wide variety of chemical constituents, light and appropriate temperatures to develop, the primary issue of concern in managing algal populations is the nutrient that is present in the least amount compared to algal needs. Typically, it is nitrogen and algal-available phosphorus compounds that are of concern. With respect to nitrogen, algae can use nitrate, nitrite, ammonia and, after conversion to ammonia, organic nitrogen compounds. All of these forms of nitrogen are nutrients for algal growth. While some blue-green algae at times can fix (utilize) atmospheric nitrogen gas (N_2) that is dissolved in water, and thereby use it as a source of nitrogen for growth, this occurs under restricted conditions, even for those blue-greens which have the potential ability to fix nitrogen gas dissolved in water.

With respect to phosphorus, it is the soluble orthophosphate that is available to support algal growth. There are many forms of phosphorus that do not support algal growth, particularly the particulate forms, as well as some organophosphorus compounds and oxygen-phosphorus polymer chain and ring compounds (condensed phosphates). Equation (1) presents the typical stoichiometry of algae.

$$106\ CO_2 + 16\ N + 1\ P + \text{trace elements} \overset{h\nu}{\Rightarrow} \text{algae} + O_2 \qquad (1)$$

For most freshwater waterbodies, it is the algal-available phosphorus in the water that limits algal growth. For marine waters, there is often surplus algal-available phosphorus compared to nitrogen. This can result in nitrogen becoming the limiting nutrient controlling the stimulation of algal growth.

While the potassium content of some soils can limit the growth of terrestrial plants, potassium is not an element that limits aquatic plant growth.

There are frequently significant problems with the approaches used by some investigators in determining whether nitrogen or phosphorus is limiting algal growth in a waterbody. The mechanical application of the Redfield nutrient ratios, which are derived from algal stoichiometry shown in Equation (1), can be highly misleading in determining whether nitrogen or phosphorus is limiting algal growth. Redfield N to P ratios of 16 to 1 on an atomic basis, or 7.5 to 1 on a mass basis cannot be used to reliably predict limiting nutrients (Lee and Jones-Lee, 1998). The approach that should be used is to examine the concentrations of available forms of nutrients at peak biomass, and then, if the concentrations present are below growth-rate-limiting concentrations, there is reasonable certainty that the nutrient that occurs under these conditions is potentially limiting algal growth.

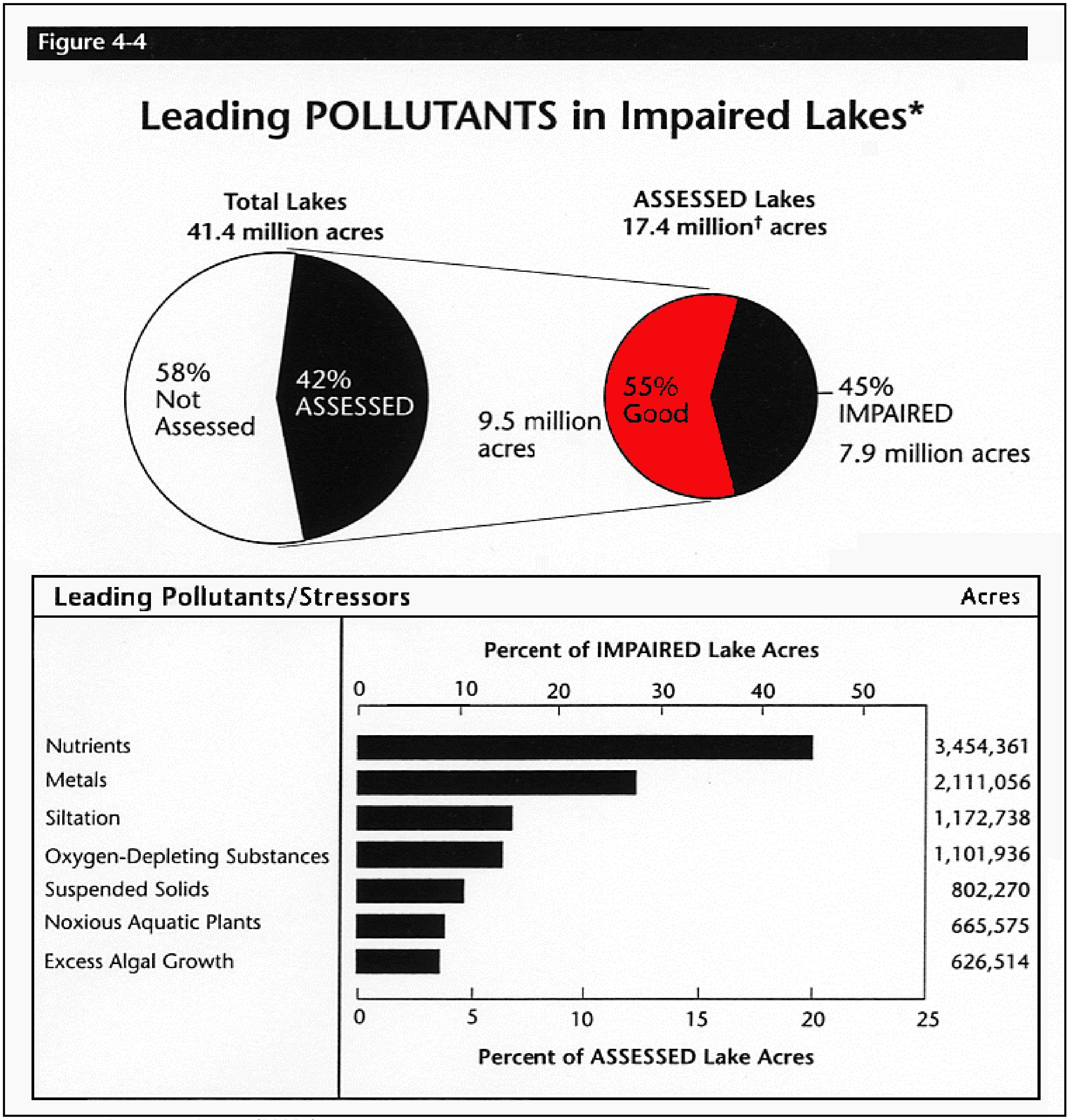


Figure 4. Source: US EPA (2000a).

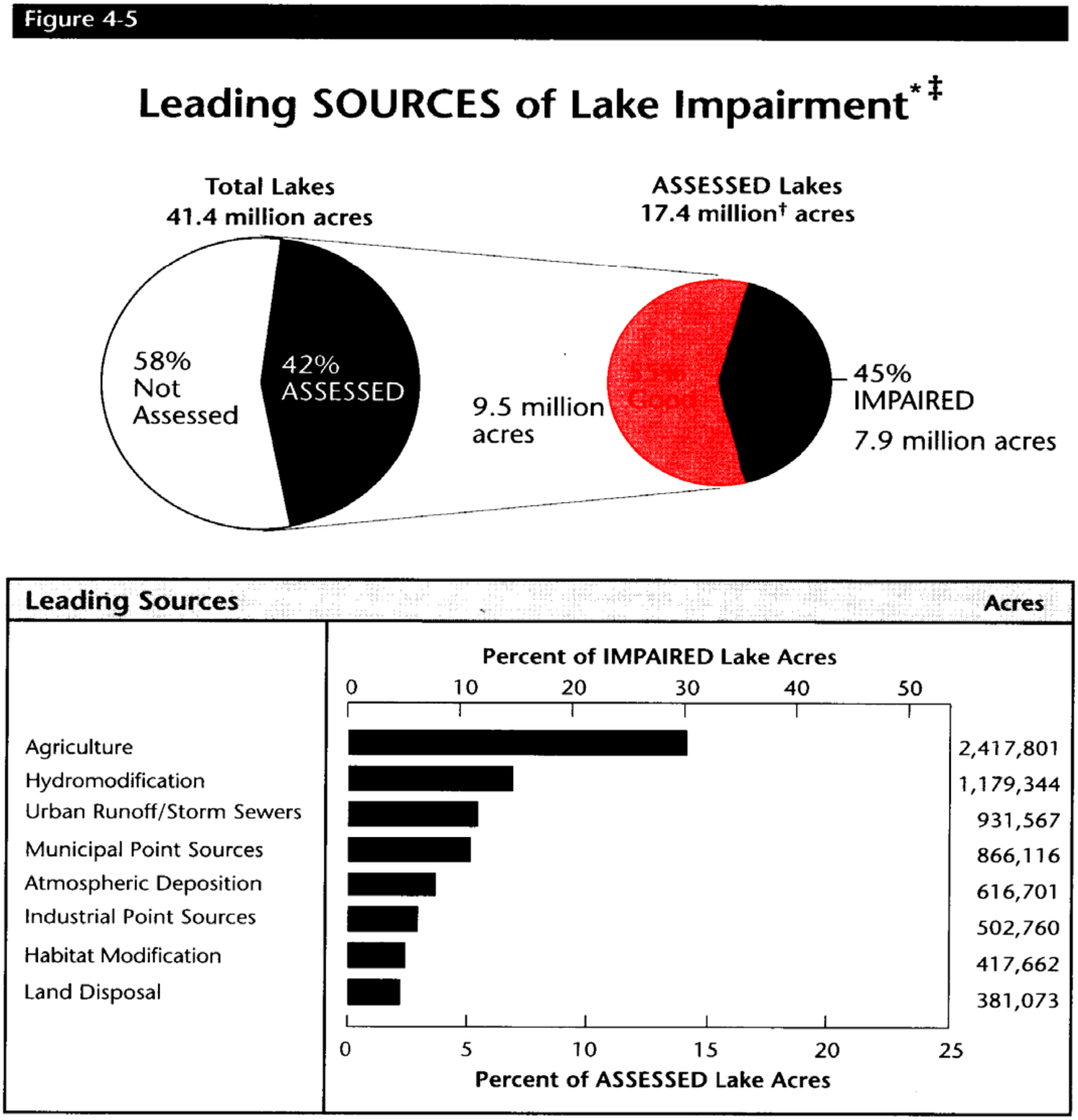


Figure 5. Source: US EPA (2000a).

In many highly fertile waterbodies, neither nitrogen nor phosphorus is limiting algal growth. Both are present above growth-rate-limiting concentrations -- i.e., they occur up on the plateau of the algal growth-nutrient concentration relationship (see Figure 6). Typically, growth-rate-limiting concentrations for phosphorus are on the order of 2 to 8 µg/L available-P, and for nitrogen are on the order of 15 to 30 µg/L available-N (in the form of nitrate, nitrite and ammonia). It is important to understand that, even at growth-rate-limiting concentrations, appreciable algal biomass can develop if there is sufficient time for algal growth to occur.

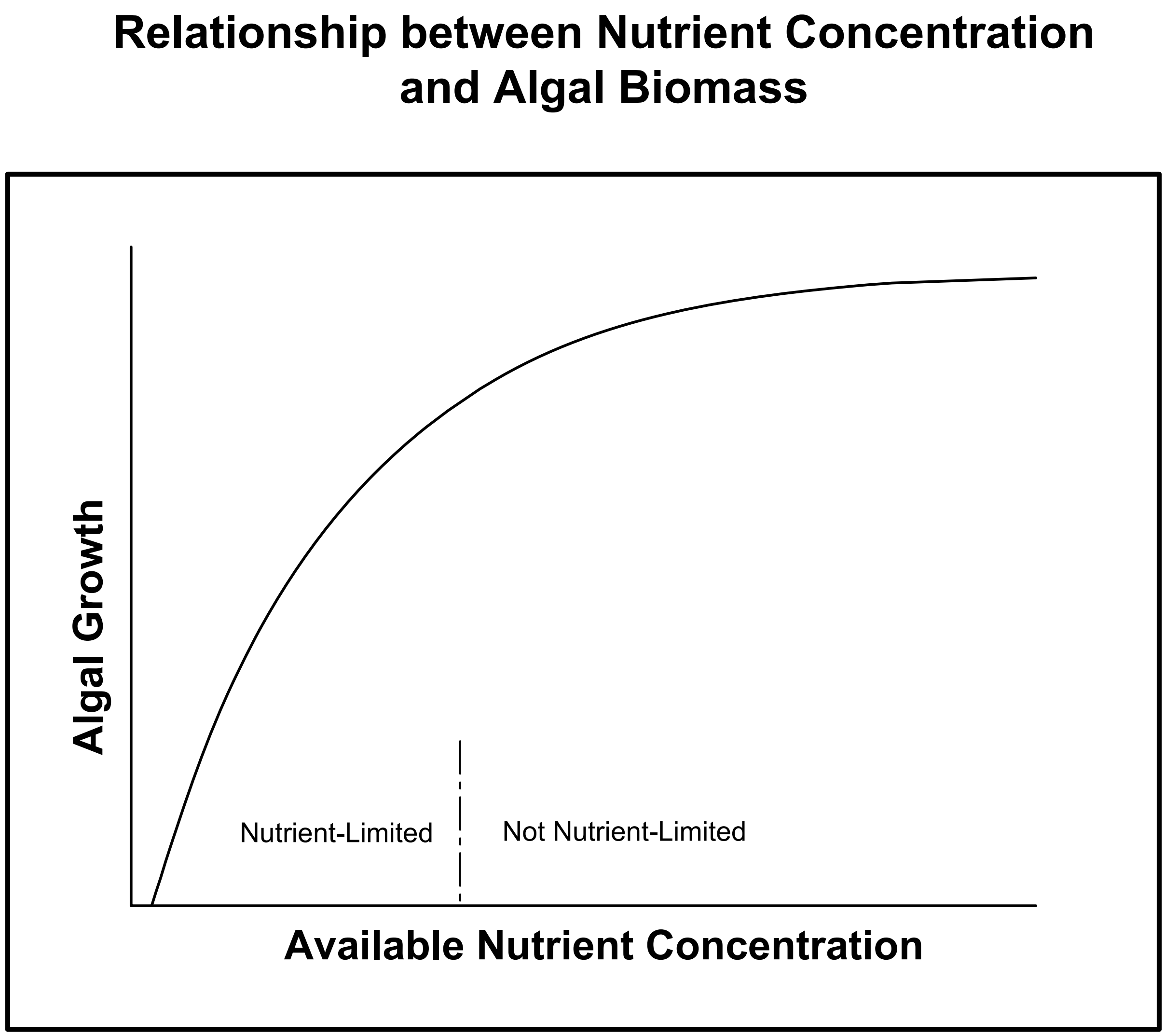


Figure 6. From Lee and Jones-Lee (2000).

Total Phosphorus versus Algal-Available Phosphorus

The US EPA (1998), as part of developing nutrient criteria, is focusing on total phosphorus. However, it was well-established many years ago that most of the particulate phosphorus in agricultural and urban stormwater runoff is not available to support algal growth.

Lee, *et al.* (1980) conducted extensive research on this topic, and also published a review of these issues for the International Joint Commission for the Great Lakes. They found, based on their work as well as the work of others, that the algal available P can be estimated as the soluble ortho-P, plus about 20 percent of the particulate P in agricultural and urban runoff. Algal-available nitrogen can be estimated as the nitrate plus nitrite plus ammonia, and some site-specific fraction of the organic nitrogen. The fraction of the organic nitrogen that is available depends on its source and age.

Part of the problem with the US EPA's approach to properly addressing algal available nutrients in developing nutrient criteria is that the Agency is relying on improper interpretation of radiophosphorus exchange studies. Studies conducted in the 1960s showed that the addition of P-32 to a water sample resulted in some of the dissolved P becoming incorporated into the solid phase and vise versa. Those familiar with radiolabel exchange experiments know that surficial exchanges do not measure available forms of nutrients in the solid phase. Algal growth experiments in which all nutrients needed for algal growth are available in surplus of algal needs except for the P in the water sample being tested, showed that most of the particulate P in ag and urban stormwater runoff from a variety of sources is not available for algal growth. These results are based on both short-term and long-term (one year) incubation. The lack of availability of part of the phosphorus in soils is well known to the ag community who find that total P in soils is not a reliable measure of plant-available P. As discussed by Jones-Lee and Lee (2001) nutrient criteria for regulating ag and urban stormwater runoff should be based on soluble orthophosphate and nitrate plus ammonia plus about 20 percent of the particulate P and N. However, if the source of the P and N are algae then most of the total N and total P will be mineralized and in time will become available to support algal growth.

Importance of Light Penetration

Almost all algal growth in waterbodies is light-limited. This results in the algae being able to photosynthesize in fertile waterbodies only in the upper few feet, due to the self-shading effects of planktonic algae. It is important to understand the coupling between nutrient loads to waterbodies and their eutrophication-related water quality as influenced by inorganic turbidity and natural color. It is well-established that erosion from a waterbody's watershed increases the turbidity in waterbodies, which in turn decreases light penetration and thereby slows algal growth. There are situations, however, where the control of erosion in a waterbody's watershed can result in greater algal growth for the same nutrient concentration than would occur if the waters were still turbid from erosion in the watershed.

Nutrient Export Coefficients

Nutrient export coefficients are the amounts of nitrogen or phosphorus exported from an area over a specific time period. They are typically expressed as grams P per square meter per year, or pounds N per acre per month, or some other mass-area-time units. Rast and Lee (1983), based on the US OECD Eutrophication Studies, developed nutrient export coefficients based on about 100 waterbodies' watersheds located across the US. These are shown in Table I.

Table I. Watershed Nutrient Export Coefficients

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 Waterbodies in Western US.
From Rast and Lee (1983).

While the actual export coefficient depends on the particular setting, these values have been shown in many situations to provide sufficient reliability to estimate the potential significance of various types of land use in a waterbody's watershed as a source of nitrogen and phosphorus. Nutrient export coefficients for agricultural lands should be evaluated based on soil characteristics, types of crops grown and other factors that tend to influence the amount of nitrogen and phosphorus exported from the land.

There will be situations where the annual export coefficient is not appropriate, such as for waterbodies with short (a few weeks to a few months) hydraulic residence times. Under these conditions, monthly export coefficients should be used, where attention is given to the sources of those nutrients that are responsible for excessive algal growth that impairs the waterbody's water quality.

Phosphorus Index

The US Department of Agriculture, the Natural Resources Conservation Service (NRCS, undated) and others have been developing a qualitative approach to estimating phosphorus fertilizer runoff from various types of agricultural lands. This effort is leading to what is called the "phosphorus index" (PI). As currently developed, the PI is composed of a number of weighting factors, which are derived from the following equations (as well as others):

Loss Rating Value for Fertilizer P = (Fertilizer P Application Rate) * (Fertilizer P Solubility Factor) * (Factor for Application & Timing of Application) * (Weighting Factor)

Subtotal for Transport =	(Soil Erosion + Runoff Class + Other Variables) / (Sum of Maximum Possible Value of Each Site Characteristic)
Site Vulnerability =	(Subtotal for Source) *)Subtotal for Transport)

These are given a qualitative rating category score. The site vulnerability is the product of the subtotal of the source and the subtotal for transport qualitative assessments/rankings. Consideration is also given to the soil test phosphorus in developing a potential vulnerability of fertilizer of a certain type (inorganic versus manure), application on certain types of crops, soil characteristics, etc., to lead to runoff of some of the applied fertilizer.

The stated objective of the PI is to provide guidance to the agricultural community on the relative potential for phosphorus applied in a fertilizer to be exported from the agricultural lands. The PI approach needs to be expanded from a qualitative discussion of phosphorus export issues to a quantitative assessment of how these various factors that lead to phosphorus export impact the phosphorus export coefficient for a particular type of soil, crop, fertilizer application rate and other dominant factors controlling phosphorus export.

Nutrient Criteria

Beginning in the 1960s, there was considerable interest in several parts of the US, especially the Midwest/Great Lakes region, to develop nutrient control programs to control excessive fertilization of waterbodies. It was recognized then that the cultural activities of man, through developing cities and agricultural activities, increased the nutrient export from land, which could increase the fertility of the waterbodies receiving the runoff/discharges. At that time, the primary focus of nutrient control was devoted to treating domestic wastewaters for phosphorus control. During the 1960s and 1970s, there was considerable research done on the relationships between nutrient loads to waterbodies and their impact on eutrophication-related water quality. By the late 1970s, the US EPA essentially terminated all efforts devoted to eutrophication management and shifted their emphasis to the control of "rodent" carcinogens that are regulated as Priority Pollutants. This shift in emphasis was not based on finding that eutrophication of waterbodies was any less of a cause of impairment of beneficial uses, but was based on political considerations. In the late 1990s, the US EPA began again to give consideration to excessive fertilization of waterbodies as a major cause of impairment of the nation's waters. At that time the Agency decided to attempt to develop numeric, chemical-specific water quality criteria for nitrogen and phosphorus, which would become the primary basis by which the Agency regulates excessive fertilization of waterbodies.

In formulating the Agency's approach for developing nutrient criteria, the Agency staff and its advisors largely ignored the massive amount of work that was done in the 1960s and 1970s relating nutrient loads to waterbodies to the eutrophication-related water quality. At that time, it was well-established that each waterbody behaves differently with respect to how it utilizes nutrients to produce aquatic plants, which in turn impair the beneficial uses of the waterbody. The Agency's approach for developing chemical-specific nutrient criteria focused on developing background concentrations of nutrients in various types of waterbodies that would be present in the absence of the activities of man in the watershed. While that approach, like the chemical concentration-based approach that the US EPA has been using since the late 1980s to regulate potentially toxic constituents such as heavy metals, is easy to administer, it, like the situation with regulation of heavy metals, is not technically valid, and can be tremendously wasteful of public and private funds in controlling nutrients from agricultural and urban areas.

The Agency's approach of attainment of worst-case-based water quality criteria/standards for regulating heavy metals and other potentially toxic constituents has been implemented for domestic and industrial wastewaters. Those discharging to domestic wastewater systems are a "captive audience," where unnecessary expenditures for treatment works associated with over-regulating the discharge of constituents is passed on to the rate-payers. However, the chemical-specific chemical concentration approach is not an implementable approach with respect to regulating stormwater runoff-associated constituents which avoids unnecessary expenditures for constituent control and will not be implemented to control heavy metals or nutrients in urban area and highway stormwater runoff and other point and nonpoint sources. The high cost of managing stormwater runoff-associated constituents, including nutrients, to meet nutrient criteria/standards based on pre-cultural nutrient concentrations in waterbodies will cause the public, who must ultimately pay for the chemical constituent management, to critically review the appropriateness of a particular nutrient control program in protecting the beneficial uses of the waterbodies of interest to them.

One of the problems with nutrient control, especially associated with the US EPA's approach of one numeric value fits all waterbodies of a certain type in an ecoregion, is that, in the moderate nutrient enrichment situation, which can be well above natural background nutrient levels, nutrients are of value in improving some aspects of beneficial uses. To attempt to return waterbodies to the pre-cultural nutrient status would, in the eyes of some, be disastrous to the fisheries of the waterbodies. As described by Lee and Jones (1991) in their paper, "Effects of Eutrophication on Fisheries," there is a well-established link between available nutrient concentrations and fish biomass (Figure 3). The classic example of this type of issue is Lake Erie, where, during the 1960s, the popular press portrayed Lake Erie as "dying." The problem was that there was DO depletion in the deeper waters of the lake. The lake, however, was not dying. It was actually "too alive," because of the large numbers of algae present. This situation prompted the US and Canadian regulatory authorities to cause domestic wastewater treatment plants to treat their discharges to Lake Erie or its tributaries for phosphorus removal. Also, agriculture in the region began to shift to no-till farming in an effort to reduce the phosphorus input associated with erosion. The fisheries in Lake Erie at the time that it was "dying" were excellent. In recent years, the fishermen in Lake Erie are complaining about the poor-quality fisheries. This same kind of situation could readily widely occur if the US EPA adopts nutrient criteria which represent "pristine" conditions for a particular ecoregion and waterbody type.

Agriculture and other nutrient dischargers face the use of nutrient (N and P) criteria to regulate nutrient releases from land. The US EPA's (1998, 1999, 2000b) current approach for developing nutrient criteria will likely lead to many waterbodies' becoming listed as Clean Water Act 303(d) "impaired" waterbodies due to nutrient concentrations above the criterion values. The 303(d) listing will lead to the need to develop TMDLs to control nutrient runoff from agricultural lands and other sources. Because of this situation, agricultural interests should become involved in the US EPA's Regional Technical Assistance Group (RTAG) efforts to establish nutrient criteria in their area, to ensure that appropriate criteria are developed for the receiving waters of runoff from agricultural lands and other nutrient sources.

The US EPA has proposed two approaches for developing nutrient criteria. The national chemical concentration-based default values are based on nutrient concentrations in the water, which are estimated based on pre-cultural activities (no ag or urban activities) in the waterbody's watershed. This relationship is shown in Figures 7 and 8.

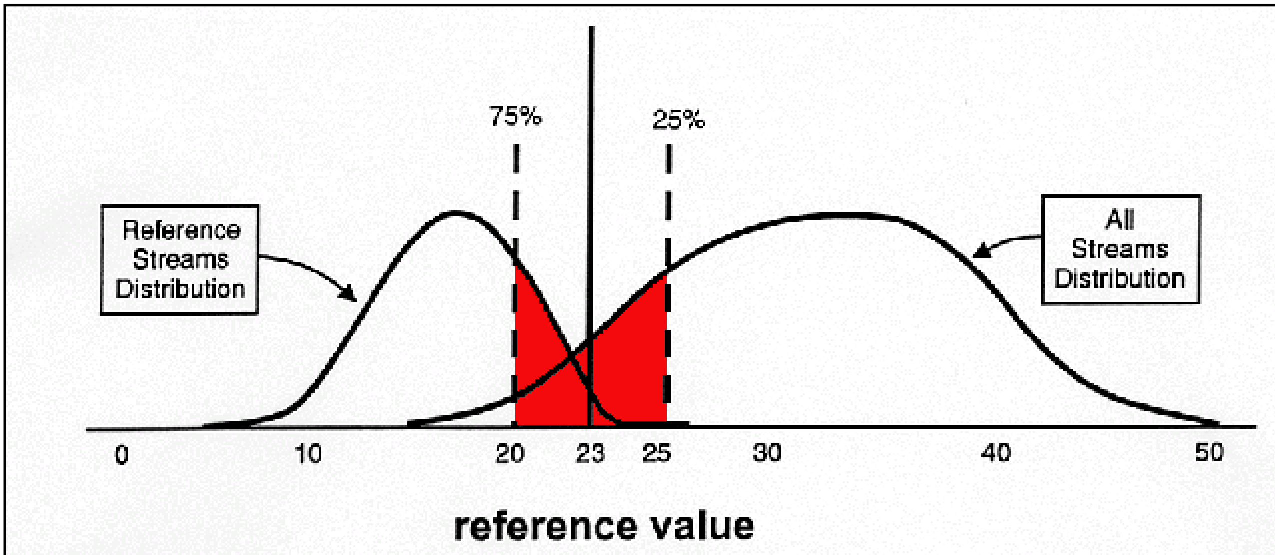


Figure 8. Selecting reference values for total phosphorus concentration (μg/L) using percentiles from reference streams and total stream populations.

Figure 7. Source: US EPA, Nutrient Criteria Technical Guidance Manual, Rivers and Streams (2000c).

As shown in Figure 7, the US EPA default nutrient criteria are based on the nutrient concentration at the intersection of the "reference" stream 75th percentile nutrient concentration with the 25th percentile concentration for all streams as the criterion value. If there are no reference streams in an area then the 25th percentile of the nutrient data for a stream becomes the nutrient criterion. This approach is arbitrary and has nothing to do with regulating the impact of the nutrients on the beneficial uses of the waterbody. Ditoro and Thuman (2001) have commented that the US EPA's default nutrient criteria approach has neglected the link between nutrient concentrations and water quality impacts and implies that 75 percent of the waterbodies in an ecoregion will not meet the nutrient criteria.

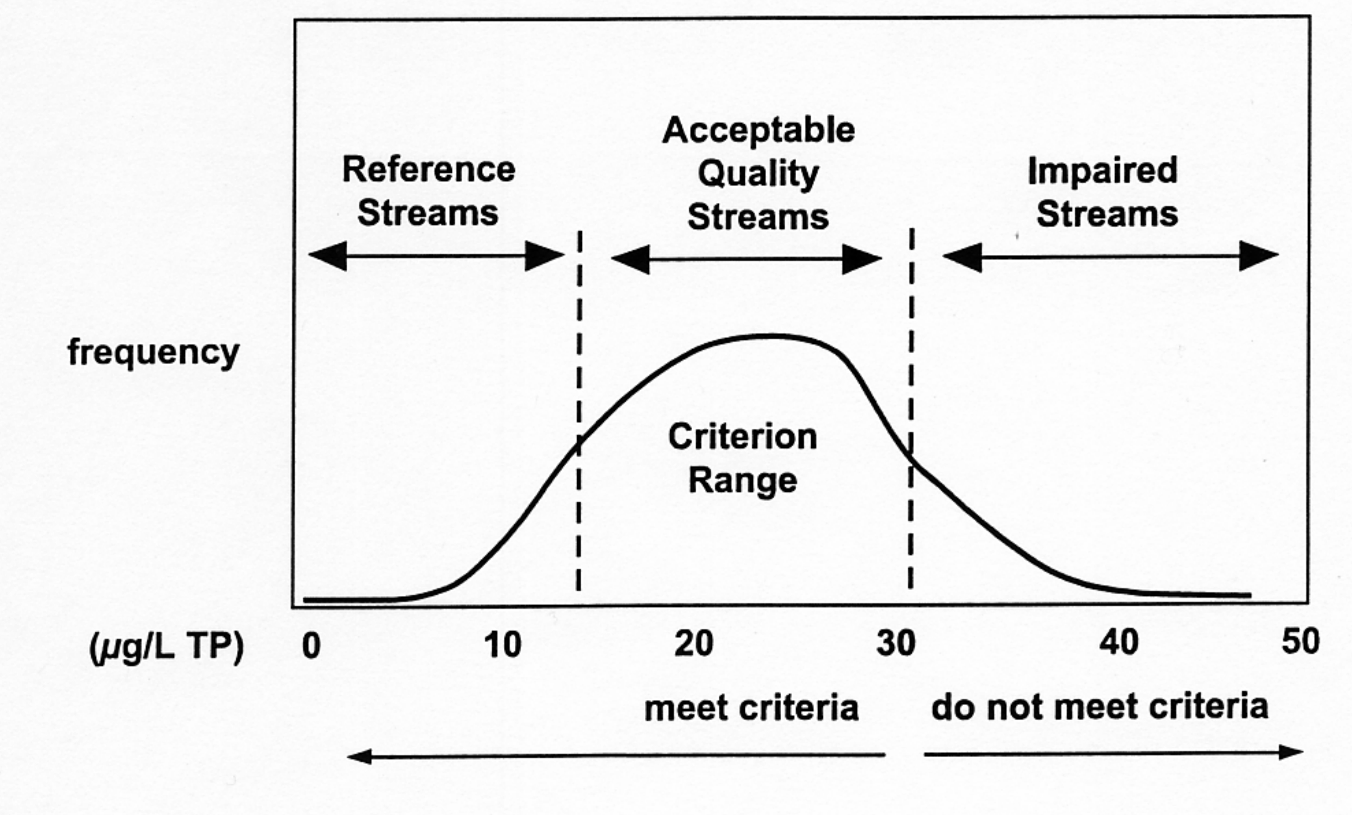


Figure 9. Frequency distribution divided into three segments that represent (from left to right) high-quality reference streams, acceptable quality streams, and impaired streams.

Figure 8. Source: US EPA, Nutrient Criteria Technical Guidance Manual, Rivers and Streams (2000c).

The US EPA default nutrient criteria development approach is made even more unreliable as the result of the Agency using total P and TKN as the "nutrients" that are used in selecting the default criterion value As discussed herein, for many waterbodies, especially in streams and rivers during elevated flows, large amounts of the total P and TKN are not in and do not convert to algal available forms. The US EPA's approach for developing ecoregion-based default nutrient criteria is obviously technically flawed and can readily lead to inappropriate regulation of chemicals. Additional information on developing the default nutrient criteria is provided in US EPA (2000c).

The Agency states that if states do not develop "scientifically defensible" nutrient criteria by the 2004 deadline, the default nutrient criteria will be imposed on the states as the state nutrient water quality standard. While recent information from the Bush administration (Grubbs, 2001) indicates that the 2004 deadline may be slipping, the Agency staff is still claiming that the states must have well-developed nutrient criteria by that date.

The US EPA default nutrient criteria development is more of the inappropriate approach that the US EPA has been using since the early 1980s in which the Agency is trying to reduce impacts of chemicals on water quality/beneficial uses to a single numeric value. Lee and Jones-Lee (1996) discussed the urgent need for the US EPA to stop the chemical concentration-based approach for regulating water quality and instead focus on regulating chemical impacts. Adoption of the chemical impact on water quality/impairment of beneficial uses approach will lead to a much more technically valid, cost-effective management of real, significant water quality impairments. Basically, the Agency is attempting to develop chemical concentration-based numeric nutrient criteria which are similar to the water quality criteria for controlling toxics. With respect to toxics, it is appropriate to consider controlling the toxicity of constituents to protect aquatic life from toxicity. However, applying this same approach to nutrients could lead to erroneous assessments of desirable nutrient loads/concentrations for waterbodies.

In developing the appropriate nutrient criteria, it is suggested that the TMDL development approach is an appropriate approach to follow. This approach involves the following steps:

- Developing a problem statement.
- Establishing the goal of nutrient control (i.e., the desired water quality).
- Determining nutrient sources, focusing on available forms.
- Establishing linkage between nutrient loads and eutrophication response (modeling).
- Initiating a Phase I nutrient control implementation plan to control the nutrients to the level needed to achieve the desired water quality.
- Monitoring the waterbody for three to five years after nutrient control is implemented to determine whether the desired water quality is being achieved.
- If not, initiating a Phase II where, through the monitoring results, the load-response model is improved and thereby able to more reliably predict the nutrient loads that are appropriate for the desired water quality.

This approach is an iterative approach, where, over a period of at least five to possibly 15 years, through two or more consecutive phases, it will be possible to achieve the desired water quality and thereby establish the nutrient loads which can be translated to in-waterbody concentrations and, therefore, the nutrient criteria for the waterbody. Information on several of these components is discussed below.

Issues that Need to be Considered in Developing Appropriate Nutrient Control Programs

There are a number of key issues that need to be considered/evaluated in formulating nutrient control programs, the most important of which is the nutrient load-eutrophication response relationship for the waterbody(ies) of concern. Each waterbody has its own water quality-related load-response relationship that needs to be evaluated. As discussed herein, the notion that this evaluation should be restricted to just the US EPA's "ecoregion" approach, where waterbodies of a particular type, such as a lake, river, stream, etc., in an ecoregion can all have the same nutrient criteria, is fundamentally flawed since it ignores the vast amount of work that was done in the 1960s and 1970s in developing technically valid nutrient control programs for various types of waterbodies located in various areas.

The primary issue of concern is the identification of the nutrient loads to a particular waterbody that cause or contribute to excessive fertilization of the waterbody -- i.e., cause water quality use impairment. Associated with this are the issues of when the water quality problems occur (in the summer, fall, winter, etc.), how they are manifested (planktonic algae, attached algae, macrophytes), what the desired eutrophication-related water quality is for the waterbody, what the hydraulic residence time (filling time) of the waterbody is and when the nutrients enter the waterbody that cause the water quality problems. The relationship among these various factors has recently been reviewed by Jones-Lee and Lee (2001). The ultimate goal of managing eutrophication-related water quality is to assess how the magnitude of the nutrient-caused water quality problem changes with a change in nutrient loads. This requires that an assessment of the cost of nutrient control to achieve desired water quality be developed.

The US EPA's nutrient chemical concentration-based default criteria development approach does not adequately consider the variety of factors that influence how nutrients impact water quality beneficial uses of waterbodies. Not all nutrients above pre-cultural conditions are adverse to water quality. For many waterbodies, nutrients above "background" are beneficial to aquatic life resources. The development of appropriate nutrient criteria requires a balancing of the desired water quality in waterbodies with the cost of controlling nutrients from various sources.

The site-specific nutrient criteria development approach advocated herein is potentially supportable by the US EPA. The Agency staff have, on a number of occasions, indicated that a site-specific approach to development of nutrient criteria for a waterbody or group of waterbodies could be accepted by the Agency, provided that it is based on a "scientifically defensible" approach. Thus far, the Agency has not defined what it means by "scientifically defensible," especially as it relates to situations where a waterbody would have high nutrient concentrations from ag runoff, where the nutrients are stimulating algal growth as measured by planktonic algal chlorophyll, well above those that, in many waterbodies, would cause significant water quality deterioration; however, in the waterbody of concern which has the elevated nutrients and chlorophyll, there is no impairment of the beneficial uses, due to the turbidity derived from erosion in the watershed. This turbidity causes the water to be "brown," with the result that the chlorophyll "greenness" is not manifested. This situation is not atypical of the situation that occurs in many of the major rivers in the US.

An example of this type of situation is the San Joaquin River above the Deep Water Ship Channel near Stockton, California. The public, regulatory agencies, and others do not perceive the San Joaquin River in that region as an impaired waterbody due to excessive nutrients and the associated algal growth, even though the algal concentrations are well-above those that, in some waterbodies, would cause water quality deterioration. It remains to be seen whether the US EPA would allow nitrogen and phosphorus concentrations a factor of 10 or more times the pre-cultural nutrient levels, where planktonic algal chlorophyll has developed to high levels but is not manifested as an impairment of the beneficial uses of the San Joaquin River.

There are, however, impairments of the downstream San Joaquin River Deep Water Ship Channel, due to the elevated nutrients which develop into algae, which, upon reaching the Channel, die and become oxygen demand. Under these conditions, the nutrient criteria development should focus on controlling nutrient discharges in the watershed which could, in turn, limit the algal biomass that enters the Deep Water Ship Channel which leads to DO depletions below the water quality objective. Since, as discussed by Lee and Jones-Lee (2000), the DO depletion problem is a summer-fall problem, there would be no need to limit the high nutrient concentrations associated with winter-spring flows in the San Joaquin River, since there is normally no DO depletion problem in the Deep Water Ship Channel at those times. However, since part of the high winter-spring flows in the San Joaquin River are exported from the Delta by water utilities and stored in water supply reservoirs where excessive algae develop which cause tastes and odors for the water utilities, the nutrient management program could be based on limiting the input of nutrients to the San Joaquin River that lead to excessive algal growths in water supply reservoirs which are principally located in Southern California, hundreds of miles from where the nutrients originated in the San Joaquin River watershed.

Attempts to limit nutrient input to the Delta because of the potential impacts of the nutrients on water supply water quality associated with the export and storage of Delta water in water utility reservoirs could be met with significant opposition by fisheries resource managers, who would see reducing nutrient input to the Delta as being contrary to improved fish production. It is obvious that there will be situations where the development of nutrient criteria, such as in the San Joaquin River watershed and Delta, cannot be meaningfully approached through the US EPA's ecoregion default criteria development approach. It will require a highly sophisticated, carefully-developed evaluation and management of nutrient sources and their impacts to protect the beneficial uses of these waterbodies without unnecessary nutrient control programs.

Conclusions and Recommendations

Excessive fertilization of waterbodies is a major cause of water quality impairment. Agricultural runoff/discharges are significant sources of nutrients which contribute to excessive fertilization of some waterbodies. There is a wide variety of factors that influence how nutrients derived from particular types of sources, such as ag land runoff, impact the fertility of waterbodies receiving this runoff. An area of particular concern to agricultural interests is the availability of phosphorus in ag land runoff to support algal growth in the waters receiving this runoff.

US EPA ecoregion-based nutrient criteria are not based on a technically valid approach for developing appropriate nutrient concentrations to protect the beneficial uses of waterbodies without unnecessary expenditures for chemical constituent control. Those concerned about the management of excessive fertilization in a particular waterbody should work with the waterbody's stakeholders to develop site-specific nutrient control objectives and appropriate control programs to meet these objectives. This is a far more technically valid approach than the US EPA's ecoregion-based default nutrient criteria development approach.

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