Managing Nutrient (N & P) Water Quality Impacts in the Central Valley, CA

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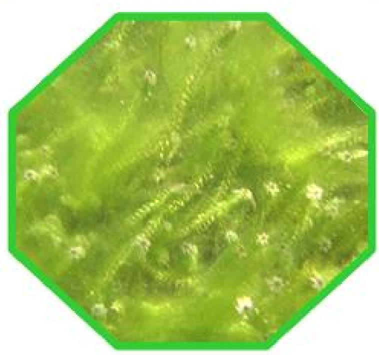
Tastes & Odors

Water Hyacinth on Channel

Algae-Caused Low DO — Fish Kills



Attached Algae

Excerpts from:
Lee, G. F. and Jones-Lee, A., "Review of Management Practices for Controlling the Water Quality Impacts of Potential Pollutants in Irrigated Agriculture Stormwater Runoff and Tailwater Discharges," California Water Institute Report TP 02-05 to California Water Resources Control Board/Central Valley Regional Water Quality Control Board, 128 pp. California State University-Fresno, Fresno, CA, December (2002). Available at: http://www.gfredlee.com/BMP_Rpt.pdf]
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Background to this Report

In 2001 the Central Valley Regional Water Quality Control Board (CVRWQCB) staff requested that Drs. G. Fred Lee and Anne Jones-Lee develop a review of managing excessive fertilization of waterbodies. The State Water Resources Control Board issued a contract to California State University Fresno Water Institute to support Drs. G. Fred Lee and Anne Jones-Lee developing a report on managing water quality problems from irrigated agriculture in California Central Valley. A comprehensive report,

> Lee, G. F. and Jones-Lee, A., "Review of Management Practices for Controlling the Water Quality Impacts of Potential Pollutants in Irrigated Agriculture Stormwater Runoff and Tailwater Discharges," California Water Institute Report TP 02-05 to California Water Resources Control Board/Central Valley Regional Water Quality Control Board, 128 pp, California State University Fresno, Fresno, CA, December (2002).
> http://www.gfredlee.com/BMP_Rpt.pdf

Included in this report were sections devoted to managing excessive fertilization of waterbodies with emphasis on non-point sources of nutrients such as runoff/discharges from irrigated agriculture. The report presented herein is derived from those sections of the overall report.

Dr. G. F. Lee's work on investigating and managing aquatic plant nutrient runoff from agricultural, forest, and urban stormwater and domestic and industrial wastewater sources began in the early 1960s. A major thrust of this work was devoted to developing information that can be used to manage excessive fertility in waterbodies. Drs. G. F. and A. J. Lee have published over 150 papers and reports on these issues. Many of their publications are available on their website, www.gfredlee.com at http://www.gfredlee.com/pexfert2.htm.

In the mid-1970s, Dr. Lee was selected by the US EPA to develop the US part of the Organization for Economic Cooperation and Development (OECD) international eutrophication study. This study involved cooperative investigation was a $50-million effort conducted by 22 countries in western Europe, North America, Japan and Australia, over a five-year period, specifically examining the relationship between nitrogen and phosphorus loads to waterbodies – especially lakes and reservoirs – and their eutrophication-related water quality responses, focusing on the growth of planktonic algae. The US part of this study involved investigation of about 100 waterbodies located throughout the country, where Dr. Lee and his graduate student (Walter Rast) compiled a synthesis of the information that was generated on each of these waterbodies by investigators of the waterbodies that were included in the US part of the OECD Eutrophication Study Program. This synthesis is published as Rast and Lee (1978). Dr. Lee was appointed by the US EPA to be the US representative to the international OECD Eutrophication Study steering committee. As a member of this committee, he was responsible for helping to organize the overall studies and review and report on the results. This study was published by OECD (1982).

Drs. Lee and Jones-Lee continued to be active in post-OECD eutrophication studies, where, through their work in other parts of the world, they continued to compile data on nutrient load-eutrophication response relationships. Through this effort they expanded the original OECD database from 200 waterbodies to now over 750 waterbodies located throughout most parts of the world. These results have been published by Jones and Lee (1982, 1986).

In 1989, Drs G. F. Lee and Anne Jones-Lee terminated their environmental engineering/science graduate level university teaching and research careers and moved to El Macero, CA (near Davis) where they became full-time consultants in various aspects of water quality management. During the past 18 years they have been active in Central Valley water quality issues in the Sacramento and San Joaquin River watersheds and the Delta. A considerable part of their consulting and committee activities has been devoted to aquatic plant nutrient water quality management issues.

Executive Summary

Nutrients

Excessive fertilization (eutrophication) is one of the most common and significant causes of impairment of beneficial uses of waterbodies. Excessive fertilization of waterbodies can have a significant adverse impact on a waterbody's water quality. As a result of the widespread occurrence of excessive fertilization of waterbodies, the US EPA has initiated development of chemical-specific numeric nutrient (nitrogen and phosphorus compounds) water quality criteria designed to be the control objective for excessively fertile waterbodies. These criteria will be used to establish state water quality standards, where exceedance of the standard will be used to designate Clean Water Act 303(d) "impaired" waterbodies that will lead to the need to implement a TMDL to achieve the nutrient water quality standard. The US EPA has established 2004 as the date by which state regulatory agencies must have made significant progress toward adopting chemical-specific nutrient criteria/standards. By the mid 2000s, there could be a large number of additional waterbodies in the Central Valley of California and nationally, beyond those already classified as impaired due to excessive concentrations of nutrients that need to have TMDLs developed and implemented in order to satisfy nutrient control requirements.

While, until now, nutrient management programs have largely focused on treating domestic and industrial wastewater discharges for nutrient removal, in the future, nonpoint runoff/discharges will also have to be treated/managed to prevent excessive fertilization of the waterbodies receiving the runoff/discharges. The current and future nutrient control programs for irrigated agriculture stormwater runoff/tailwater discharges will create a significant demand for reliable information on BMPs to control nutrient discharges in a technically valid, cost-effective manner.

At this time there is limited information on the efficacy and cost-effectiveness of various stormwater runoff/tailwater discharge water quality BMPs, such as vegetative cover, buffer strips, grassy swales, detention basins, etc, that are often listed as water quality BMPs that can be used to control nutrients and, for that matter, other constituents in agriculturally-derived stormwater runoff/discharges from irrigated and non-irrigated agriculture in the Central Valley of California. Central Valley irrigated agriculture, in many respects, is significantly different from agriculture in other parts of the country. This difference arises from the significantly different climate in this area where precipitation occurs for a few months each winter. This necessitates crop irrigation, which leads to irrigation field (tailwater) discharges during the late spring and summer. The tailwater discharges have a significantly different potential pollutant composition than stormwater runoff. There is need for guidance on how to properly develop nutrient control BMPs that will control the nutrient runoff/discharges in the Central Valley to a specified degree in a cost-effective manner. This report provides guidance on approaches that could be used to develop appropriate nutrient management programs/BMPs for agricultural runoff/discharges.

The development of technically valid, cost-effective waterbody excessive fertilization management programs is technically different than most other pollutant control programs. Excessive fertilization problems can occur long periods of time after nutrient release/discharge and at considerable distances downstream. This makes directly relating nutrient releases/discharges to impacts on water quality more difficult. Another complicating factor in developing nutrient management programs is that the impacts of excessive fertilization are often subjective and are dependent on the public's response to the aquatic plant biomass in the waterbodies of the area. The often remote but real connection between nutrient concentrations/ loads in discharges from an area and the social impact in another downstream area can readily cause the US EPA's proposed chemical-specific numeric nutrient criteria to be technically invalid. Because of the complexity of excessive fertilization, the development of a technically valid, cost-effective nutrient management program often requires a substantially larger information base on the characteristics of nutrient releases and downstream waterbodies than is typically needed for management of toxic pollutants.

The approach that should be followed in developing a BMP to control nutrient runoff/discharges is similar to the approach that is used to develop a nutrient control program to meet a TMDL requirement to control excessive fertilization of a waterbody. In developing the appropriate nutrient criteria BMP control objective, it is suggested that the TMDL development approach is an appropriate approach to follow. This approach involves the following steps:

- Developing a problem statement − i.e., what is the excessive fertilization problem of concern?
- Establishing the goal of nutrient control (i.e., the desired eutrophication-related water quality).
- Determining nutrient sources, focusing on available forms.
- Establishing linkage between nutrient loads and eutrophication response (modeling).
- Developing and initiating a Phase I nutrient control implementation plan to control the nutrients to the level needed to achieve the desired water quality. This will require the selection, implementation, and evaluation of various nutrient control methodologies (BMPs).
- 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, initiate a TMDL implementation 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 waterbody of concern 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 nutrient-related desired water quality and thereby establish the allowable nutrient loads which can be translated to in-waterbody concentrations and, therefore, the nutrient criteria that are appropriate for the waterbody. This information can then be used to develop appropriate BMPs for the location and type of agriculture being practiced in the area of concern. Information on several of these issues is presented in this report.

Because of the importance of the US EPA's efforts to develop nutrient criteria to regulate nutrient discharges, which in turn will control the development of appropriate BMPs, this report includes a discussion of the problems with the US EPA's current approach for developing nutrient criteria, as well as a recommended approach for determining the allowable nutrient discharges from a source that will protect the eutrophication-related water quality of downstream waterbodies. The US EPA has adopted two approaches for developing nutrient water quality criteria/standards. One of these is the Agency's "default" approach, where emphasis is on assessing the pre-cultural nutrient concentrations in a waterbody as a basis for establishing the allowable nutrient concentrations. The US EPA's proposed approach for developing default nutrient criteria is recognized as technically invalid by many who are familiar with how nutrients impact water quality. The Agency's approach could result in massive expenditures for nutrient control from point and nonpoint sources beyond that which is needed to achieve the desired nutrient-related beneficial uses of a waterbody. Further, this approach could be significantly detrimental to the aquatic life (fisheries)-related beneficial uses of waterbodies, as a result of adversely impacting the trophic structure of waterbodies.

The Agency's other proposed approach for developing nutrient criteria/standards potentially involves the regulatory agencies and the regulated community, as well as others interested, working together to develop site-specific nutrient criteria/standards for a waterbody or group of similar waterbodies. According to the US EPA, the site-specific criteria development approach must be "scientifically defensible." The Agency; however, does not define what that means. This report discusses recommended approaches for developing site-specific nutrient criteria that will protect the nutrient-related beneficial uses of a waterbody without significant unnecessary expenditures for nutrient control, through the implementation of BMPs. The nutrient control section of this report is based on 42 years of the senior author's experience in investigating and managing excessive fertilization of waterbodies in the US and many other countries. Background information on these issues is provided on the authors' website, www.gfredlee.com.

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Acronyms and Abbreviations

ac	acre
ac-ft	acre-feet
ag	agriculture
AMD	acrylamide
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BMPs	best management practices
BOD	biochemical oxygen demand
BOD_5	five-day BOD
BOD_{10}	ten-day BOD
BOD_u	BOD ultimate (~30-Day)
CBOD	carbonaceous BOD
cfs	cubic feet per second
CO_2	carbon dioxide
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region (RWQCB)
CTR	California Toxics Rule
CWA	Clean Water Act
DFG	California Department of Fish and Game
DO	dissolved oxygen
DOC	dissolved organic carbon
DWSC	Deep Water Ship Channel of the San Joaquin River, near Stockton, CA
EC	electrical conductivity
ft	feet
ft/sec	feet per second
g	grams
H_2O	water
ISWP	Inland Surface Waters Plan
lbs/day	pounds per day
MCL	maximum contaminant level
m^2	square meters
mg/L	milligrams per liter
mi	miles
µg/L	micrograms per liter
µmhos/cm	micromhos (reciprocal ohms) per centimeter
MPN	most probable number
µS/cm	microsiemens per centimeter
m/sec	meters per second
N	nitrogen
NBOD	nitrogenous BOD
ng/L	nanograms per liter
NH_3	un-ionized ammonia or ammonia, which is the sum of NH_3 plus NH_4^+
nitrate-N	nitrate-nitrogen
NO_2^-	nitrite
NO_3^-	nitrate

Acronyms and Abbreviations (continued)

NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NRCS	National Resources Conservation Service
NTU	Nephelometric turbidity units
O_2	oxygen
OCls	organochlorine pesticides and PCBs
OP	organophosphate pesticide
Org N	organic nitrogen
P	phosphorus
PAHs	polynuclear aromatic hydrocarbons
PAM	polyacrylamide
PCBs	polychlorinated biphenyls
PI	phosphorus index
ppt	parts per thousand (salinity)
ppt	parts per trillion (ng/L) (concentrations of chemicals)
RWQCB	Regional Water Quality Control Board, Central Valley Region
SAR	sodium adsorption ratio
SCS	Soil Conservation Service
SJR	San Joaquin River
SJR TAC	San Joaquin River DO TMDL Technical Advisory Committee
SOD	sediment oxygen demand
SRWP	Sacramento River Watershed Program
SWAMP	surface water ambient monitoring program
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
THM	trihalomethane (chloroform and chloroform-like compounds)
TIE	toxicity identification evaluation
TKN	total Kjeldahl nitrogen = NH_3 plus OrgN
TMDL	total maximum daily load
TOC	total organic carbon
TON	threshold odor number
TSS	total suspended solids
TUa	toxic units (acute)
USBR	US Bureau of Reclamation
USDA	US Department of Agriculture
US EPA	US Environmental Protection Agency
USGS	US Geological Survey
VSS	volatile suspended solids
WDR	waste discharge requirement
WQO	water quality objective
WWTP	wastewater treatment plant (domestic)

Aquatic Plant Nutrients

Aquatic plant nutrients (nitrogen and phosphorus compounds) are a major cause of water quality use impairment in the San Joaquin River watershed, the Delta, and in water supply reservoirs for water utilities that use Delta water as a raw water source. The Delta experiences excessive growth of water hyacinth, *Egeria densa* and other aquatic plants which impair recreational use of the Delta waters. Algae develop in water utility water supply reservoirs that use Delta water as a raw water source that cause taste and odor problems in the treated waters. Agricultural activities in the San Joaquin River watershed and Delta are major sources of aquatic plant nutrients that lead to these water quality use impairments.

The San Joaquin River Deep Water Ship Channel (DWSC), during the summer and fall, experiences dissolved oxygen concentrations below water quality objectives that arise in part from algae that develop in the San Joaquin River watershed waterbodies. Gowdy (2002) has recently reviewed this situation. The nutrient sources for these algae are primarily derived from agricultural tailwater and subsurface drain water discharges. The algae that develop in the San Joaquin River and it tributaries are transported to the DWSC, where they die and decompose leading to depressed dissolved oxygen concentrations. This situation has led to the development of a TMDL that would include evaluating the potential for nutrient control from agricultural tailwater and subsurface drain water discharges in the Mud and Salt Slough watersheds. There is need to evaluate management practices that can be applied to agricultural lands for nutrient control in these watersheds.

As discussed in a subsequent section of this report, the excessive fertilization of a waterbody can lead to significant water quality problems for aquatic life, through low dissolved oxygen, violation of the pH water quality objective, altered aquatic life habitat and impaired use of the water for domestic water supplies and recreation. While some fertilization of waterbodies can be beneficial to the waterbody's fisheries, excessive fertilization can be detrimental to the development of a desirable fishery.

The US EPA, as part of developing a more effective national and local waterbody excessive fertilization control program, is requiring that all states develop chemical-specific numeric water quality standards that can be used to manage excessive fertilization of waterbodies. The implementation of nutrient-based water quality standards could lead to increased listing of waterbodies as Clean Water Act 303(d) impaired waterbodies due to excessive fertilization, which in turn will lead to TMDLs that are designed to control excessive concentration of nutrients and their water quality impacts through the growth of excessive aquatic plants in the Central Valley.

NCSU (2000) presents a summary of the management measures for nutrients derived from agricultural lands. These are presented below.

> "***Management Measure for Nutrients***
>
> *Develop, implement, and periodically update a nutrient management plan to: (1) apply nutrients at rates necessary to achieve realistic crop yields, (2) improve the timing of nutrient application, and (3) use agronomic crop production technology to increase*

nutrient use efficiency. When the source of the nutrients is other than commercial fertilizer, determine the nutrient value and the rate of availability of the nutrients. Determine and credit the nitrogen contribution of any legume crop. Soil and plant tissue testing should be used routinely. Nutrient management plans contain the following core components:

1. *Farm and field maps showing acreage, crops, soils, and waterbodies. The current and/or planned plant production sequence or crop rotation should be described.*
2. *Realistic yield expectations for the crop(s) to be grown, based primarily on the producer's actual yield history, State Land Grant University yield expectations for the soil series, or local NRCS information for the soil series.*
3. *A summary of the nutrient resources available to the producer, which at a minimum include:*
   - *Soil test results for pH, phosphorus, nitrogen, and potassium;*
   - *Nutrient analysis of manure, sludge, mortality compost (birds, pigs, etc.), or effluent (if applicable);*
   - *Nitrogen contribution to the soil from legumes grown in the rotation (if applicable); and*
   - *Other significant nutrient sources (e.g., irrigation water, atmospheric deposition).*
4. *An evaluation of field limitations based on environmental hazards or concerns, such as:*
   - *Sinkholes, shallow soils over fractured bedrock, and soils with high leaching potential'*
   - *Lands near surface water;*
   - *Highly erodible soils;*
   - *Shallow aquifers;*
   - *Combinations of excessively well drained soils and high rainfall seasons, resulting in very high potential for surface runoff and leaching; and*
   - *Submarine seeps, where nutrient-laden ground water from upland areas can directly enter the ocean through tidal pumping (e.g. along the coastline of Maui, Hawaii).*
5. *Use of the limiting nutrient concept to establish the mix of nutrient sources and requirements for the crop based on a realistic yield expectation*
6. *Identification of timing and application methods for nutrients to provide nutrients at rates necessary to achieve realistic crop yields, reduce losses to the environment, and avoid applications as much as possible to frozen soil and during periods of leaching or runoff*
7. *Provision for the proper calibration and operation of nutrient application equipment."*

The NCSU (2000) report provides a discussion of each of these management measures and should be consulted for additional information on them. The report also provides a summary of experiences obtained in various areas using the various nutrient management measures; however, few of these experiences are applicable to the situation in the Central Valley.

The US EPA (NCSU, 2000) discussion of the current information on BMPs to control potential pollutants derived from agricultural lands includes a discussion of "precision farming" as a means of potentially reducing the N and P export from agricultural lands. Based on a recent review of information on high-tech crop production, it appears to be possible to significantly increase the yields of certain crops by what is being called "precision farming" approaches. Basically, this approach involves detailed soil mapping of the nutrient characteristics of the soil to provide for nutrient addition to specific areas where there is a deficiency, proportional to the deficiency. This approach maximizes the crop yield for the fertilizer applied. It apparently can at the same time result in reduced nutrient losses from the land to surface and ground waters. Presented below is a write-up on precision farming that was developed by the North Carolina State University Water Quality Group for the US EPA.

"Precision Farming - A New Era of Production

The Precisely Tailored Practice

Precision farming, also known as site-specific management, is a fairly new practice that has been attracting increasing attention both within and outside the agricultural industry over the past few years. It is a practice concerned with making more educated and well-informed agricultural decisions. Precision farming provides tools for tailoring production inputs to specific plots (or sections) within a field. The size of the plots typically range from one to three acres, depending on variability within the field and the farmer's preference. By treating each plot as much or as little as needed, farmers can potentially reduce the costs of seed, water, and chemicals; increase overall crop yields; and reduce environmental impacts by better matching inputs to specific crop needs. Rather than applying fertilizer or pesticides to an entire field at a single rate of application, farmers first test the soil and crop yields of specific plots and then apply the appropriate amount of fertilizer, water, and/or chemicals needed to alleviate the problems in those sections of the field. Precision farming requires certain technology, which is an added cost, as well as increased management demands.

The Computer-Aided Approach

The approach of precision farming involves using a wide range of computer-related information technologies, many just recently introduced to production agriculture, to precisely match crops and cultivation to the various growing conditions. The key to successfully using the new technologies available to the precision farmer to maximize possible benefits associated with this approach is information. Data collection efforts begin before crop production and continue until after the harvest. Information-gathering technologies needed prior to crop production include grid soil sampling, past yield monitoring, remote sensing, and crop scouting. These data collection efforts are even further enhanced by obtaining precise location coordinates of plot boundaries, roads, wetlands, etc., using a global positioning system (GPS).

* * *

Although precision farming has not yet been widely adopted to date, this practice continues to attract increasing attention both on and off the farm. Much of the off-the-farm enthusiasm for precision farming can be attributed to the eminent good sense of matching input application to plant needs. Precision farming is simply a more finely tuned version of the kinds of BMPs already recommended at the field level. Because this technology is still somewhat new to the industry, there is much more to learn about the potential overall impact *of precision farming on water and air quality relative to conventional techniques. But one thing is certain: precision farming has the potential to enhance economic return (by cutting costs and raising yields) and to reduce environmental risk (by reducing the impacts of fertilizers, pesticides, and erosion).”*

In August 2001 the American Chemical Society Agrochemical Division held a symposium on phosphorus control from agricultural lands. Lee and Jones-Lee (2002c) presented a paper at this symposium on “Assessing the Water Quality Impacts of Phosphorus in Runoff from Agricultural Lands.” Several of the papers presented at this symposium were devoted to precision farming as a means of reducing nutrient runoff and increasing crop yield. The proceedings of this symposium are in press by the American Chemical Society.

As part of developing nutrient control programs from agricultural lands, precision farming should be examined for selected areas in the watershed and for selected crops and soil types to determine if increased crop yield can result in increased profit to pay for the precision farming data requirements and, at the same time, reduce the amounts of nutrients contributed from the precision-farmed area, compared to conventional farming techniques. Adopting this approach should lead to a better understanding of factors that influence nutrient export from various areas and crops.

The USDA National Resources Conservation Service (NRCS) website (http://www.nrcs.usda.gov/technical/ecs/nutrient/590.html) contains a discussion on nutrient management. The NRCS recommends that a plan for nutrient management should be developed which specifies the form, source, amount, timing and method of application of nutrients on each field to achieve realistic production goals while minimizing nitrogen and/or phosphorus movement to surface and/or ground waters. NRCS also indicates that erosion, runoff, and water management controls shall be installed, as needed, on fields that receive nutrients. The NRCS nutrient management program includes:

- Soil sampling and laboratory analysis
- Plant tissue testing
- Assessment of nutrient application rates
- Nutrient application timing and
- Nutrient application methods.

The NRCS provides additional guidance on manure or organic byproducts applied as plant nutrients.

The US Department of Agriculture (USDA-SCS, 1992) has developed guidance on minimizing P losses from fertilized fields. The USDA Recommended Best Management Practices for phosphorus fertilization include the following:

“Phosphorus BMPs

4.1 Sample the tillage layer of soil in each field on a regular basis and have soil analyzed to determine available soil P levels prior to applying P fertilizer.

4.2 *Credit all available P from manures and other organic residues to the P requirement for the crop.*

4.3. *Fertilize soils with 'low' to 'medium' P soil test values using environmentally and economically sound agronomic guidelines. In general, soils testing 'high' will not respond to additional P and should not receive fertilizer unless a banded starter is needed to compensate for low soil temperatures. Phosphorus fertilizers should not be applied to soils testing 'very high' for soil P.*

4.4 *Divide large, non-uniform fields into smaller fertility management units based upon yield potential or soil type and fertilize according to P levels determined through soil analysis.*

4.5 *Apply P fertilizers where they can be most efficiently taken up by the crop. Band application of P in the root zone reduces surface loss potential and enhances nutrient availability, especially in cold or P deficient soils.*

4.6 *Incorporate surface applied P into the soil where any potential for surface runoff or erosion exists.*

4.7 *Minimize soil erosion and corresponding P losses by establishing permanent vegetative cover, conservation tillage and residue management, contour farming, strip cropping, and other management practices as feasible. When erosion potential is severe, install structures such as diversions, terraces, grass waterways, filter fences, and sediment basins. Contact your local SCS office if you need assistance in evaluating erosion potential and control options.*

4.8. *Maintain a buffer strip (where fertilizer and manure is not applied) a safe distance from surface water and drainage channels.*

4.9 *Maintain grass filter strips on the downhill perimeter of erosive crop fields to catch and filter P in surface runoff.*

4.10 *Manage irrigation water to minimize runoff and erosion by meeting the Irrigation BMPs or the SCS approved Irrigation Water Management practice standard and specification."*

Osmond and Gilliam (2002) have discussed the potential benefits of riparian forest buffer systems to control nutrients lost from agricultural lands from entering a watercourse. These systems consist of grasses, trees, shrubs and other vegetation growing along streams. According to Osmond and Gilliam (2002), these vegetative buffers:

- *"Protect water resources from nonpoint source pollutants, such as sediment and nutrients,*
- *Moderate fluctuations in stream temperature,*
- *Control light quantity and quality in the stream,*
- *Enhance habitat diversity,*
- *Stabilize stream banks and modify channel morphology, and*
- *Enhance food webs and species richness."*

Osmond and Gilliam discuss that there are many factors that determine the effectiveness of riparian buffers in removing agriculturally derived pollutants, with the most important factor being the hydrology of how water moves through or over the buffer.

The agricultural community in the Neuse River Basin in North Carolina is required by state regulations to reduce the nitrogen loading to the Neuse River by 30 percent by 2003. Wossink and Osmond (2002) have provided information on BMPs that can be used to affect nutrient reduction from agricultural lands.

Table 2 is from the Wossink and Osmond website summary of nitrogen BMPs that are effective in the Neuse River Basin.

Table 2

BMPs in the Neuse River Basin and their Effectiveness in Nitrogen Reduction

Design	N-reduction[d]
Trees 30 ft + grass 20 ft[a]	85 %
Tree buffer ≥ 20 ft	75 %
Shrub buffers ≥ 20 ft	75 %
Grass buffers ≥ 30 ft	65 %
Filter strips ≥ 20 ft[b]	40 %
Nutrient management	Variable
Cover crop	5-15 %
No-till or strip-till (corn only)	15 %
Controlled drainage[c]	40 %

a. The forested area is next to the stream, and the grass area is away from the stream.

b. Only effective if the drainage area above the filter strip has greater than 1 % but less than 10 % slope. Filter strips must be planted with permanent vegetation (grass, legumes, and/or other forbs).

c. Only effective if the slope in the channel is less than 1 % and the water table can be kept within 36” of surface soil for 50 % of field area.

d. Reduction rates are based on research and approval of the Neuse Basin Oversight Committee.

Source: Based on decisions by the Neuse River Basin Oversight Committee

In the North Carolina climatic regime, vegetative buffer strips can be effective in reducing the nitrogen export from agricultural lands. Wossink and Osmond have indicated that the installation costs for BMPs in the Neuse River Basin were about $19 per acre, with an annual maintenance cost of $1.25 per acre. These costs are not necessarily applicable to the San Joaquin River watershed. Site-specific BMPs that cover the San Joaquin River watershed’s characteristics need to be evaluated to determine the cost of their construction and operation. It is of interest to note that the state of North Carolina is providing cost-share programs to help agriculture fund BMPs.

Cole, *et al.* (1997) has provided information on the influence of vegetative buffers for the removal of chlorpyrifos, other pesticides and nutrients in Oklahoma. They found that vegetative buffers were effective in reducing pesticide and nutrient runoff due, in part, to dilution. Boyd, *et al*. (1999) examined the ability of vegetative filter strips to remove several pesticides, including chlorpyrifos, in Iowa. They found higher infiltration rates of water and pesticides into the soil due to lower water velocity in the runoff. They reported that chlorpyrifos removal, which was primarily associated with chlorpyrifos sorbed on sediments, was controlled by sediment retention by the vegetative strip.

A search of the Internet reveals that many of the state university agricultural extensions have developed websites where they provide information on BMPs pertinent to the control of various potential pollutants in agricultural stormwater runoff. An example of this type of situation is the Ohio State University Extension (Leeds, *et al*., 2002; Brown, *et al*., 2002). Similar information has been provided by the Colorado State University agricultural extension and the University of Idaho Cooperative Extension System (2002) College of Agriculture. A review of the publications from these university extensions shows that they all provide about the same information with respect to BMPs for controlling potential pollutants in agricultural stormwater runoff/discharges. Much of it is similar in content to the USDA-SCS BMP guidance discussed above.

Wu, *et al.* (2002) discussed the experience that has been gained in attempting to develop BMPs to control nutrient runoff from irrigated agriculture in the Orange County Upper Newport Bay watershed. Polyacrylamides (PAM) were applied to various test areas, with the goal of reducing nutrients, particularly phosphorus, associated with sediment transport that is found in tailwater from areas which are devoted to growing strawberries. PAM is a coagulating agent which causes the soil particles to aggregate, and, therefore, tend to stay in place or settle out on the field, rather than be present in the tailwater discharges. The results of the Wu, *et al*. (2002) studies on the use of polyacrylamides to control erosion and the associated phosphorus were inconclusive because of problems with application.

Robins, *et al.* (2002) reported that they had conducted a search of the literature for information on TMDLs that would be applicable to irrigated agriculture in the Central Valley. Based on this research, they concluded that there is essentially no information on this topic. This led the Yolo County Resource Conservation District to obtain funds from CALFED to undertake a one-year study of various BMPs for irrigated agricultural runoff in Yolo County.

The Yolo County Resource Conservation District (Yolo RCD, 2002) studied runoff from plots, several of which had cover crops planted, compared to runoff from fallow land. The runoff samples were analyzed for nitrate, phosphate, ammonia and sediment. Problems were encountered in attempting to sample the runoff with the samplers used by the Yolo RCD. The cover crop plot had 46 percent lower sediment discharge than the fallow land. The results of the nutrient analysis from the two types of plots were confusing, in that sometimes higher nitrate concentrations were found from the fallow land than from the cover crop land, while at other times the reverse was true. The Yolo RCD speculated that there may have been some nitrogen fixation occurring in the cover crop plots, which would increase the nitrogen runoff compared to the fallow land.

The Yolo RCD (2002) conducted studies on the impact of sediment traps on tailwater releases/stormwater runoff. The various sediment traps studied by the Yolo RCD had a 0.1 to 1.6 ton/acre trapping of suspended sediment. Typically, the percent of sediment captured ranged from about 60 to 86 percent, with the highest efficiency early in the season and the efficiency dropping off during the course of the season. In general, it was concluded that all of the sediment traps studied were not large enough to provide a high degree of sediment trapping.

For the three measurable storms studied by the Yolo RCD, the cover crop treatment reduced total runoff by 71 percent in one storm and increased it by 37 percent in another storm. Peak runoff was delayed by 15 to 20 minutes. Peak runoff was reduced by 0 to 20 percent in the cover crop area. The average sediment concentrations in the runoff waters for the two storms were reduced by 17 to 46 percent. The average nutrient (nitrate and ammonia) concentrations in the runoff water were reduced in one storm by 43 and 49 percent, respectively; however, in the same event, higher runoff was observed from the cover crop treatment.

With respect to nutrient control, there was some attenuation of ammonia and nitrate at the beginning of the season; however, by later in the season, the sediment traps did not significantly remove nitrate or ammonia from the tailwater. The phosphate data were inconsistent and inconclusive.

The sediment traps retained from a minus 13 percent for a full trap actually contributing sediment to the tailwater, to 98 percent retention near the beginning of an irrigation season. During mid-season, sediment traps were removing 33 to 55 percent of the sediment in many of the ponds. Nutrient removal in the ponds was inconsistent. The tailwater ponds captured 11 to 97 percent of the sediment, with one pond discharging 39 percent greater sediment than the inflow.

While not in their CALFED report, the Yolo County RCD prepared a summary of the cost of construction of the various systems studied. Their table of costs is presented in Table 3.

Angermann, *et al.* (2002) reported on the hydrologic response patterns of three ground treatments relative to water movement over and through resident vegetation, bare soil and ripped resident vegetation. This study has relevance to the runoff/infiltration of pesticides, nutrients, and other pollutants used in Central Valley orchards. They found infiltration for ripped resident vegetation was approximately an order of magnitude greater than for bare soil. Resident vegetation yielded intermediate results. Under near-saturated soil-water conditions, the differences in the response patterns between resident vegetation and bare soil were markedly decreased.

Knell and Snyder (1998) reported on some of the problems in developing and implementing agricultural drain water quality improvement in the Imperial Irrigation District (IID) in the Imperial Valley of California. They discussed their experience in developing BMPs to control nutrient input to the Salton Sea in the Southern California desert from the Imperial Irrigation District. Overall, limited success has been achieved thus far in this effort. Knell and Setmire (1998) reported that IID, in cooperation with the Bureau of Reclamation, is conducting a $2-

million, three-year study devoted to investigating the feasible methods for managing water quality issues associated with agricultural drain water. Since the original report was prepared in 1997, the results of this three-year study should soon become available and be incorporated into the Colorado River Basin Regional Water Quality Control Board's Salton Sea Nutrient TMDL. The BMP development activities of the Colorado River Basin Regional Water Quality Control Board should be periodically reviewed, through the Salton Sea Nutrient TMDL Advisory Committee activities, since this nutrient control effort is somewhat ahead of the Central Valley Regional Board's in developing BMPs to control nutrient releases from irrigated lands.

N. Rothfleisch and J. Smith presented "Suggested Best Management Techniques for the Salton Sea Nutrient TMDL" at the September 25, 2002, meeting of the Technical Advisory Committee for the California Regional Water Quality Control Board, Colorado River Basin Region, devoted to development and implementation of a nutrient total maximum daily load for the Salton Sea. Rothfleisch is with Imperial County Farm Bureau and Smith is with NRCS/USDA. A printout of their PowerPoint slide presentation was made available for review.

Table 3
Tailwater Pond Installation and Maintenance Costs (1999)
With Return System and Banks Vegetated for Wildlife Benefit

Task	**Cost/Unit in $**		**Units**		**Total Cost in $**	
	Low	**High**	**Low**	**High**	**Low**	**High**
Pond						
Planning/Engineering	50.00	50.00	10	10 hours	500.00	500.00
Pond Excavation & pipe install[1]	1.15	1.40	2500	7500 cu. yds.	2,875.00	10,500.00
Flashboard riser[2]	175.00	525.00	1	1 each	175.00	525.00
Pipe/Barrel extension[3]	9.00	15.00	20	100 feet	180.00	1,500.00
subtotal pond construction cost					*3,730.00*	*11,525.00*
Return System						
Lay pipe		2.00	1800	1800 feet	3,600.00	3,600.00
Return pipe materials[4]	1.25	1.35	1800	1800 feet	2,250.00	2,430.00
Pump installed[5]	4,000.00	10,000.00	1	1 each	4,000.00	10,000.00
subtotal return system construction					*9,850.00*	*16,030.00*
Vegetation Management						
Planning & design	50.00	50.00	2	6 hour	100.00	300.00
Bed preparation	50.00	50.00	1	2 hour	50.00	100.00
First weeds spray[6]	25.00	25.00	1	1 hour	25.00	25.00
Herbicide material	60.00	60.00	0.125	0.25 gallons	7.50	15.00
Seeding/incorporation	25.00	25.00	1	3 hours	25.00	75.00
Seed (20-30 #/ac. for 0.25 ac.)[7]	10.00	30.00	5	7.5 pounds	50.00	225.00
Winter weed mgmt.(spot spray)	10.00	10.00	1	2 hour	10.00	20.00
Broadleaf herbicide	22.00	22.00	0.125	0.25 gallons	2.75	5.50
Spring weed mgmt.(spot spray)	10.00	10.00	1	2 hour	10.00	20.00
Broadleaf herbicide	22.00	22.00	0.125	0.25 gallons	2.75	5.50
Mowing	40.00	40.00	1	2 hour	40.00	80.00
Spot weeding (hand crew)	10.00	10.00	15	35 hours	150.00	350.00
Irrigation Set-up (drip system)						
Small pump (for multiple sites)	300.00	800.00	1	1 each	300.00	800.00

Irrigation supplies	150.00	150.00	1	1 each	150.00	150.00
Installation labor	10.00	10.00	5	15 hours	50.00	150.00
Irrigation labor	10.00	10.00	5	20 hours	50.00	200.00
Additional plantings:						
Plants (Trees & shrubs)	1.50	2.50	25	50 starts	37.50	125.00
Waterline plants (rushes/sedges)	0.20	0.40	100	300 plugs	20.00	120.00
Labor	10.00	10.00	4	8 hours	40.00	80.00
subtotal vegetation cost					*1,120.50*	*2,846.00*
Total Installation Cost					**$14,700.50**	**$30,401.00**

(See endnotes on following page) *SOURCE: Yolo RCD (1999)*

Table 3 (Continued)

Annual Management (First 3 years)						
2nd Fall pre-emergent[8]	0	75.00	0	1 treatment		75.00
Application labor	10.00	10.00	0	2 hours		20.00
Winter spot spraying	10.00	10.00	2	4 hours	20.00	40.00
Material	22.00	90.00	0.125	0.25 gallon	2.75	22.50
Spring mowing	40.00	40.00	1	2 hour	40.00	80.00
Irrigation for trees and shrubs (6x)	10.00	10.00	4	8 hours	40.00	80.00
Dredging of pond or sed. Ditch	50.00	50.00	2	6 hours	100.00	300.00
Initial Annual Maintenance Costs					*202.75*	*617.50*
Perpetual Maintenance Costs (Beyond 3 years)						
Winter spot spraying[9]	10.00	10.00	0	4 hours		40.00
Material	22.00	90.00	0.125	0.25 gallon	2.75	22.50
Spring mowing	40.00	40.00	1	2 hour	40.00	80.00
Dredging pond or sed. ditch[10]	50.00	50.00	2	6 hours	100.00	300.00
Total Perpetual Annual Maintenance Costs					*142.75*	*442.50*
Annual Cost of Project Averaged Over Ten Years					**$1,630.80**	**$ 3,535.10**
Annual savings on irrigation water with return system						
(for 100ac. tomatoes w/water cost of $15/ac.ft.):						**$2,000.00**

SOURCE: Yolo RCD (1999)

Endnotes:

[1]This includes cutting the trench and setting in a flash board riser inlet. Cost per cubic yard of soil moved varies depending on the equipment required. A belly scraper type excavator and bulldozer may cost around $1.10 per cubic yard, while a bucket excavator is in the range of $1.40 per yard. A bucket excavator would be necessary in locations with shallow ground water. Often, as much as can be dug with bulldozer and scraper will be done until a bucket excavator is needed. This helps to reduce project cost/time.

[2]The size of the flash board riser depends on the peak flow anticipated through the pond. Your local NRCS field office can assist you in determining this. Risers are available in plastic and corrugated metal pipe (CMP). In corrosive soils, the NRCS requires (for cost share assistance) dipping CMP pipes and risers in hot asphalt, which adds about 25% to the item cost. Costs in this row reflect the range associated with item size and composition.

[3]This cost range reflects between 15" CMP (not dipped) and 18" CMP dipped in hot asphalt. Length of pipe depends on pond design.

[4]This estimate is for 8" or 10" PVC low-head pipe run underground to the top of a field with a 1/4 mile run. In a flat enough field, water could be returned to the head with a reverse ditch, but it moves slowly and will seep a lot of water unless it is lined. It also requires periodic cleaning and recutting.

[5]The range of installed pump costs is that between a 5 Hp submersible electric capable of 520 gpm with 20' of lift and a diesel motor, pump and suction line. The latter is much more costly, but it can be used at multiple sites.
[6]Mechanical means of weed control can substitute for the chemical means in this example. To minimize post-project weed pressure, the project site should be kept clean of weeds for at least one season before breaking ground. After the pond is built and ground prepared, it is best to let fall rains bring up the first weeds, kill them, and then plant.
[7]Prices for native grass seed vary greatly between species, from $5 to $50 per pound. The appropriate mix for a site depends on pond design, soil, and climatic conditions. Broadcast seeding rates can also be varied, depending on the project goals, but under 20 pounds per acre is not recommended.
[8]If annual weed pressure is tremendous, application of a preemergence herbicide can offer relief to a young native grass stand. However, the herbicide will also suppress any germination of native grass seed produced in the first year.
[9]Spot treatment of weeds is necessary in order to suppress undesirable broadleaf and grass weeds. This example gives a range of costs from a common broadleaf herbicide to that of a glyphosate/oxyflourfen mix. Spot treatment can also be accomplished manually and/or mechanically, although at a greater labor expense.
[10]If a sediment ditch is successful in catching sediment, it must be dredged out periodically. Depending on the site, this could be multiple times per season or only once every year or two. This is typically accomplished with a bucket excavator to dig out the ditch and a scraper to pick up and distribute the soil once it has dried. A tailwater pond without a sediment ditch will require similar maintenance in order to remain functional. Because this poses a conflict with wildlife habitat goals for a pond, the RCD strongly recommends the two-pond system of a sediment trap and pond.

Information from this presentation is summarized below. The focus of the management program for controlling excessive fertilization of the Salton Sea is on controlling phosphorus loads to the Salton Sea. They summarized various approaches, which include:

On-farm practices

"Watershed & Subwatershed practices
Reduction of P in the Salton Sea
Source from Mexicali and local cities"

The on-farm practices include:

"*Irrigation Water Management*
Runoff Reduction
Banding P preplant in concentrated zone
Precision Application Rates"

Rothfleisch and Smith focus the on-farm practices on approaches that could control erosion-associated phosphorus. They did not consider the extremely important issue discussed in a subsequent section of this report of how much of the phosphorus that would be controlled through erosion control would become available in the Salton Sea. Since a large part of the particulate phosphorus in agricultural land runoff in other areas has been found to be unavailable to support algal growth, this is an important component of any credible phosphorus management program. Without this, large amounts of funds could be spent controlling particulate phosphorus, which would have little or no impact on the eutrophication-related water quality of the Salton Sea.

Rothfleisch and Smith's on-farm practices include:

"*Wide, flat pan ditch reduces loss of silt*
Using Filter Strips
Polyacrylamide
Silt BMPs identified by Alamo River Silt TMDL"

With respect to irrigation water management, Rothfleisch and Smith focused on *"determining and controlling the rate, amount, and timing of irrigation water applied to minimize soil erosion, runoff, and fertilizer movement in surface runoff water.*" They also suggested that, through the use of liquid phosphorus applications on certain crops, they could better control the phosphorus uptake by the crops. Under reducing runoff, Rothfleisch and Smith suggest:

"*Use better irrigation management*
Use a temporary pump-back system
Apply P during one irrigation instead of two per year"

The slide on "Banding of Phosphate Preplant in a Concentrated Zone" includes:

"*Concentrated band of P may not be tied up as rapidly by the soil chemistry*
Less water-run applications of P needed during the life of an alfalfa or Bermuda grass crop"

However, they note that more research is needed in this area.

The "Precision Application Techniques" include grid sampling and use of GPS to apply only the amount of P needed to those areas where it is needed.

The use of polyacrylamides during irrigation can be accomplished by mixing them with irrigation water, or they can be sprayed on drain water exiting the field. The polyacrylamide additions enhance infiltration and reduce the potential for soil erosion.

According to Rothfleisch and Smith, the silt TMDL for the Alamo River could reduce particulate phosphorus added to the Salton Sea. With respect to the watershed and subwatershed practices, Rothfleisch and Smith note that wetland nutrient removal projects are effective but may be expensive to build and maintain. They also suggest that alum and polymer treatments to the tributary rivers to the Salton Sea near the river outlets could be effective in controlling available phosphorus added to the Salton Sea. There are questions, however, about environmental impacts and effectiveness with respect to the discharge of alum floc to a highly saline waterbody, compared to where it has been used in the past in freshwater systems. Issues of cost also have to be addressed.

With respect to reducing phosphorus in the Salton Sea, commercial fish harvesting, natural fish harvesting by birds and fishermen, and natural fish die-off are methods discussed by Rothfleisch and Smith. Reducing the phosphate from the local cities and Mexicali could be effective, since Mexicali may contribute up to 25 percent of phosphate entering the Salton Sea.

Peterson, *et al.* (2002) presented the results of modeling of nutrient transport in the Imperial Irrigation District. The model that was developed was reported by Peterson, *et al.*, to be useful for evaluating the impact of water conservation measures on sediment transport. This in turn could be effective in reducing the total phosphorus discharged by irrigated lands.

Oxygen Demand Constituents. The San Joaquin River Deep Water Ship Channel (DWSC) near Stockton, California, experiences severe dissolved oxygen depletion throughout the year, but especially during the summer and fall months. As discussed by Lee and Jones-Lee (2001, 2002d) and Gowdy (2002), this problem is related, to a considerable extent, to the discharge of nutrients in irrigated agriculture tailwater that develop into algae in the San Joaquin River and its tributaries. The algae are carried into the Deep Water Ship Channel, where they die, decompose, and consume oxygen. While the city of Stockton's domestic wastewater discharge of ammonia has, at times, been shown to be a major contributor to the DO depletion in the Deep Water Ship Channel, the primary source of oxygen demand for the DWSC is ultimately nutrients derived from agricultural runoff. There is need for information on the development of BMPs to control nutrient releases from irrigated agriculture that develop into algae that cause oxygen depletion in the DWSC, especially from the Mud and Salt Slough watersheds. Additional information on the processes that lead to low DO in the DWSC is provided in a subsequent section. Some of these same processes and impacts will be applicable to other nutrient-rich waterbodies in the Central Valley.

Lake Erie and Chesapeake Bay Watershed Nutrient Management Programs. Beginning in the 1960s work was initiated in some areas on nutrient control in agricultural runoff. One of the first of these efforts was associated with the development of an excessive fertilization control program for Lake Erie. In the 1970s the International Joint Commission (IJC) for the Canadian/US Great Lakes formed the Pollution from Land Use Activities Reference Group (PLUARG) (IJC, 2000). The program developed by this group was specifically designed to control phosphorus releases from agricultural lands to tributaries of Lake Erie. Logan (2000), in a review of the experience of phosphorus control in the Lake Erie watershed, has indicated that little progress has been made in achieving effective phosphorus control in agricultural runoff in the 30 years that this program has been in place.

The Chesapeake Bay watershed is another area where there has been a major effort to control nitrogen and phosphorus in agricultural land runoff. Sharpley (2000) reviewed the experience in achieving a 40-percent nitrogen and phosphorus reduction in the Chesapeake Bay watershed. He indicated that, after 15 years or so of control efforts, limited progress is being made in achieving phosphorus and nitrogen control in agricultural land runoff. Sprague, *et al*. (2000) presented a review of factors affecting nutrient trends in major rivers of the Chesapeake Bay watershed. They point out that it is difficult to discern major changes in the contribution of nutrients from agricultural lands in this watershed due to year-to-year variability in nutrient export. This variability is related to a number of factors, including climate. They note that one of the principal methods for nutrient export reduction from agricultural lands has been land retirement – i.e., termination of agricultural activities on the land.

Groundwater Pollution. Letey (1994) has pointed out that groundwater pollution by irrigated agriculture is an inevitable consequence of irrigated agriculture in the Central Valley. Without sufficient infiltration of the irrigation water and surface water runoff/discharges, the concentrations of salts will build up to such an extent as to cause the soil to become nonproductive. As part of practicing irrigated agriculture, it is essential that there be transport of salts from the root zone through the vadose zone and into the groundwater system and the flushing of salts from the surface soils to surface watercourses.

Hanson (2002) discussed the problems of protecting groundwaters from pollution by irrigated agriculture. He concluded that the key to preventing nitrate pollution of groundwaters from irrigated agriculture is a reduction in nitrogen fertilizer application. He also indicated that micro-irrigation is a potentially effective method of reducing groundwater pollution; however, the cost of installation of a micro-irrigation system is such that it may not be widely used. Hanson stated that, at this time, it is unknown whether irrigated agriculture in California can meet groundwater quality standards through improved irrigation practices. He further indicated that this is an area that needs additional study.

Lee and Jones-Lee (2002e) have discussed the need for proactive monitoring of irrigated agricultural areas for the potential to cause significant groundwater pollution. The current monitoring approach of measuring an increase in constituents in groundwater is not a reliable approach for protecting groundwaters from pollution by irrigated agriculture, since the groundwaters have to be polluted before action is taken. There is need to develop and implement vadose zone monitoring under irrigated agricultural areas, where the concentrations of constituents in the vadose waters are measured, and a prediction is then made as to whether these concentrations are sufficient to significantly impair the designated beneficial uses of the groundwaters under the areas devoted to irrigated agriculture. Vadose zone monitoring using an array of vacuum cup lysimeters is an approach that could serve as an early warning system for significant pollution of groundwaters. Lee and Jones-Lee (2002e) have provided additional information on vadose zone monitoring.

Overall State of Agricultural Runoff Nutrient Control BMPs. There is a significant lack of quantitative knowledge on the ability of various so-called water quality BMPs to control nutrients in runoff/discharges from agricultural lands. This arises from the fact that there have been few reliable studies on the effectiveness of detention basins, vegetative strips, etc, for controlling nutrients in agricultural land runoff under the variety of conditions that are encountered. The studies that have been done have largely been non-quantitative in assessing the amount of runoff that occurs under various BMP-treated/managed runoff situations. What is needed for various forms of nutrients is information on the amounts of nutrients present in an area subject to runoff, coupled with proper evaluation of a sufficient number of representative field plots, with and without BMP treatment, under the various hydrological regimes, soil conditions and other factors that can influence the transport of aquatic plant nutrients from agricultural lands.

Development of Nonpoint Source Nutrient Management Programs

Introduction

The excessive fertilization (eutrophication) of California's Central Valley waterbodies, especially in the San Joaquin River watershed and the Delta, as well as agricultural drains and agricultural runoff/discharge-dominated waterbodies in the Sacramento and San Joaquin River watersheds, is a widespread, significant water quality problem that is leading to impairment of the beneficial uses of many of these waterbodies. This situation is common throughout the US and in many parts of the world. The excessive fertilization of waterbodies caused the US EPA to develop chemically-based numeric nutrient (N and P compound) criteria that can be used as the basis for developing state water quality standards/water quality objectives (WQOs). These WQOs will be used to define waterbodies that are Clean Water Act 303(d) "impaired" because of excessive growths of aquatic plants due to excessive nutrient loads/concentrations. This in turn will lead to the need to develop TMDLs to control the excessive nutrient loads and/or conditions that lead to the eutrophication-related water quality problem. Generally, the control of excessive nutrient loading/concentrations will be based on controlling nutrient discharges from agricultural/rural and urban sources using best management practices (BMPs). This section of this report provides information that is pertinent to developing BMPs/management programs to control the impacts of excessive concentrations/loads of nutrients in Central Valley waterbodies.

Overview of the Background Information Needed for Nutrient BMP Development

The development of technically valid, cost-effective waterbody excessive fertilization management programs is technically different than for most other pollutant control programs. Usually the area of greatest concern for controlling the impact of pollutants (such as pesticides and potentially toxic heavy metals/organics) is near the point of discharge of the pollutant to a waterbody. In excessive fertilization problems, the impact of nutrients can take place long periods of time (months to a year or more) after nutrient release/discharge and at considerable distances downstream. Nitrogen released from cornfields in the upper Midwest or the eastern side of the Rocky Mountains can cause adverse impacts on eutrophication-related water quality in the Gulf of Mexico. In the Central Valley of California, nutrients released in stormwater runoff/tailwater discharges from agricultural fields in the Mud and Salt Slough watersheds near Fresno can contribute to excessive algal growth in water supply reservoirs located in Southern California that use Delta water as a water supply source.

Another complicating factor in developing nutrient management programs is that the impacts of excessive fertilization are often subjective with respect to impairing the recreational use of waterbodies, where they are dependent on the public's response to the aquatic plant biomass in the waterbodies of the area. Large amounts of algae in waterbodies in one area may be judged by the public as excessive, while in another area the same amount of algae may be acceptable. The often remote but real connection between nutrient concentrations in discharges from an area and the social impact in another downstream area can cause the US EPA's proposed chemical-specific numeric default nutrient criteria to be technically invalid. Because of the complexity of excessive fertilization, the development of a technically valid, cost-effective nutrient management program often requires a substantially larger information base on the characteristics of nutrient releases and downstream impacted waterbodies than is typically needed for management of toxic pollutants.

Figure 2 presents a conceptual model diagram of the role of BMPs in managing the water quality impacts of nitrogen and phosphorus derived from agricultural and urban stormwater runoff/discharges. As indicated, unmanaged runoff can contribute sufficient nutrients to some waterbodies to develop sufficient algae and other aquatic plants (water weeds) to significantly adversely impact the beneficial uses of the waterbody. The management practices (BMPs) are imposed either as source control or treatment of the runoff/discharge waters to reduce the amount of nitrogen and phosphorus compounds present in these waters to acceptable levels to achieve the desired nutrient-related water quality in the waterbodies of concern. The key to a cost-effective excessive fertilization management program is an understanding of the degree of nutrient control from the various sources needed to achieve the desired water quality in the potentially-impacted waterbodies.

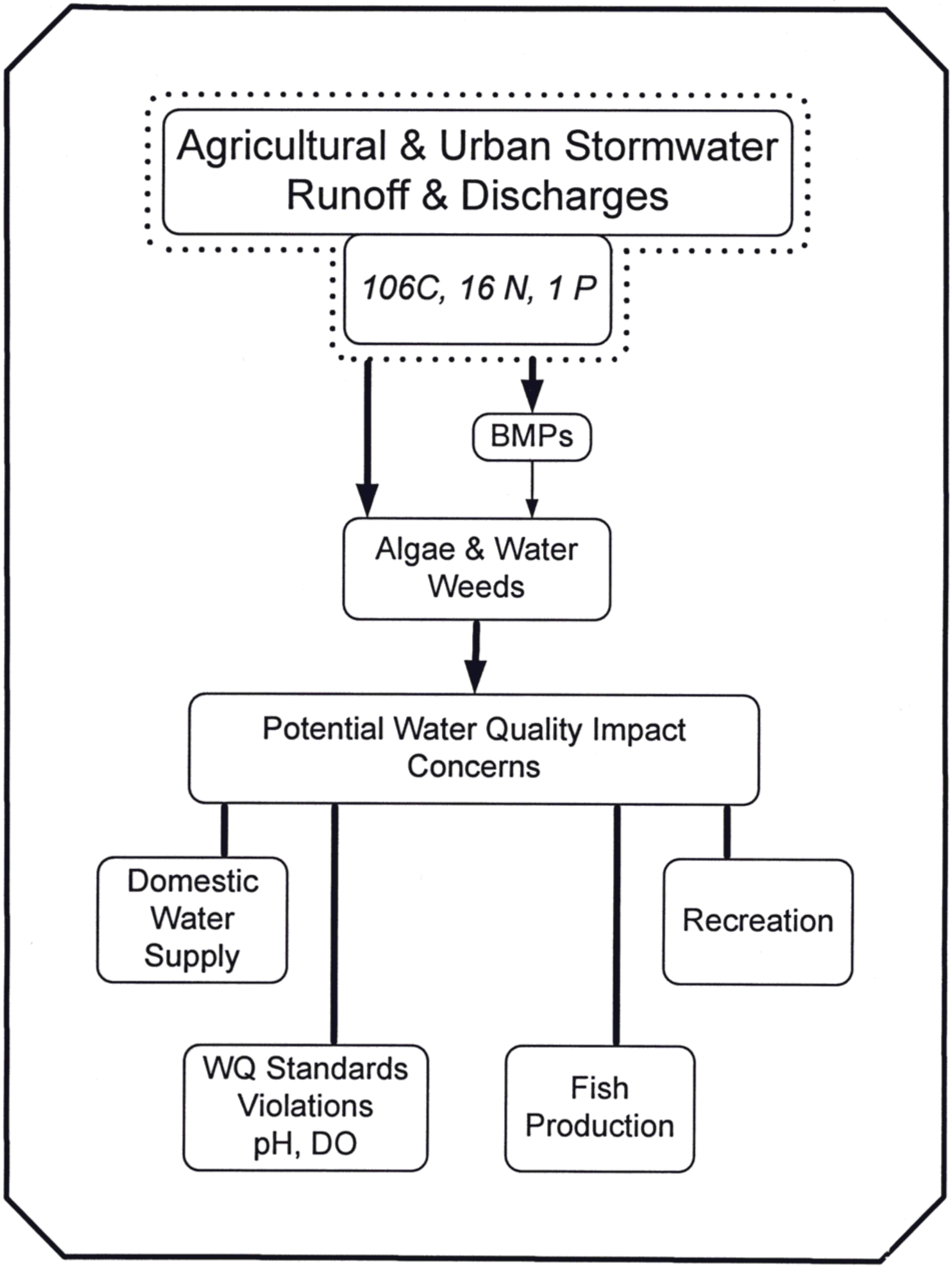
As discussed in this report, the approach that should be followed in developing a BMP to control nutrient(s) runoff/discharges to the desired degree is similar to the approach that is used to develop a nutrient control program to meet a TMDL requirement to control excessive fertilization of a waterbody. This approach involves a statement of the problem, definition of the nutrient control goal, determination of nutrient sources and modeling of nutrient loads to eutrophication response. This information is used to develop and implement a nutrient management plan. 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 that are appropriate for the waterbody and the appropriate BMPs for the location and type of agriculture being practiced in the area of concern. Information on several of these components is presented in this report.

In order to select a BMP that is cost-effective for control of nutrients from agricultural land runoff/discharges, it is necessary to first clearly define the objective of the BMP, with particular reference to the degree of nutrient control needed to protect the beneficial uses of the waterbody being impacted by nutrient runoff/discharges. In order to make this evaluation, an understanding must be gained of the relationships between the impact of a particular nutrient(s) load derived at various times on the eutrophication-related water quality of the waterbody of concern. It is suggested that the nutrient dischargers in an area should join forces to fund nutrient load-eutrophication response evaluation/modeling for the waterbody that is being affected by the discharges of the region. Associated with this modeling/evaluation, an assessment would need to be made of the desired eutrophication-related water quality that should be achieved in the waterbody(ies) of concern. Based on the load-response modeling/evaluation, the allowable nutrient load to the waterbody is determined. As discussed elsewhere in this report, it is extremely important, in developing a technically valid, cost-effective nutrient control program, to focus on the available nutrient loads, and not total loads. Further, the prospective BMPs should be evaluated with respect to their ability to control nutrient concentrations in the runoff/discharge waters to a certain degree under the climatological and other conditions under which the BMP must function reliably. The approaches that can be used to make these evaluations are discussed in this report.

Water Quality Impacts of Waterbody Excessive Fertilization

The first step in developing a BMP for nutrient control in stormwater runoff/discharges is to understand the water quality problems that can occur in waterbodies that receive excessive nutrients. The excessive fertilization of waterbodies is a long-standing, well-recognized cause of water quality problems 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 either can be floating, such as water hyacinth or duckweed, or attached-emergent. The impacts of excessive fertilization-eutrophication on a waterbody's water quality were

Figure 2. Conceptual Model of the Role of BMPs in Nutrient Management



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 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 experiences 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/aquatic plant 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.

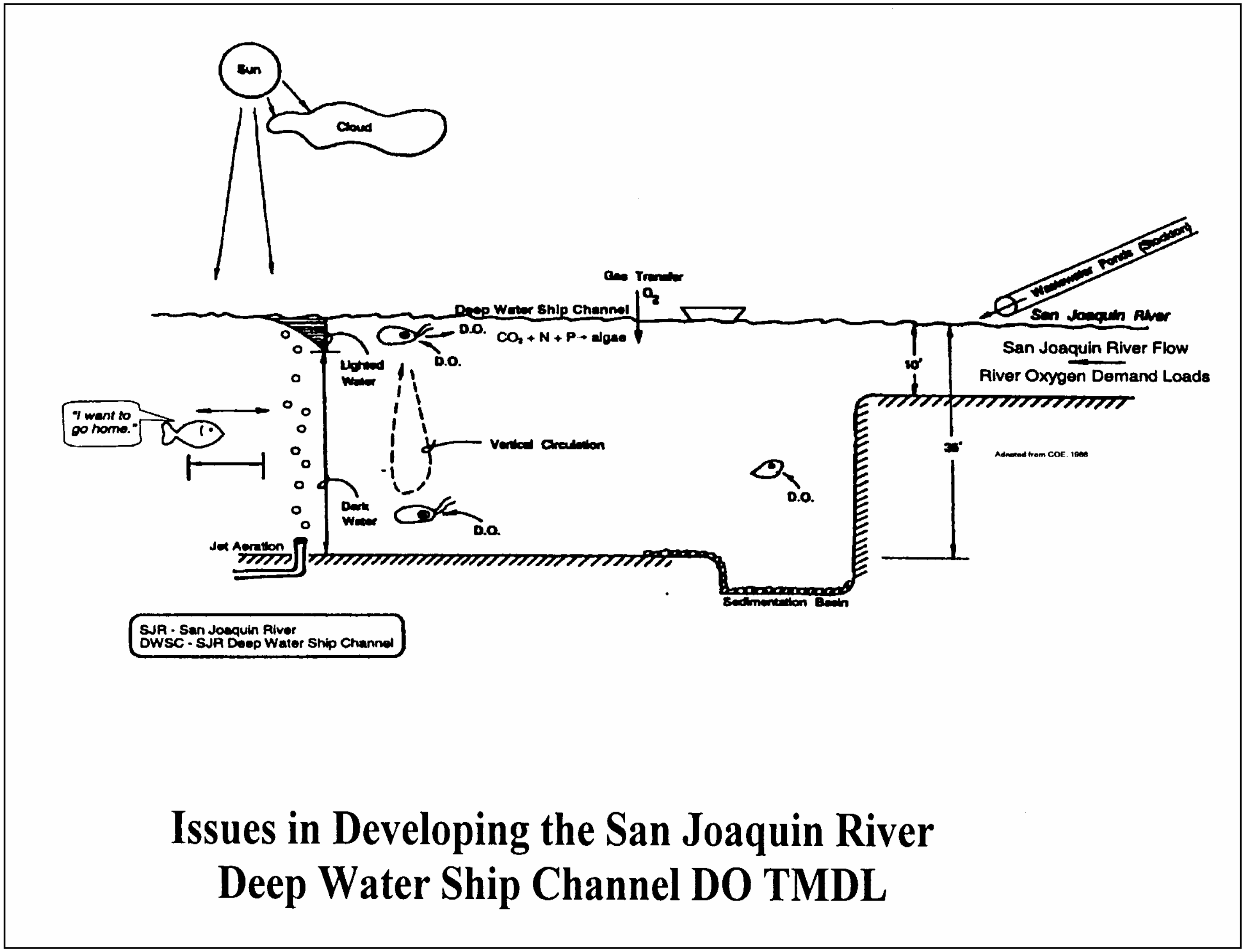
Algae and other aquatic plants, upon their death, can become important sources of biochemical oxygen demand (BOD). Richards (1965) has shown that one phosphorus atom, when converted to an algal cell, which subsequently dies, can consume 276 oxygen atoms as part of the decay process. Equation (1) describes this process. While, ordinarily, the DO depletion issue is a near-bottom 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) so that there are DO depletion problems in the surface waters as well (see Lee and Jones-Lee, 2000; 2001, 2002d).

$$\text{algae} + O_2 \xrightarrow{\text{(dark)}} CO_2 + H_2O + N + P \qquad (1)$$

Figure 3 presents a diagram which shows the DO depletion issues in the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) near Stockton, CA. 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/processes involved are shown in Figure 4.

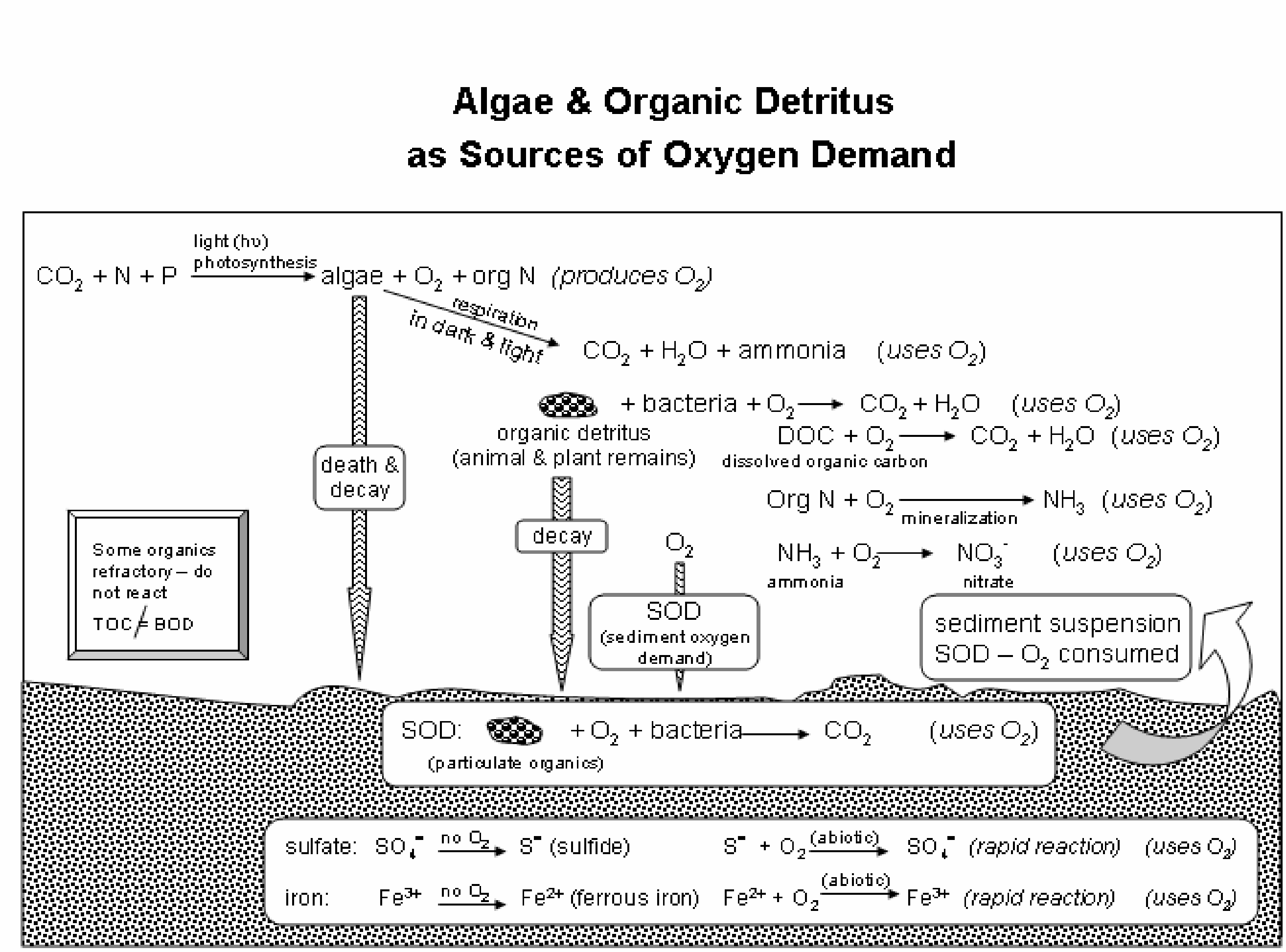
Toxic Algae. One of the major stimuli for increased US EPA attention to excessive fertilization is the *Pfiesteria* problem in Chesapeake Bay and other coastal waterbodies (US EPA, 2000a), where fish kills have occurred due to the presence of toxic algae. Fish kills associated with toxic algae are not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

Figure 3. DO Depletion Processes in the San Joaquin River Ship Channel



From Lee and Jones-Lee (2000).

Figure 4. DO Depletion Reactions in the SJR DWSC

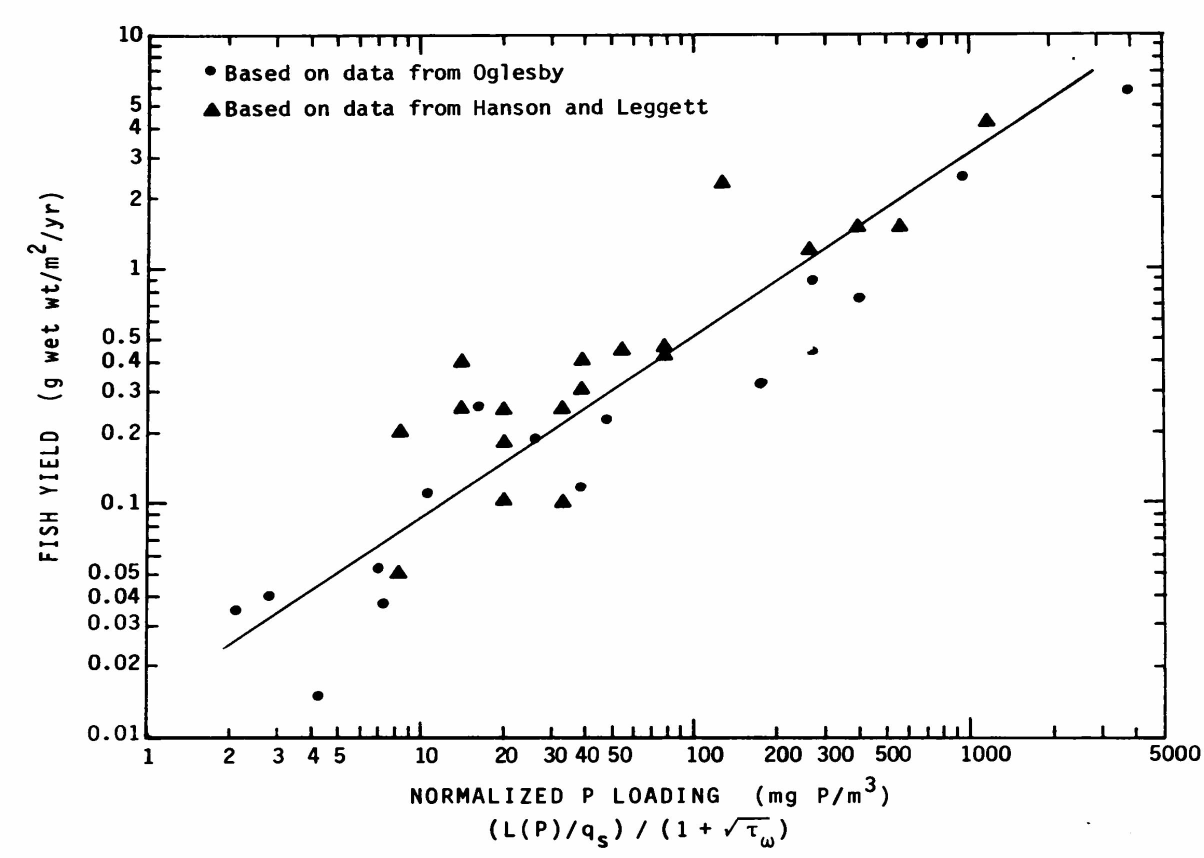


From Lee and Jones-Lee (2000).

Impaired Recreation. Excessive growth 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.

Impact on Fisheries. Fertilization of waterbodies improves fish production in terms of total biomass; however, as Lee and Jones (1991b) 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 levels, often dominate the increased production. These relationships are shown in Figure 5. (The normalized phosphorus load terms are discussed in Figure 10.)

Figure 5. Effect of Phosphorus Loads on Fish Production

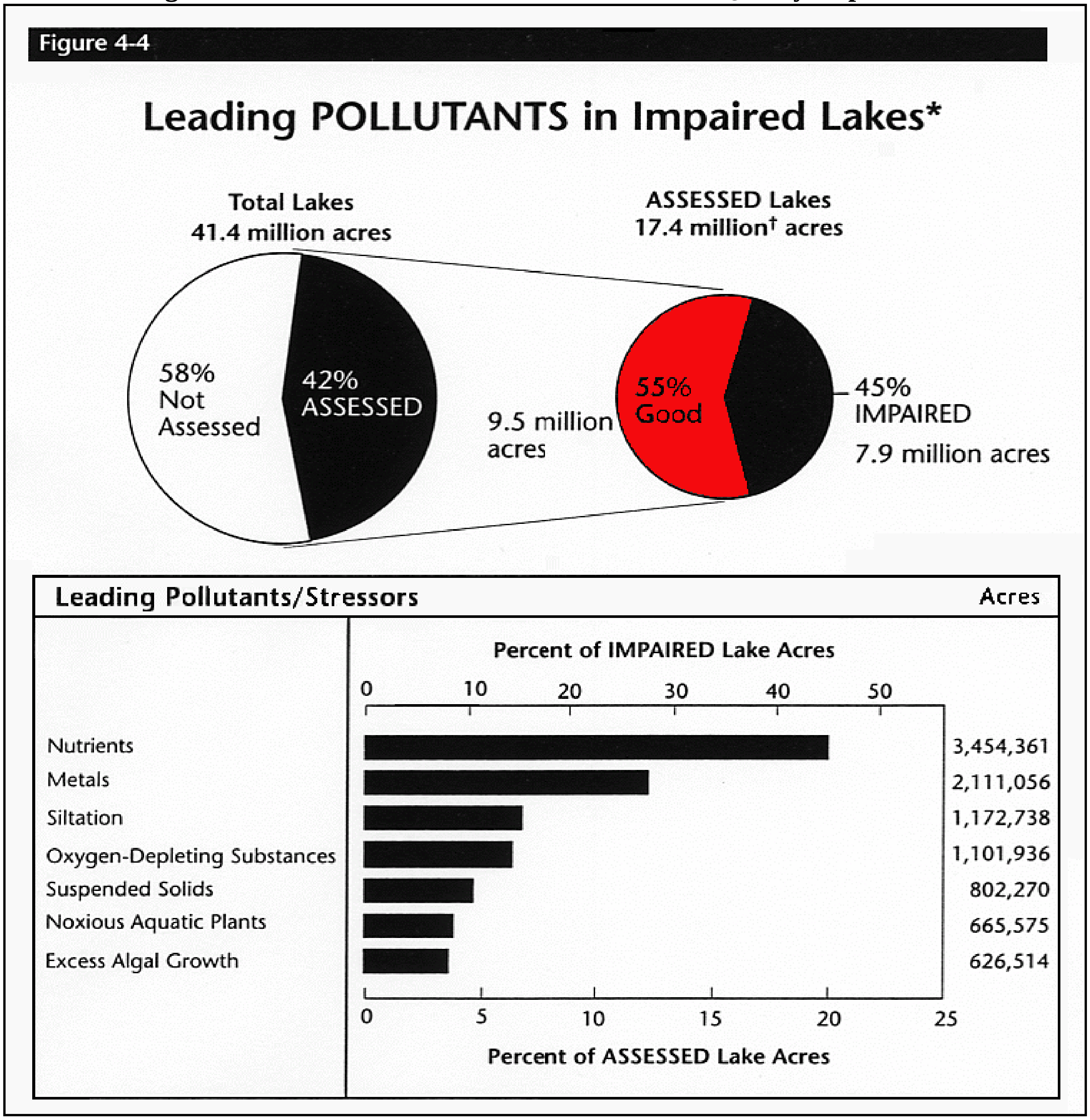


Source: Lee and Jones (1991b)

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. This can be detrimental to the aquatic resources of a waterbody.

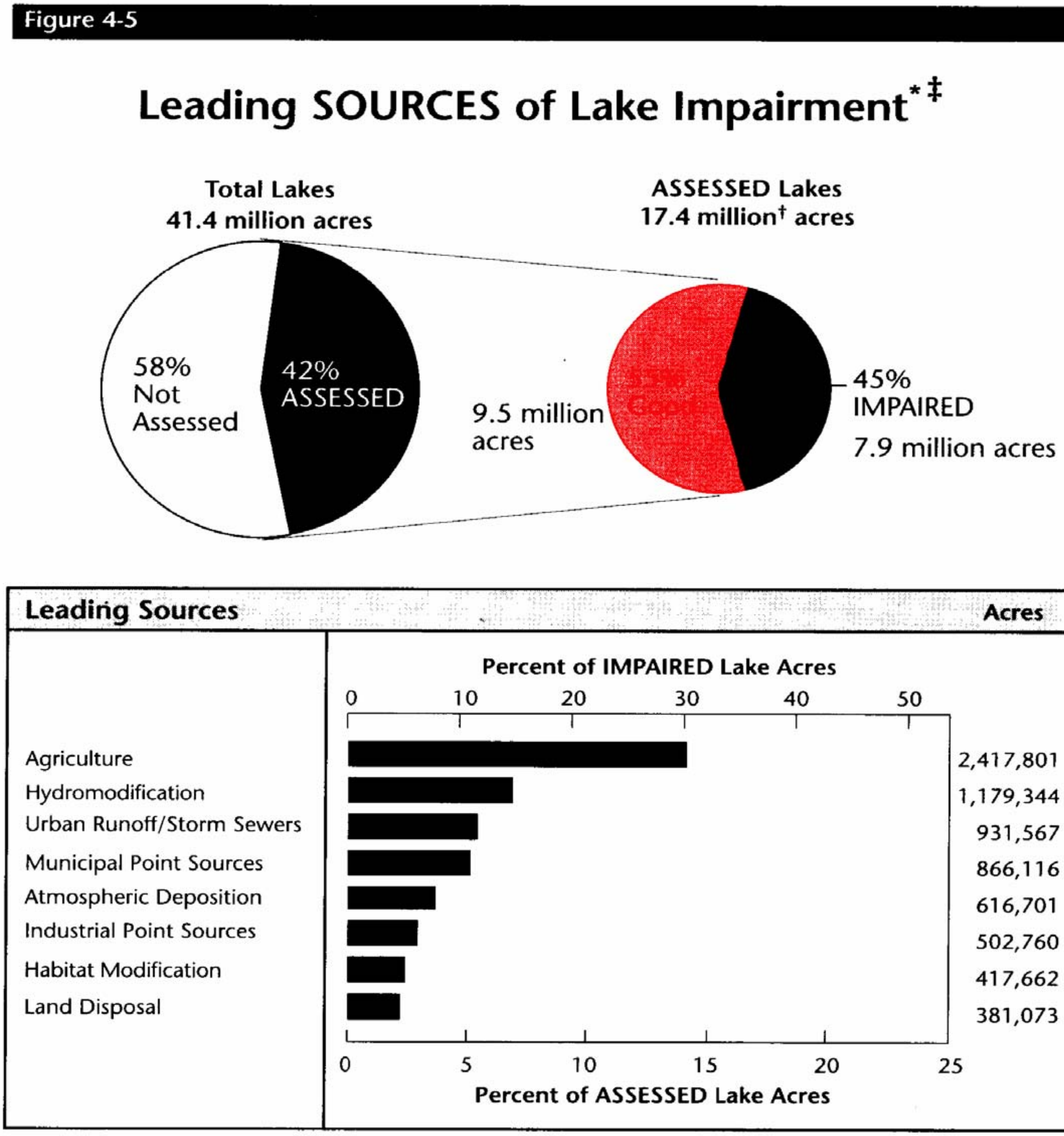
Overall Impacts of Excessive Fertilization. Excessive fertilization is one of the most important causes of water quality impairment of waterbodies. The US EPA (2000a), in its last National Water Quality Inventory, has listed nutrients as the leading cause of water quality impaired lakes and reservoirs (Figure 6). Further, as shown in Figure 7, the Agency lists agriculture as the primary source of constituents (nutrients and sediments) that impair lakes.

Figure 6. Role of Nutrients as a Cause of Water Quality Impairment



Source: US EPA (2000a)

Figure 7. The Primary Sources of Lake Water Quality Impairment



Source: US EPA (2000a)

Nutrient Issues

Nutrients of Concern. 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 (2) presents the typical stoichiometry of algae.

$$106\ CO_2 + 16\ N + 1\ P + \text{trace elements} \xrightarrow{h\nu} \text{algae} + O_2 \qquad (2)$$

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 (2), 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).

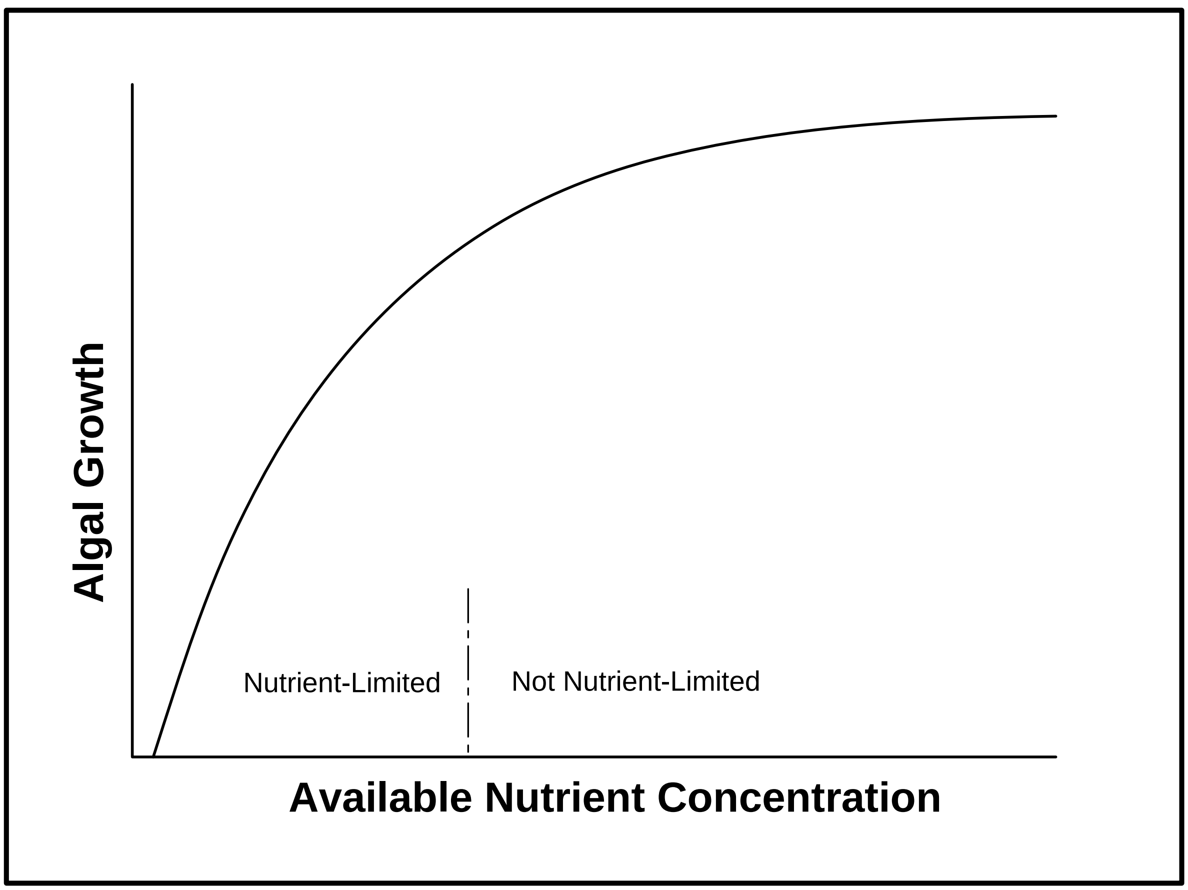
The approach that should be used to determine whether nitrogen or phosphorus is limiting algal growth is to examine the concentrations of available forms of nutrients at peak biomass, and then, if the concentrations present are below growth-rate-limiting concentrations, there is reasonable certainty that the nutrient that occurs under these conditions is potentially limiting algal growth.

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 8). 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.

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.

Figure 8

Relationship between Nutrient Concentration and Algal Biomass



From Lee and Jones-Lee (2000).

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 agricultural 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 agricultural 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 agricultural 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 is algae, then most of the total N and total P will be mineralized and, in time, will become available to support algal growth.

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 7.

Table 7
Watershed Nutrient Export Coefficients

Land Use	***Export Coefficients (g/m²/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	

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 in the Central Valley 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. Since the low-DO problems in the San Joaquin River Deep Water Ship Channel discussed above are primarily summer problems, the nutrient sources that are of primary concern are those that develop into algae during the summer/fall. The winter/spring nitrogen and phosphorus present in stormwater runoff from agricultural lands do not contribute to the excessive algal growth during the summer since they are flushed from the SJR DWSC watershed during the winter/spring flows.

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 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.

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 can increase 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.

Issues that should 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). One of the goals 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 has, 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 agricultural 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.

Evaluating Allowable Nutrient Load to Waterbodies. To establish the allowable nutrient load for a waterbody, it is necessary to model the nutrient load-eutrophication response relationships for the waterbody. There are basically two types of models:

- An empirical, statistical model, such as the Vollenweider-OECD Eutrophication model discussed herein, which involves a large database on how nutrient concentrations or loads relate to the nutrient-related water quality characteristics of the waterbody.
- A deterministic model, in which differential equations are used to describe the primary rate processes that relate nutrient concentrations/loads to algal biomass.

The deterministic modeling approach, while able to be tuned to relate nutrient loads to eutrophication response, may have limited predictive capability. Because of the number of equations used, there is no unique solution to the model, and therefore, tuning the model may not properly represent the conditions that would be important in predicting eutrophication response (such as planktonic algae) under altered nutrient loads.

Desired Nutrient-Related Water Quality. The first step in developing appropriate nutrient water quality criteria is to establish the desired nutrient-related water quality for the waterbody(ies). This should be done through a public process conducted by the regulatory agency. Such issues as no violation of the average/worst-case diel DO and pH, minimizing adverse impacts of nutrients on algal-caused domestic water supply raw water quality (i.e., controlling tastes and odors, filter runs, etc.) and water clarity/Secchi depth are important eutrophication-related water quality parameters for those waterbodies where the excessive fertilization is manifested as planktonic algae. The Secchi depth is based on the visual observation of the depth at which a 20 cm circular disk painted with black and white quadrants can be observed from the surface. With respect to water clarity, the issue is basically one of the depth of the waterbody at which the bottom sediments can still be seen from the surface. Waterbodies with high degrees of clarity (i.e., the bottom can be seen even at depths of 20 or more feet) are ones with low planktonic algal content. For more eutrophic waterbodies, typically the sediments can only be seen at a depth of a few feet.

Another factor that is important is water greenness, which is measured by planktonic algal chlorophyll. In areas where there are a number of lakes and reservoirs with different areal nutrient loads and, therefore, degrees of fertility, the public has the opportunity to compare waterbodies that are green with those that are clear. The public's perception of high water quality in those areas where there are marked differences in lake water clarity is quite different than in areas where all the waters have the same general greenness due to planktonic algae. A factor that influences the perception of greenness of a waterbody is the inorganic turbidity. Often, quite high levels of planktonic algal chlorophyll can be present in a shallow waterbody or river without the public perceiving it to be excessively fertile, if the waterbody is brown due to inorganic turbidity.

Figure 9 is a modification of Vollenweider's (1976) relationship in which he defined "excessive" and "permissible" phosphorus loadings to lakes and reservoirs, considering the waterbody's mean depth and hydraulic residence time. Rast and Lee (1978), based on the results of the US OECD Eutrophication studies, expanded this relationship to include mean summer planktonic algal chlorophyll and Secchi depth that is due to planktonic algae.

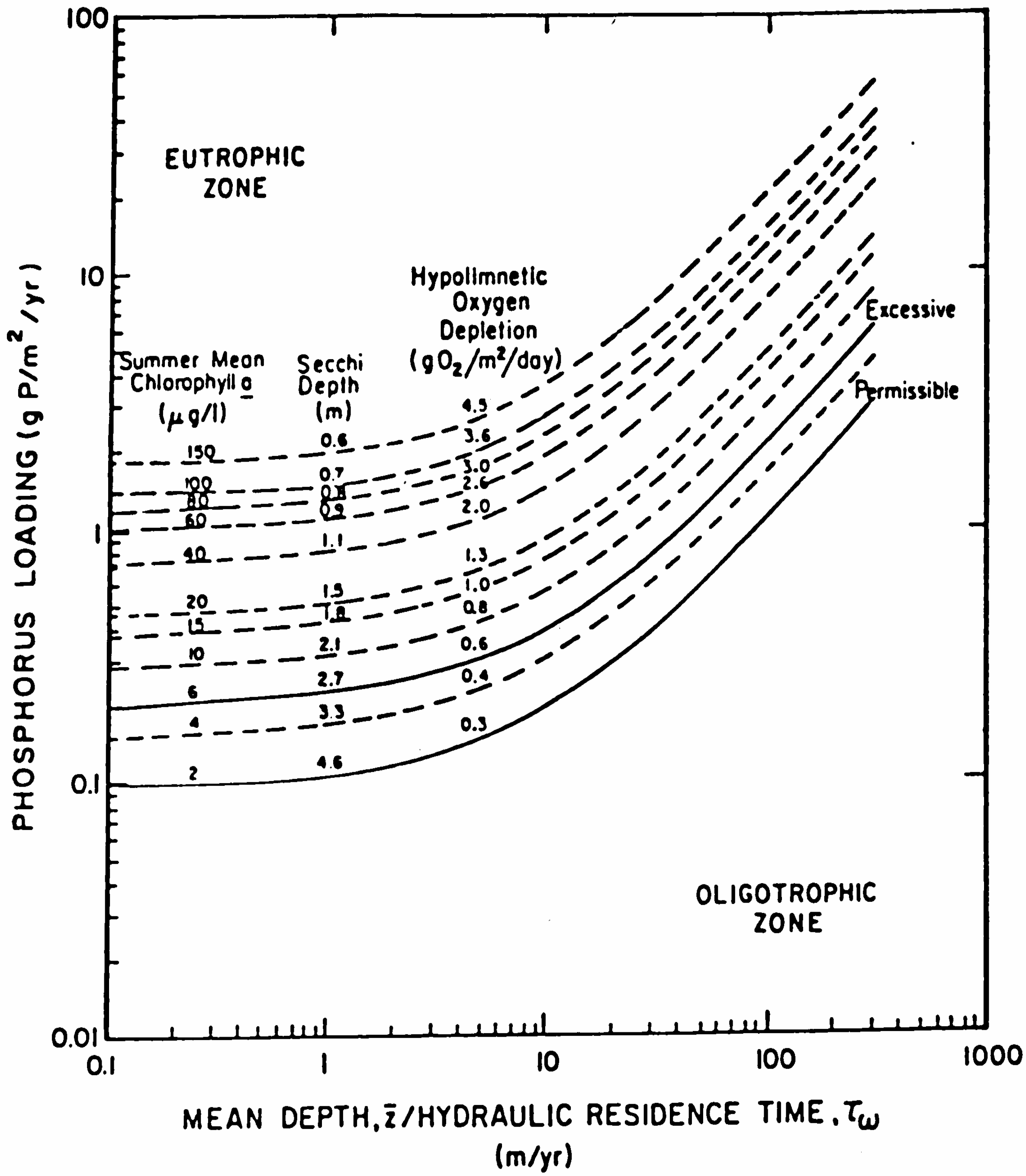
From this relationship, the stakeholders in a waterbody's watershed can determine the desired greenness of the water and water clarity. Other response parameters (such as domestic water supply tastes and odors, etc.) can be included in this relationship. Once these are defined, then the allowable available phosphorus load can be determined. This is an appropriate approach to follow in establishing critical nutrient concentrations/loads for waterbodies that are found to follow the results of the Vollenweider-OECD Eutrophication study program discussed herein.

As discussed by Lee, *et al*. (1995a,b,c), if the water quality problems due to excessive fertility are due to macrophytes, attached algae, etc., an assessment of the percent of the area with excessive concentrations of water weeds should be made, in terms of both the current conditions and the conditions that are desirable. Shallow water area water weeds are important fish habitat.

For lakes/impoundments that do not follow the phosphorus load-eutrophication response relationship that was developed in the OECD Eutrophication studies, as well as rivers and streams, it is necessary to conduct site-specific studies to determine the eutrophication-related water quality of interest to the public/stakeholders impacted by fertilization of the waterbody. As part of reviewing the desired water quality, an assessment should be made of the desired fisheries. For waterbodies that stratify, an assessment should be made as to whether there is a desire to maintain coldwater fisheries in the hypolimnion. Also, consideration should be given to developing a waterbody that has a high-value sports fishery, compared to one with low nutrients which would have low planktonic algae and high water clarity, but low fish production.

Carlson (1977) proposed a trophic state index system that is based on total phosphorus, chlorophyll and Secchi depth. Except for the inclusion of total phosphorus as a parameter, this approach was an improvement over previously discussed multiparameter approaches that have been used in the past. He developed spectra of Secchi depths and chlorophyll and P concentrations for a group of Minnesota lakes and then outlined a numerical ranking system for waterbodies based on their relative positions within these spectra. There are, however, several technical problems with his system. As discussed by Rast and Lee (1978), Carlson's index is based on a limited number of waterbodies in one geographical region of the US. It also fails to consider the beneficial uses of the waterbody being considered, how the values of the evaluation parameters affect the beneficial uses, and the public's perception of water quality.

Figure 9. Modified Vollenweider Phosphorus Loading Relationship

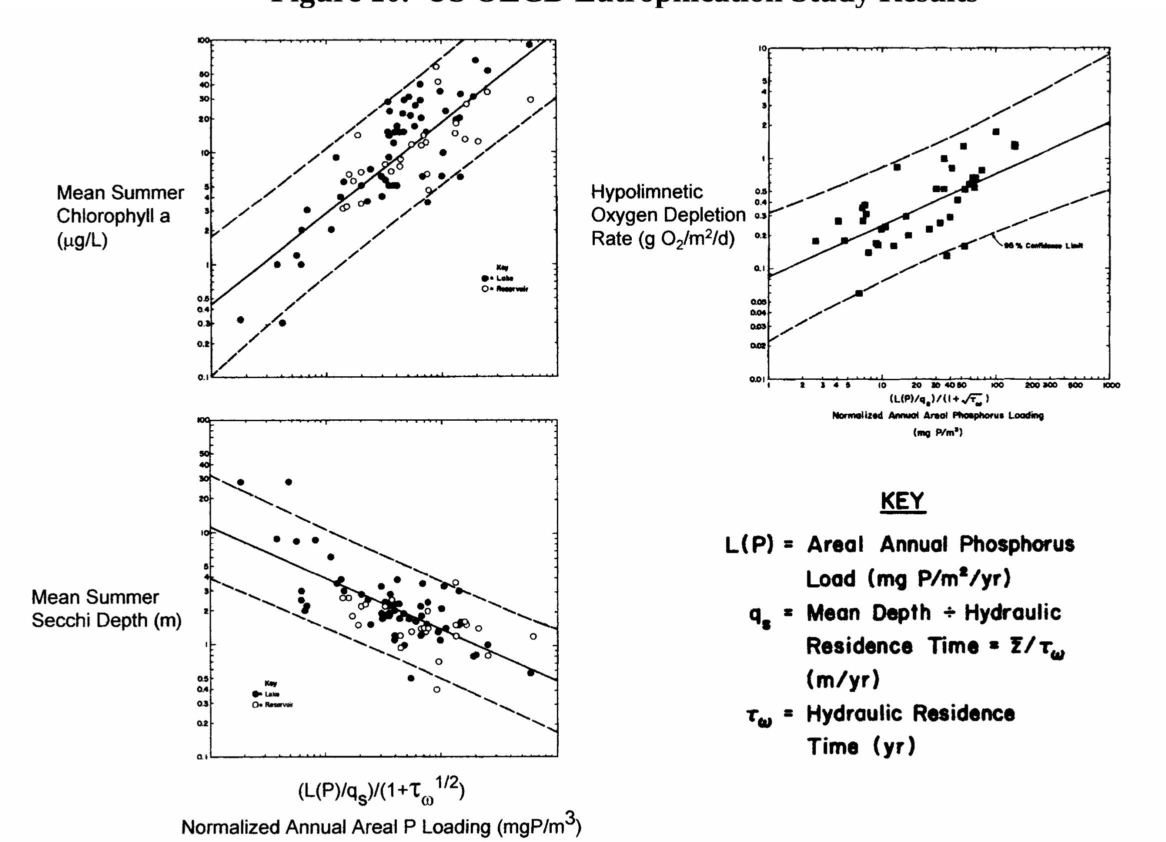


Relationship Between Vollenweider Phosphorus Loading Diagram, Summer Mean Chlorophyll a and Secchi Depth (After Rast and Lee, 1978)

The summing of values assigned for the various response parameters has inherent in it the same problems of skewing as for the multiparameter indices. In addition, while Secchi depth can be a useful eutrophication response parameter, it must be used judiciously. There are situations in which inorganic turbidity, erosional material or color exerts a significant control over water clarity, masking the contribution made by planktonic algae. Under these conditions it would be improper to include, in a trophic state indexing system, a factor for water clarity. The problems associated with using in-lake P concentrations as an indicator of water quality have been discussed previously herein and by Rast, *et al.* (1983).

A second component of the recommended approach for developing nutrient criteria and associated BMPs to achieve these criteria is to evaluate the nutrient loads/concentrations to achieve the desired nutrient-related water quality. If the waterbody is a lake or reservoir and the water quality problem is excessive planktonic algae, it should be determined whether the waterbody fits the updated Vollenweider-OECD eutrophication modeling results (see Jones and Lee, 1982, 1986). If so, it is possible to predict the desired water quality, based on the relationships developed by Vollenweider (1976), which were formulated based on the OECD (1982) and post-OECD eutrophication studies. Figure 10 presents the results of the OECD eutrophication studies that show the relationship between the normalized phosphorus load to the waterbody and the planktonic algal chlorophyll, Secchi depth and hypolimnetic oxygen depletion rate that results in the waterbody. These relationships were developed by Rast and Lee (1978).

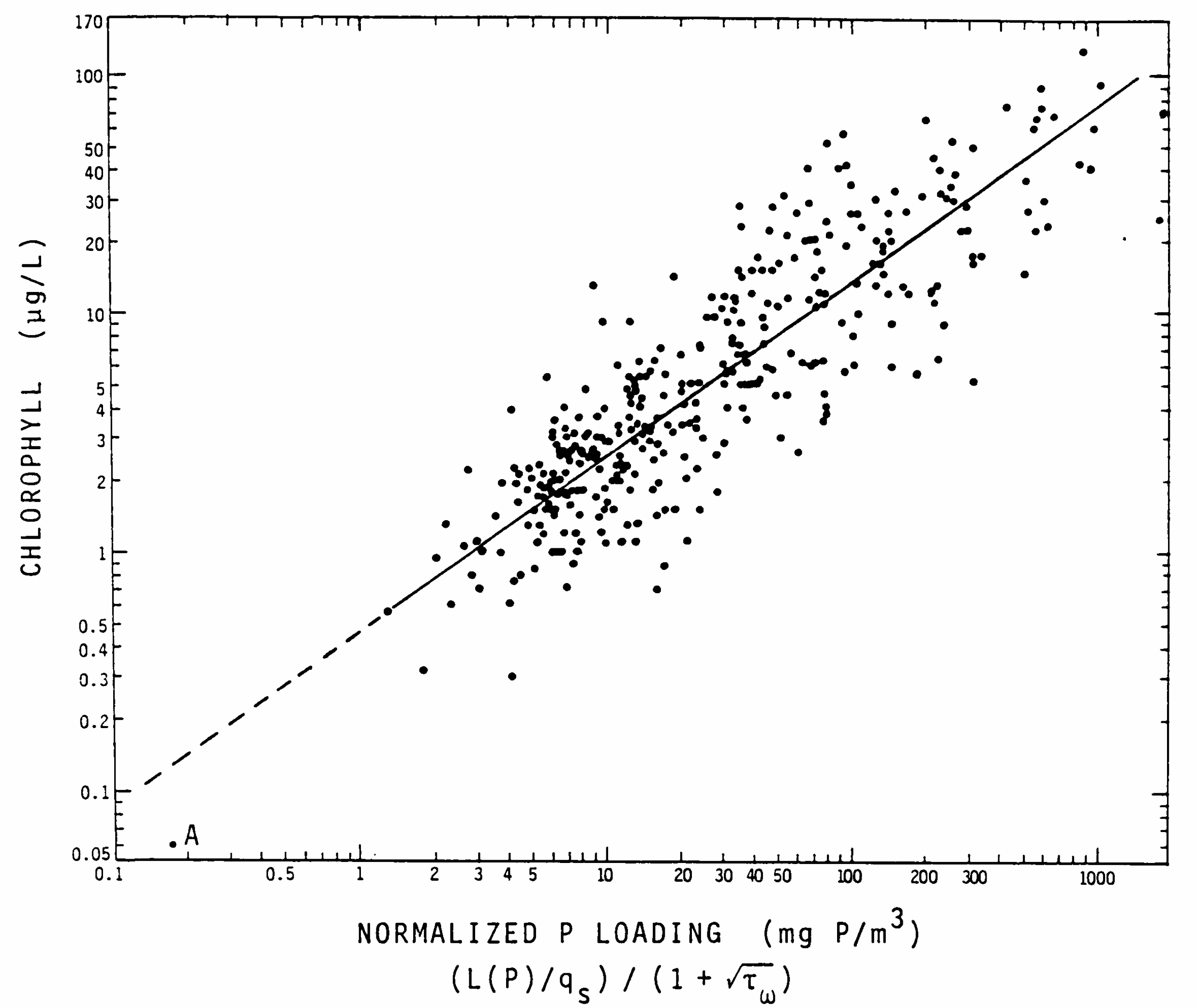
Figure 10. US OECD Eutrophication Study Results



From Rast and Lee (1978).

Figure 11 presents the updated normalized phosphorus load-planktonic algal chlorophyll relationship that was developed by Jones and Lee (1986). Each of the dots on this figure, as well as Figure 10, represents a lake, reservoir or estuary where the nutrient load-eutrophication response has been measured for at least a year. At this time, there are over 750 waterbodies that make up this database.

Figure 11. Updated Normalized Phosphorus Load-Planktonic Algal Chlorophyll Results

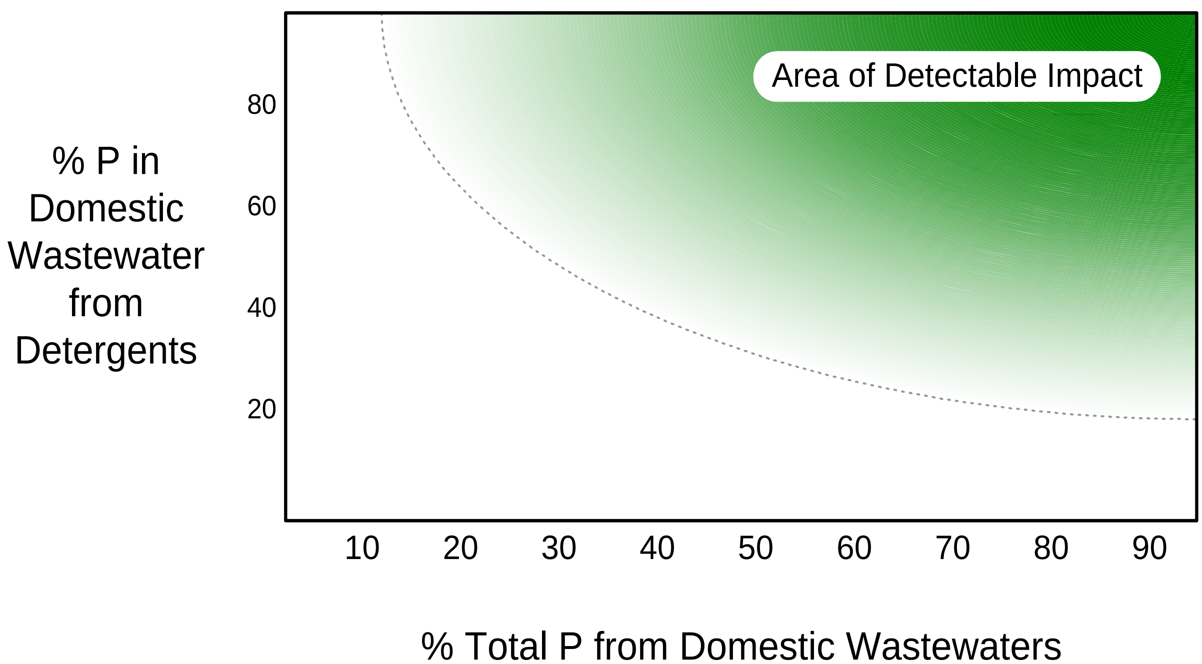


From Jones and Lee (1986).

Lee and Jones (1992) have provided information on the minimum monitoring program needed for most waterbodies to evaluate whether the phosphorus load-eutrophication response relationship for the waterbody fits the results obtained in the Vollenweider-OECD eutrophication studies and post-OECD studies summarized by Jones and Lee (1986). In general, this monitoring program involves sampling the tributaries to the waterbody at about biweekly intervals over one year for measurements of flow and nitrogen and phosphorus compounds. Also, at about weekly intervals, for each of the major parts of the waterbody, samples are taken of the water column for planktonic algal chlorophyll, Secchi depth, temperature and dissolved oxygen.

One of the issues of concern in excessive fertilization management is whether small amounts of phosphorus or other nutrient control will have a significant impact on the waterbody's eutrophication-related water quality. In the late 1960s through mid-1970s, there was considerable discussion about the potential value of banning detergents containing phosphate that are used for cleaning. Many of the detergent phosphate ban proponents claimed that even though the phosphorus contributed to domestic wastewaters from detergents was a small part of the total phosphorus present in domestic wastewaters, removal of detergent phosphate would result in a significant improvement in the waterbody's eutrophication-related water quality. Lee and Jones (1986) examined this situation and concluded that at least 20 to 25 percent of the available phosphorus load to waterbodies needs to be controlled to effect a discernible change in the eutrophication-related water quality, such as planktonic algal chlorophyll or algal-controlled Secchi depth. This relationship is shown in Figure 12. This relationship is not restricted to detergent phosphate or wastewater-derived phosphate, but is applicable to all sources of available phosphorus.

Figure 12. Impact of Altering Phosphorus Load on Eutrophication Response



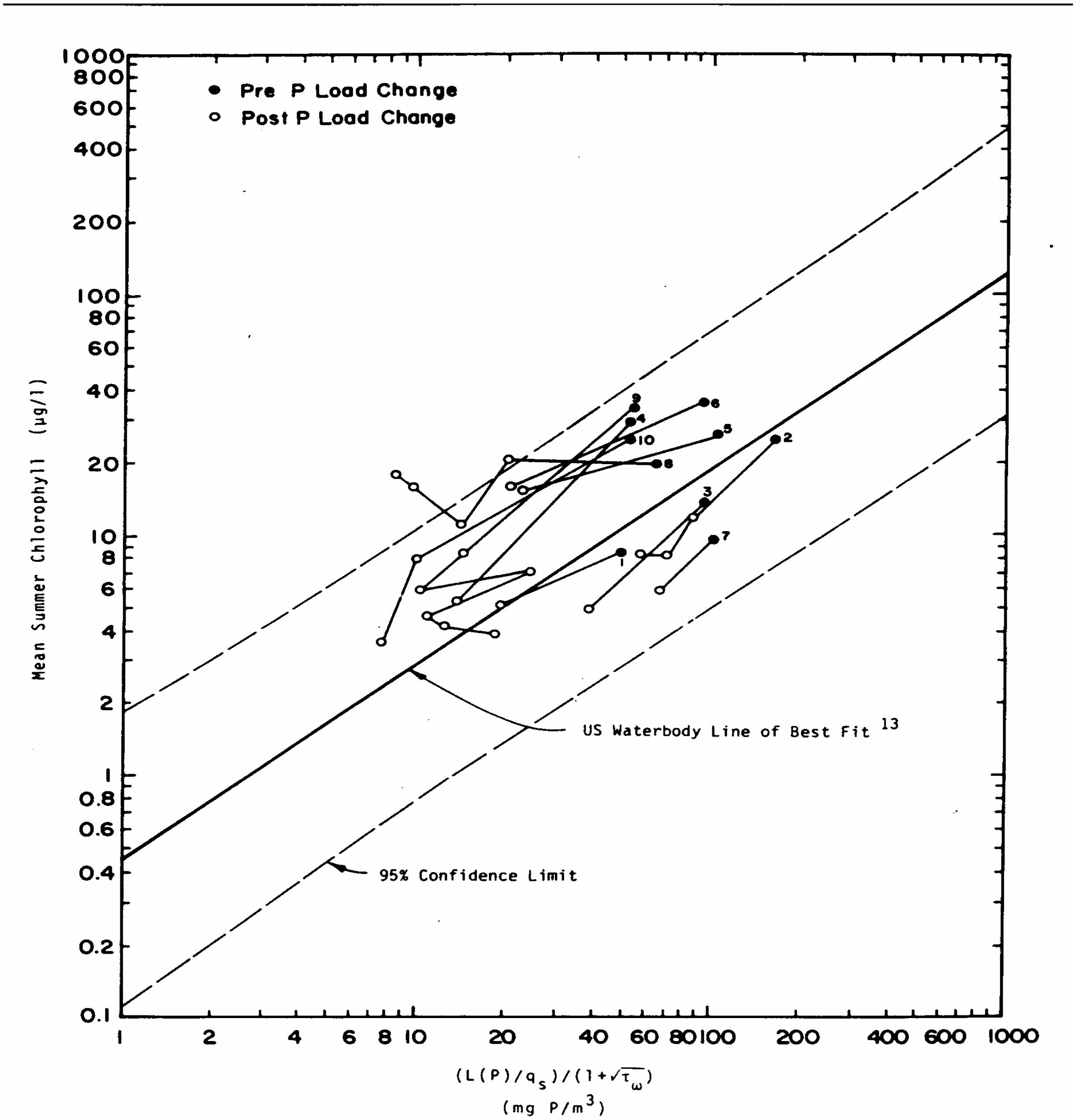
From Lee and Jones (1986).

Impact of Phosphorus Control

A number of studies have shown that significant decreases in algal-related water quality problems occur in waterbodies in which phosphorus control on the inputs to the waterbodies is practiced. Rast, *et al.* (1983) examined the literature for information on how planktonic algal chlorophyll changed in waterbodies where phosphorus control was practiced in the watershed. This information is presented in Figure 13. The basic relationship presented in Figure 13 is the

Vollenweider normalized loading of phosphorus relative to the planktonic algal chlorophyll that develops in the waterbody. It would be expected that waterbodies that respond to phosphorus loading changes would track parallel to the line of best fit for the normalized phosphorus load-planktonic algal chlorophyll relationship. As shown, this is what occurs for many waterbodies.

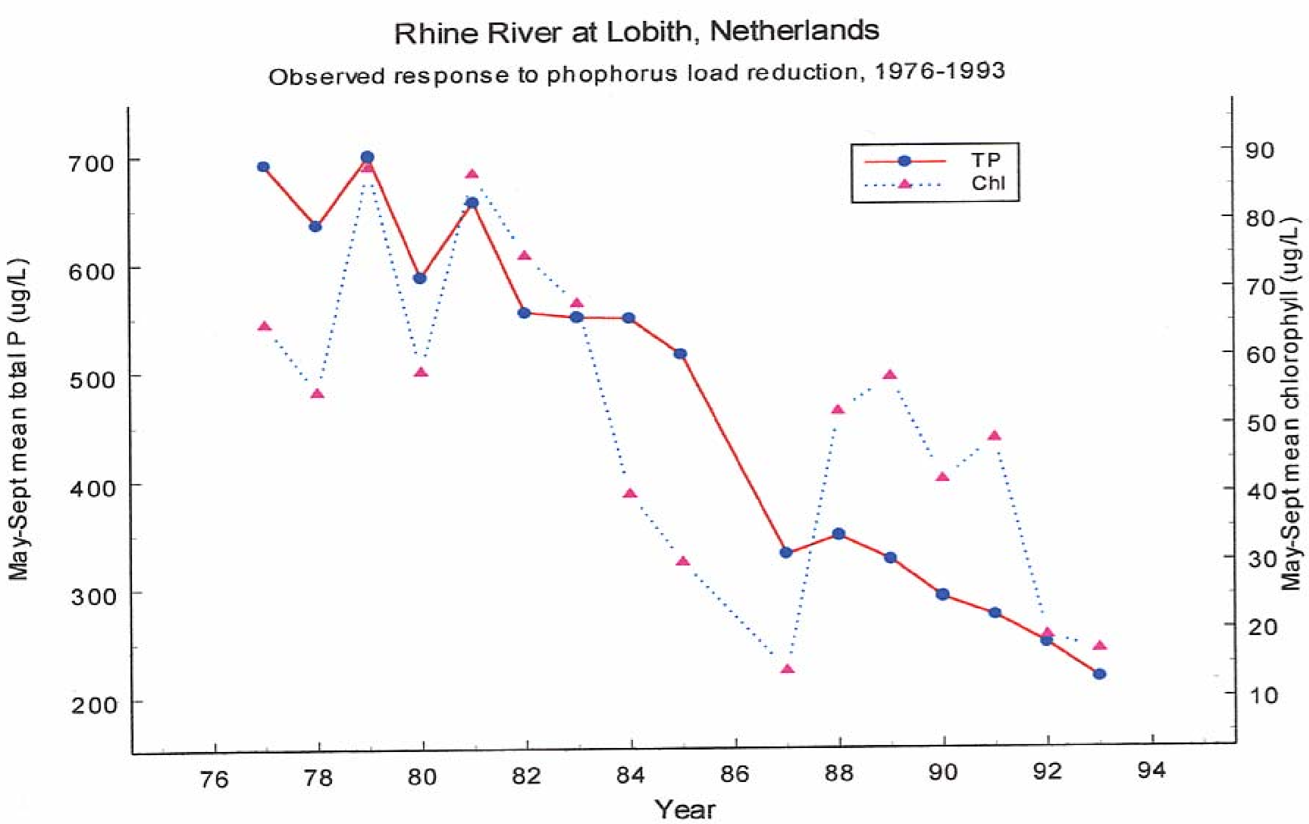
Figure 13. Effect of Phosphorus Loads to Waterbodies on Planktonic Chlorophyll



From Rast, et al. (1983).

It is important to note, however, that the phosphorus concentrations in these waterbodies were not at growth-rate-limiting concentrations. Lee (2001) has recently discussed this issue, pointing out that improvements in eutrophication-related water quality can occur even though growth-rate-limiting concentrations of phosphorus were not achieved in the phosphorus control program. Figure 14 shows the impact of reducing phosphorus loads to the Rhine River in Europe on the planktonic algal chlorophyll found in the River. A similar situation was observed when the phosphorus loads to the Ruhr River in Europe were reduced (Albrechtl, 1988). The DO depletion problems that had been experienced in the River were significantly decreased following reduced phosphorus loading. Again, decreases in phosphorus loading/in-river concentrations to these rivers resulted in decreases in planktonic algae, which reduced the oxygen demand.

Figure 14. Effect of Phosphorus Reduction on Chlorophyll in the Rhine River



Source: *Dutch Governmental Institute on Inland Water Management and Waste Water Treatment (1994). Provided by E. Van Nieuwenhuyse, USBR, Sacramento, CA..*

Rate of Recovery

One of the issues of particular concern in eutrophication management is the rate of recovery of a waterbody following reduction in the nutrient/phosphorus loads. The large amounts of phosphorus stored in lake sediments have caused some to incorrectly conclude that reducing the phosphorus load from the watershed would result in little improvement in water quality. This would be especially true for waterbodies which have long hydraulic residence times. However, Sonzogni, *et al.* (1976) have demonstrated that the rate of recovery of eutrophication-related water quality for waterbodies where a reduced phosphorus load has occurred is governed by the phosphorus residence time in the waterbody. The phosphorus residence time is the total mass of phosphorus in the waterbody divided by its annual load. It accounts for phosphorus removal to the sediments and through the waterbody's outlets. This is typically much shorter than the hydraulic residence time. For example, for Lake Michigan, the hydraulic residence time (filling time) is about 100 years. The phosphorus residence time for this lake is six years. For many waterbodies (lakes and reservoirs), the phosphorus residence time is about one year.

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 its 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 mid-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 began 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. Because of the importance of nutrient criteria and state water quality standards based on these criteria in ultimately determining the degree of treatment/management of nutrients for agricultural runoff/discharges, it is important that those who are developing water quality nutrient control BMPs become familiar with the US EPA's approaches for developing nutrient criteria. A discussion of these issues is presented below.

In formulating the Agency's approach for developing nutrient criteria, the Agency staff and its advisors largely ignored the large 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 wasteful of public and private funds in controlling nutrients derived 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 beneficial uses. To attempt to return waterbodies to the pre-cultural nutrient status would, to some, be detrimental to the fisheries of the waterbodies. As described by Lee and Jones (1991b) in their paper, "Effects of Eutrophication on Fisheries," there is a well-established link between available nutrient concentrations and fish biomass (Figure 5). The classic example of this 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. The fishermen in Lake Erie are now complaining about the poor-quality fisheries due to the overall reduced productivity of the lake. This situation could readily occur in many areas if the US EPA adopts nutrient criteria which represent "pristine" conditions.

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,c, 2001) 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/urban stormwater runoff management 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 for runoff from agricultural/urban lands and other nutrient sources.

The US EPA has proposed two approaches for developing nutrient criteria. The chemical concentration-based default values are based on nutrient concentrations in the water, which are estimated based on pre-cultural activities (no agriculture or urban activities) in the waterbody's watershed. This relationship is shown in Figures 15 and 16. As shown in Figure 15, 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 in the area 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 15. US EPA Default Nutrient Criteria Development Approach

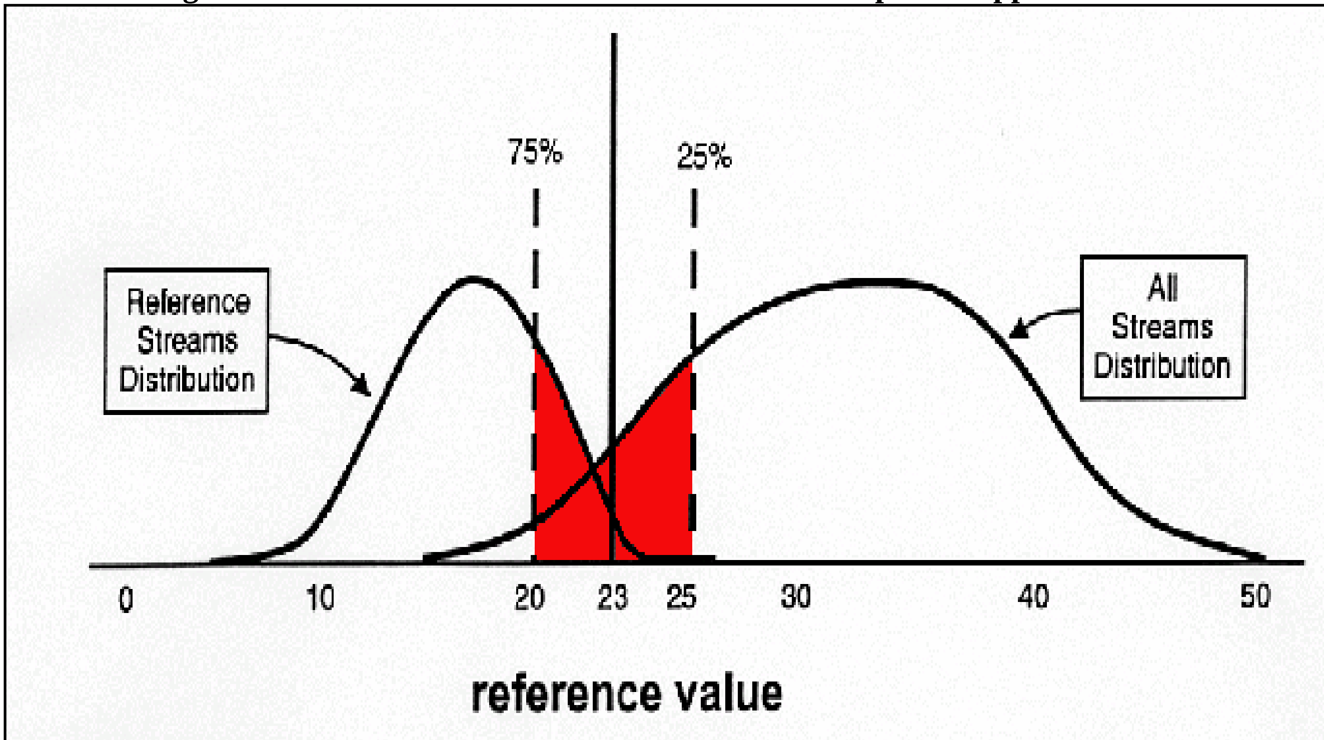


Figure 8. Selecting reference values for total phosphorus concentration (μg/L) using percentiles from reference streams and total stream populations.

Source: US EPA, Nutrient Criteria Technical Guidance Manual, Rivers and Streams (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.

Figure 16. Nutrient Criteria Issues

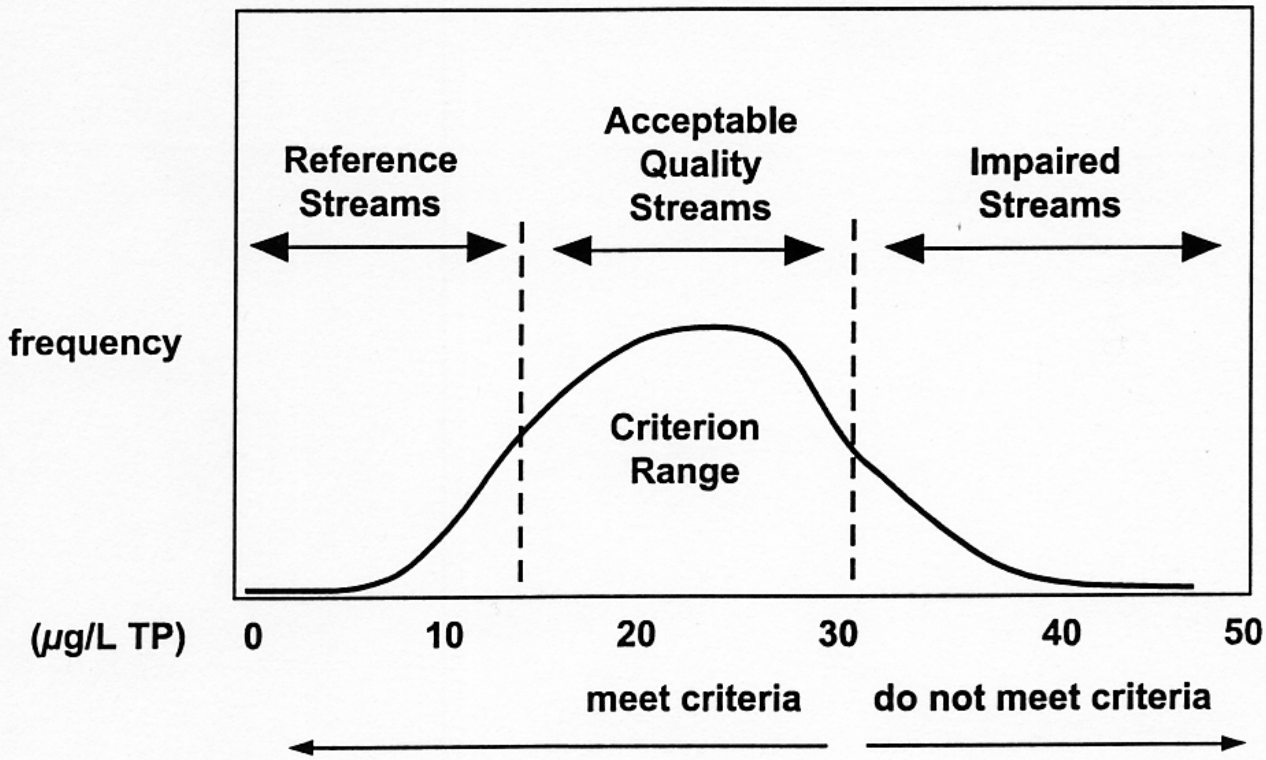


Figure 9. Frequency distribution divided into three segments that represent (from left to right) high-quality reference streams, acceptable quality streams, and impaired streams.

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. 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 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 (1995, 1996) discussed the need for the US EPA to terminate the use of 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 − i.e., what is the excessive fertilization problem of concern?
- 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).
- Developing and initiating a Phase I nutrient control implementation plan to control the nutrients to the level needed to achieve the desired water quality using appropriate BMPs.
- 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 in Phase I 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.

Regionalization of Nutrient Criteria Development within the Central Valley. The development of site specific nutrient criteria in the Sacramento/San Joaquin River watersheds and the Delta should involve regionalization of the watersheds to reflect the differences in how nutrients impact water quality/beneficial uses in various parts of these watersheds and downstream waters in the Delta. The recommended approach toward nutrient criteria regionalization in the Central Valley is presented below.

- **San Joaquin River Basin**
  The San Joaquin River Basin should be defined based on the watershed upstream of Vernalis. This watershed should be divided into two distinct units. One is the reservoirs and upstream of the reservoirs on the eastern side. The other is the rivers, streams and sloughs downstream of the reservoirs on the eastern side, as well as all western side streams, rivers and sloughs.
- **Deep Water Ship Channel**
  Because of its unusual morphological and hydrological characteristics, the San Joaquin River Deep Water Ship Channel between the Port of Stockton and Disappointment Slough/Columbia Cut should be classified as a distinct nutrient criteria unit that needs individual attention. The San Joaquin River Deep Water Ship Channel downstream of

Disappointment Slough/Columbia Cut should be classified as part of the Delta unit. For much of the summer, fall and early winter, the water in the San Joaquin River channel below Columbia Cut is primarily Sacramento River water that is being transported to the state and federal projects' export pumps.

- **Lake McLeod and the Port of Stockton Turning Basin**
  The City of Stockton has special nutrient-related problems in Lake McLeod and the channel that connects the Lake to the Port of Stockton Turning Basin, where, at times, this dead-end channel experiences excessive growths of blue-green algae. This situation is somewhat unique in the Central Valley. This area should be considered a separate single-nutrient criteria unit.
- **Freshwater Part of the Delta**
  The Delta should be classified as a single nutrient criteria unit, although the South Delta may need to be considered as a separate sub-unit, since at times it is dominated by San Joaquin River water that is transported into the South Delta via Old River. The water quality situation will likely change in about 2007 when CALFED installs and begins to operate the permanent barriers in this area.
- **Water Users Downstream of the Delta**
  The water supply reservoirs that are filled to a substantial extent with Delta water that are used for domestic water supply purposes should be considered a separate nutrient criteria unit because of their unique nutrient-caused problems for domestic water supplies.
- **Sacramento River Watershed**
  The Sacramento River watershed below Shasta and all other reservoirs should be classified as a single nutrient criteria unit. A special category of waterbodies in the valley floor of the Sacramento River watershed would include the domestic wastewater and agricultural drain effluent-dependent waterbodies. These waterbodies will likely need to be classified as separate nutrient criteria units since the impairment of the beneficial uses of these waters by nutrients is manifested significantly differently than in the mainstem of the Sacramento River and its major tributaries.

  Upstream of the reservoirs and any tributary that does not have a reservoir on it should be classified as another nutrient criteria unit. The rivers/tributaries to Shasta should be a third unit.

Recommended Nutrient Criteria Development Approach. For each of the nutrient criteria development units, the Regional Board should organize a stakeholder process to hold a series of meetings in each of the regions to allow public input on the nutrient-related water quality that is desired within each region. The Regional Board would then, through normal Board procedures, formally adopt the nutrient eutrophication-related water quality characteristics that, through the public process, are determined to be appropriate.

<u>SJR Mainstem</u>. Some of the characteristics that would be considered for the mainstem and major tributaries below reservoirs for the San Joaquin River would be an impairment of uses related to excessive growths of planktonic algae. Even though there are high nutrient concentrations and high planktonic algal chlorophyll in these areas, it is believed that the public who utilize these areas for recreation or other purposes do not consider the waters in this region "impaired" because of excessive fertility. This is due in part to the high background inorganic turbidity

derived from upstream erosion. In the opinion of the authors, there is no justification for claiming that there is an impairment of the beneficial uses of the San Joaquin River and its major tributaries below the reservoirs, as well as non-reservoir-derived tributaries, due to nutrients. The nutrient criteria issue for the mainstem of the SJR becomes that of establishing criteria for this reach of the mainstem and its tributaries based on the impacts of the nutrients and the algae that develop from the nutrients on the beneficial uses of waters downstream of Vernalis.

While unlikely, it is possible, especially if the high levels of inorganic turbidity derived from upstream watershed erosion were significantly controlled, that the public/stakeholders who are concerned about nutrient-related San Joaquin River water quality could judge that the high levels of nutrients/algae present in the mainstem water are detrimental to the beneficial uses of the River. If this occurs, then the issue of developing nutrient control programs in the SJR watershed to address the perceived nutrient-related water quality problems in the mainstem of the San Joaquin River above Vernalis/Mossdale would need to be considered.

<u>SJR Upstream of Reservoirs</u>**.** With respect to the eastside reservoirs and upstream of these reservoirs, generally, the nutrient-related water quality in the tributaries and the reservoirs is high, and there is no need to limit nutrient inputs to these waterbodies. There may be localized areas, especially downstream of wastewater inputs to the tributaries, where there could be an alteration of the aquatic-life-related characteristics. Under those situations, unless there is severe degradation of the waterbody, it could be appropriate to develop a sub-classification of aquatic-life-related beneficial uses which would allow alteration of the beneficial uses from those that would occur if there were no nutrient inputs from local sources.

<u>SJR Deep Water Ship Channel</u>. The issues of the impact of nutrients on the Deep Water Ship Channel water quality are being addressed in the low-DO TMDL being conducted by the CVRWQCB. The prevention of DO concentrations below the water quality objective through upstream control of algae, carbonaceous oxygen demand and nitrogenous oxygen demand that contribute to the low DO, as well as channel aeration and management of flows through the DWSC, should eliminate the need for any further nutrient control that might arise from exceedances of nutrient criteria, even though the total nutrients present are well in excess of any US EPA default nutrient criteria development guideline value. This approach is recommended since the beneficial uses of the DWSC would be protected if the DO objective is not violated. It should be noted that the impacts of nutrients/algae on the DWSC are significantly ameliorated by the elevated inorganic turbidity present in the channel waters. If the turbidity were reduced, it is possible that the additional algal growth that could occur in the DWSC could impair recreational and other uses of these waters.

<u>SJR Mainstem Tributaries</u>**.** It is unlikely that it will be possible to control nutrient concentrations in the mainstem of the San Joaquin River and the Deep Water Ship Channel to prevent algal growth in the mainstem of the San Joaquin River in excess of the concentrations typically considered desirable. Normally, planktonic algal chlorophyll levels of less than about 10 µg/L are acceptable. As discussed above, however, the elevated planktonic algal chlorophyll within the SJR is not significantly detrimental to the beneficial uses of the mainstem of the River, largely as a result of the inorganic turbidity in these waters. The high cost and the difficulty of controlling nutrients in stormwater runoff from agricultural land and some wastewater discharges

create a situation where it will likely be difficult if not impossible to reduce the nutrient concentrations in the mainstem of the SJR to achieve low levels of planktonic algal chlorophyll in these waters.

During the summers of 2000 and 2001, over 50 to 90 percent of the oxygen demand present in the SJR at Vernalis/Mossdale was derived from algae discharged to the SJR by Mud and Salt Sloughs, and the SJR above Lander Avenue (Highway 165). It may be possible that nutrient control within the tributaries of the SJR (such as Mud and Salt Sloughs and the SJR above Lander Avenue) could potentially significantly reduce the planktonic algal chlorophyll/oxygen demand load within these tributaries so that the headwaters of the SJR start out with significantly lower algal concentrations and, therefore, total oxygen demand. This, in turn, would significantly lower the algal-related oxygen demand that is present in the SJR at Vernalis and that, at times, is discharged to the DWSC. Under these conditions, the residual elevated concentrations of nutrients in the tributary waters would not develop a large algal oxygen demand in their transport to the DWSC, since there is insufficient time between where the tributaries to the SJR enter the SJR and Vernalis/Mossdale to allow algae to develop to excessive levels within the SJR.

Algal Culture Studies**.** There is need to investigate the potential impacts of selective nutrient control in the major SJR tributaries on the potential to reduce the algal-related oxygen demand that is contributed to the mainstem of the SJR that at times represents a significant contribution of oxygen demand to the DWSC. An experimental approach for conducting studies of this type could be based on the work that the senior author conducted in the 1960s and 1970s as part of eutrophication management studies conducted in other areas of the US. The experiments include removing phosphorus from tributary water through the use of alum and examining the growth of algae as a function of the phosphorus content of the water. These investigations could lead to the development of nutrient criteria within the SJR tributaries designed to limit algal growth within these tributaries in order to reduce algal-related oxygen demand contributed to the DWSC.

Delta**.** There are several aspects of the San Joaquin River watershed discharges of nutrients/algae into the Delta that need to be evaluated with respect to the need for nutrient control to protect beneficial uses. One of these is the issue as to whether the nutrients that are developed within the SJR watershed that enter the Delta, either through Old River or through the Deep Water Ship Channel, cause significant adverse impacts on the beneficial uses of the Delta waters. The Delta has several nutrient-related water quality problems, such as excessive growths of water hyacinth and egeria, which necessitate herbicide application for their control. There are low-DO problems within at least the South Delta and possibly the Central Delta related to the algal-caused oxygen demand that develops in the SJR upstream of Vernalis and within the DWSC that is discharged to Delta waters either via Old River or through the DWSC under high SJR DWSC flow conditions. While low-DO situations are documented in the South Delta, there is a lack of data on the dissolved oxygen concentrations in the Central Delta as influenced by the export pumping of South Delta water to Central and Southern California.

Delta Water Exporter Reservoirs**.** The water utilities that export water from the Delta for domestic water supply purposes that store this water in downstream reservoirs experience taste and odor problems and other treatment problems associated with algal growth in these reservoirs.

Part of the nutrients that contribute to these problems are derived from the San Joaquin River watershed. Nutrient control from agricultural and other sources to eliminate algal growth in water utility reservoirs that export Delta water could be expensive, and could be judged to be excessively expensive when considered in light of the ability of agricultural interests in the SJR watershed to financially support anything other than modest nutrient control. One of the issues that needs to be evaluated, however, is whether it may be more cost-effective for the water utilities that experience these problems to provide the additional treatment than to try to initiate nutrient control in the SJR watershed.

Impact of Nutrients on Fisheries Resources. One of the paradoxes of the nutrient situation within the Delta is that some fisheries resource managers feel that there is insufficient primary production within the Delta to support desirable fish populations. It is well-known from the literature that significantly limiting nutrients entering a waterbody will reduce fish biomass. Controlling nutrient inputs to the Delta could be contrary to fisheries production within the Delta. Part of the problem with the low planktonic algal chlorophyll relative to the nutrients available within the Delta is sometimes attributed to invasive benthic organism harvesting of phytoplankton by *Corbicula*, a freshwater clam. There is need to better understand the relationship between phytoplankton biomass in the Delta and fish production.

Summary. In summary, the primary problems of excessive nutrients associated with the San Joaquin River watershed are excessive growths of algae that contribute to the low-DO problem in the DWSC. This problem will be solved through a combination of nutrient control, oxygen demand control, aeration, and management of flows through the DWSC. The focus of the need for nutrient control within the SJR watershed then shifts to problems caused by excessive growths of water hyacinth and egeria and the taste, odor and other water quality problems that develop for domestic water supplies that use Delta waters as a raw water source.

The first step in exploring the development of a nutrient control program in the SJR watershed to control excessive water hyacinth/egeria development and algae in water supply reservoirs is an evaluation of the level of nutrient control needed from the SJR watershed, from the Sacramento River watershed and from in-Delta sources, to manage the water hyacinth/egeria and algal-caused tastes and odors to the desired level. Associated with formulation of a management plan and nutrient criteria to address this issue should be an evaluation of the cost of trying to control nutrients from municipal and industrial wastewaters and agricultural runoff/discharges, as well as atmospheric and other sources.

Establishing Nutrient Load-Eutrophication Response Relationships

Under current guidance, the US EPA provides a default national nutrient criteria development process which is based on an assessment of nutrient concentrations that would be expected in the waterbody in the absence of cultural activities (urbanization, agriculture, etc.) in the watershed. This chemical-concentration-based approach does not necessarily reflect the site-specific nature of how nutrient loads/concentrations impact nutrient-related water quality. The Agency also allows for a "scientifically defensible" development of site-specific nutrient criteria that will protect the beneficial uses of the waterbody for which the criteria are being developed. Generally, those who have worked on eutrophication management find that the US EPA's default nutrient criteria development approach can readily lead to technically invalid assessments of the allowed nutrient loads to a waterbody to protect the waterbody's beneficial uses without unnecessary expenditures for nutrient control.

It is recommended that, for each of the Central Valley nutrient criteria units defined above, site-specific investigations be conducted to determine the appropriate available nutrient load to the waterbody to achieve the public-desired nutrient-related water quality in the waterbody. Generally, this will require the development of an available nutrient load-eutrophication response relationship (model) for the waterbody. Jones-Lee and Lee (2001) provided a review of the OECD nutrient load-eutrophication response relationships that can be used for some waterbodies to estimate the nutrient load to achieve the desired eutrophication-related water quality. This approach, if properly applied, can work well for certain types of waterbodies, especially lakes and reservoirs where the nutrient impacts are manifested in excessive growths of planktonic algae. For other waterbodies, however, such as streams, rivers, near-shore marine waters, etc, there will be need to conduct site-specific investigations to determine the appropriate available nutrient load to achieve the desired eutrophication-related water quality. It is important that those conducting these studies be familiar with and fully understand eutrophication management literature. Failure to do so can lead to unreliable development of nutrient criteria for a waterbody.

In general, the development of appropriate nutrient criteria for a waterbody requires the development of appropriate available nutrient loads to achieve the desired eutrophication-related water quality. As discussed by Jones-Lee and Lee (2001) and Lee and Jones-Lee (2002f), it is extremely important that the available phosphorous load be used rather than the US EPA's recommended approach of total phosphorous, especially from agricultural and urban stormwater runoff. Using total P to estimate the potential impact on the growth of algae can significantly overestimate the amount of phosphorous in the water that is available to support algae and other aquatic plant growth.

With respect to developing nutrient criteria for the Delta, its tributaries and downstream water users, there will be need to develop site-specific nutrient loads which can, in turn, be translated into concentrations for each of the nutrient management units. This process should follow the approach that is used today in developing and implementing TMDLs. The important difference from conventional TMDLs is that the control goal is not a water quality standard, but is a publicly developed desired degree of fertility (eutrophication-related water quality) that is appropriate for each nutrient management unit. This approach can lead to scientifically defensible nutrient criteria for a waterbody.

Control of Phosphorus and Nitrogen Releases/Discharges

The control of excessive fertilization of waterbodies has largely focused on controlling the phosphorus in domestic wastewaters. At this time there are about 100 million people in the world whose domestic wastewaters are treated for P removal. Lee and Jones (1988) have reviewed the North American experience in controlling the excessive fertilization of waterbodies. In general, it has been found that the approach that has been used is to control phosphorus added to the waterbody from domestic wastewater sources through tertiary treatment of the wastewaters. It has been found that such treatment can be practiced at many domestic wastewater treatment plants by alum (aluminum sulfate) addition at a cost of a few cents per person per day for the population served by the treatment plant. In addition to chemical treatment methods, enhanced biological treatment of domestic wastewaters has also been developed to significantly reduce the phosphorus content of domestic wastewaters. Typically, either chemical or enhanced biological treatment can achieve a 90- to 95-percent reduction in the domestic wastewater effluent phosphorus concentrations. This approach is potentially applicable to removal of P in agricultural tailwater ponds.

Nitrogen removal from domestic wastewaters is also possible, although not as readily achievable. This generally involves nitrification of ammonia and organic nitrogen to nitrate, followed by denitrification. The costs are somewhat greater (5 to 10 times) than for phosphorus removal. While phosphorus control in domestic wastewaters is widely practiced, nitrogen control has only been implemented to a limited extent because of the higher cost and the fact that, for most freshwater waterbodies, phosphorus control is the most effective way to control excessive fertilization of the waterbody. While P and N removal have been found to be effective in controlling the excessive fertilization of some waterbodies, there are waterbodies where agricultural land runoff of nutrients is a significant source of nutrients which will need control if the water quality impacts of excessive fertilization are to be effectively managed.

Information on controlling nitrogen and phosphorus in nonpoint source runoff/discharges has been provided earlier in this report. As discussed, traditional agricultural best management practices, such as detention basins and vegetative strips, have not been evaluated with respect to their ability to control nitrogen and phosphorus in agricultural land runoff/discharges in the Central Valley.

The key issue of concern in regulating nutrient discharges under Porter-Cologne relates to the CVRWQCB's Basin Plan (CVRWQCB, 1998) requirements for control of "biostimulatory" substances. According to the Basin Plan,

> ***"Biostimulatory Substances***
>
> *Water shall not contain biostimulatory substances which promote aquatic growths in concentrations that cause nuisance or adversely affect beneficial uses."*

As the nutrient criteria are developed they will likely be used to define excessive discharge of biostimulatory substances (aquatic plant nutrients). As currently planned, the regulation of nutrients as specific chemical species will not likely take place before about 2007. It will take at least that long to proceed from the current state of nutrient criteria development, which is only just beginning, until these criteria are adopted as water quality objectives as part of amending the CVRWQCB Basin Plan.

As discussed elsewhere in this report, considerable attention will soon be given to nutrient discharges from agricultural lands as part of interpretation of the data generated in the CVRWQCB's (2002b) agricultural waiver monitoring program. Nutrients have been specified in both CVRWQCB (2001a) Resolution No. 5-01-236 and by the staff in their December 2001 (CVRWQCB, 2001b) and February 2002 (CVRWQCB, 2002b) draft Phase I agricultural waiver monitoring programs as parameters that are to be monitored. The actual chemical species that are to be monitored have not thus far been defined. Once this monitoring program starts, which is now scheduled to be sometime this fall, there will be need to determine the concentrations of nutrients in waters dominated by agricultural land runoff/discharges that represent excessive concentrations of nutrients. For the next five years or so, excessive nutrients will be defined under the biostimulatory water quality objective. This should involve giving consideration to the variety of factors discussed previously in this report which relate how a nutrient(s) discharge/release from agricultural lands may impact the receiving water's beneficial uses. For those waters which are found to have excessive concentrations of algae or other aquatic plants, there will be need to develop BMPs to control the nutrients in stormwater runoff/tailwater discharges as well as subsurface drain waters. This will lead to the need to select appropriate BMP(s) to manage the excessive discharge of nutrients from agricultural lands.

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