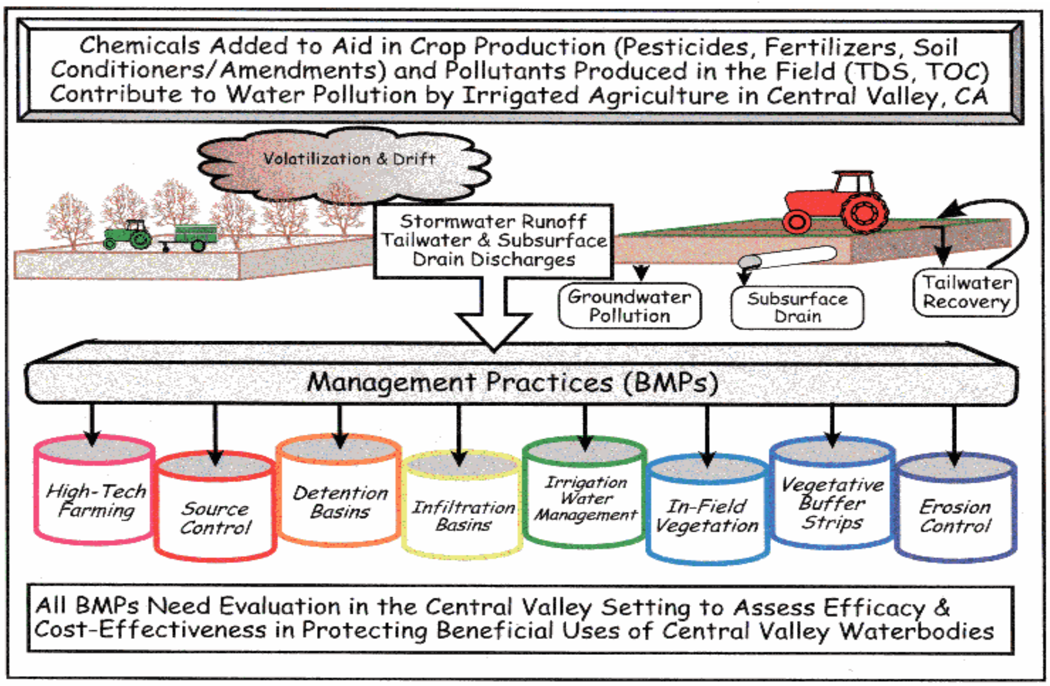
CALIFORNIA WATER INSTITUTE

Report TP 02-05

Review of Management Practices for Controlling the Water Quality Impacts of Potential Pollutants in Irrigated Agriculture Stormwater Runoff and Tailwater Discharges



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Report to
State Water Resources Control Board and the
The Central Valley Regional Water Quality Control Board
Sacramento, CA

December, 2002

DISCLAIMER

This publication is a technical report by staff of the California Water Institute to the California State Water Resources Control Board and the Regional Water Quality Control Board, Central Valley Region. No policy or regulation is either expressed or intended.

Disclosure Statement

Funding for this project has been provided in part by the U.S. Environmental Protection Agency (US EPA) pursuant to Assistance Agreement No. C9-989268-99-0 and any amendments thereto which has been awarded to the State Water Resources Control Board (SWRCB) for the implementation of California's Nonpoint Source Pollution Control Program. The contents of this document do not necessarily reflect the views and policies of the US EPA or the SWRCB, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This project was conducted by Drs. G. Fred Lee and Anne Jones-Lee as employees of the California Water Institute, California State University, Fresno. In addition to the support provided to this project by the California Water Institute and the Central Valley Regional Water Quality Control Board, it was supported by G. Fred Lee & Associates, El Macero, California.

Acknowledgment

The authors appreciate the assistance provided Jerrold. Bruns, and Kelly. Briggs, the Central Valley Regional Control Board. The assistance of Les Grober, Rudy Schnagl and Joe Karkowski, of the CVRWQCB staff, in reviewing the draft report is appreciated. We also wish to acknowledge the initial support given this project by Dr. Valerie Connor, formerly of the CVRWQCB, who was responsible for originally initiating the project. The assistance of various scientists and engineers who provided information which served as the basis for this report is greatly appreciated.

California Water Institute
California State University, Fresno

The California Water Institute was started with seed money provided by the Proposition 13 Water Bond Measure, approved by voters in 2000. The Institute is housed at the California State University, Fresno.

The goal of the Institute is to provide a place where agricultural, urban, and environmental interests can be brought together in an unbiased, open, collaborative process to develop a shared vision of how to best utilize our water resources. It is the stated purpose of the Institute to work on collaborative solutions to pressing water issues facing the State. The staff of the Institute includes economists, chemists, crop water usage specialists, resource specialists, and environmental engineers. In addition, faculty at the California State University, Fresno, collaborate with the Institute in important research efforts.

Project Organization

This project was originated by Dr. Valerie Connor, then of the Central Valley Regional Water Quality Control Board (CVRWQCB), now with the State Water Resources Control Board. In its initial conception, an overview discussion of the potential effectiveness of best management practices (BMPs) for control of potential pollutants in agricultural land stormwater runoff/tailwater discharges in the Central Valley was to be presented in this report. Drs. G. F. Lee and A. Jones-Lee have many years of experience in evaluating the water quality impacts of agriculturally-derived potential pollutants. Dr Lee's work on urban stormwater runoff water quality management began in the 1960s while he was a Professor of Water Chemistry and Director of the Water Chemistry Program at the University of Wisconsin, Madison. Further, the authors have been working with Mr. S. Taylor of RBF Consulting of Irvine, California, since the mid-1990s, in developing BMPs for controlling potential pollutants in urban area and highway stormwater runoff.

The urban stormwater runoff water quality management community has developed compilations of BMPs that can be used to "manage" the water quality impacts of potential pollutants in urban stormwater runoff. This information has been summarized in Drs. Anne Jones-Lee and G. Fred Lee's Stormwater Runoff Water Quality Science/Engineering Newsletter (see www.gfredlee.com). These BMPs are, in general, the same as those that are advocated as water quality BMPs for agricultural land runoff/discharges. As originally envisioned, this report was to provide guidance on BMP selection that could be used by the agricultural community, regulatory agencies and others for controlling the water quality impacts of irrigated agriculture stormwater runoff and tailwater discharges in the Central Valley of CA.

It was thought that, through a review of the agricultural water quality BMP literature, a similar compilation of information could be developed for the same kinds of BMPs used in urban stormwater runoff water quality management, as for stormwater runoff-associated constituents derived from agricultural lands. Upon initiation of this study, it was found that the US EPA contracted with North Carolina State University to develop a comprehensive review of agricultural water quality BMPs. This report was completed in draft form in 2000. It covered the topics that were originally envisioned to be topics that were to be covered by the authors in developing the review of the agricultural BMP literature that was to be completed in this study. The authors (Lee and Jones-Lee) have conducted additional literature review and have found that the US EPA-developed report reliably presents the current state of information on agricultural water quality BMPs. It was found by the US EPA (North Carolina State University) and the authors, based on review of the agricultural water quality BMP literature, that the state of the science/engineering and experience was such that it is not possible to develop typical expected removals and the associated costs of BMPs to remove the dominant potential pollutants in agricultural land stormwater runoff that are applicable to irrigated agriculture in the California Central Valley situation. As discussed herein, there have been few quantitative investigations of the amounts of pesticides, nutrients, total organic carbon, salts, and other constituents of potential concern that are removed by conventional agricultural water quality BMPs that are applicable to the situation in the Central Valley of California.

At this time, there is some qualitative information available on the effectiveness of conventional agricultural water quality BMPs in controlling organophosphate pesticide stormwater runoff/discharges in the Central Valley of California, through the work of the Sacramento River Watershed Program OP Focus Group. Further, as a separate topic under this contract, guidance is being developed by the authors on the approach for managing the excessive bioaccumulation of the organochlorine legacy pesticides, such as DDT, dieldrin, toxaphene, etc. The CVRWQCB staff, working with agricultural interests in the San Joaquin River Watershed, has developed or is developing BMPs to control selenium, boron and total dissolved solids derived from agricultural lands. The greatest information gap that exists now for controlling one of the major water quality problems in the Central Valley occurs with approaches that could be used to develop best management practices for nutrients (nitrogen and phosphorus compounds) derived from agricultural lands.

There is increasing awareness that nutrients (nitrogen and phosphorus compounds) are a major cause of water quality impairment in the Central Valley. With the development of chemical-specific numeric water quality nutrient criteria/standards, the number of waterbodies in the Central Valley that are classified as impaired because of excessive concentrations of nutrients will likely increase significantly. This could lead to a Clean Water Act 303(d) listing of these waterbodies for which TMDLs to control nutrient runoff/discharges will have to be developed. There is already growing need for information on nutrient control BMPs. The demand for information in this topic area will increase significantly in the next few years. This report provides guidance on how technically valid, cost-effective BMPs for control of nutrients in agriculture stormwater runoff/tailwater discharges could be developed.

This report provides an overview review and guidance to the literature on the information available on Central Valley agricultural practices (BMPs) that are, or could be, used to control the discharge/releases of agriculturally-derived pollutants. In addition, information is provided on the approach that can be used to develop appropriate BMPs to manage stormwater runoff/tailwater discharges of aquatic plant nutrients from irrigated agriculture in the Central Valley.

G. Fred Lee, PhD, DEE
Anne Jones-Lee, PhD

Executive Summary

With increased attention being given to controlling the water quality impacts of chemical constituents present in stormwater runoff and tailwater discharges from irrigated agricultural land, there is need to apply best management practices (BMPs) to control the runoff/discharge of potential pollutants that are impairing the beneficial uses of the receiving waters for the runoff/discharge. The US EPA (2002a) uses "management measures" rather than the term "BMPs" to describe control programs, based on the uncertainty as to what is the "best" management practice. In this review "management measures," "management practices," and "BMPs," are all used synonymously.

A review of the literature on agricultural water quality BMPs shows that there is limited quantitative information on the ability of various so-called "BMPs" that are sometimes advocated as treatment technology to reduce the concentrations of chemical constituents in agricultural land runoff/discharges nationally. This lack of information is particularly acute in the Central Valley of California, where there are potentially a dozen or so TMDLs that could be implemented in the San Joaquin River watershed over the next 10 years or so to control constituents that are present in agricultural land runoff/discharges. There is need to provide agricultural interests, the regulatory community and others, with quantitative information on potential water quality BMPs that could be applied to a particular type of agricultural land runoff/discharge situation to control one or more potential pollutants in the discharge/runoff to a specified degree in a cost-effective manner.

While it was not possible to develop a compilation of how various types of conventional agricultural runoff BMPs would be expected to control various types of agriculturally-derived pollutants in Central Valley runoff/discharge waters, information of this type for the same types of BMPs and constituents is provided in this report for urban stormwater runoff. The urban stormwater runoff water quality management field faces many of the same water quality problems as occur with agricultural stormwater runoff. Urban stormwater management BMP development is considerably advanced over agricultural water quality BMP development and, therefore, can provide guidance to the agricultural community on appropriate BMP development.

While the original purpose of this study was to provide overall guidance on the potentially effective BMPs for agricultural land runoff/discharges for the common potential pollutants such as pesticides, nutrients, and other constituents, the lack of information in this topic area necessitated a revision in the originally anticipated approach in developing this report. Rather than providing information on the potential effectiveness of vegetative areas and detention ponds, etc., for various types of agricultural runoff settings that occur in the Central Valley of California, the focus of this report became one of developing guidance on how to properly develop BMPs to control potential pollutants in agricultural land runoff/discharges. The potential pollutants that are derived from irrigated agricultural land runoff/discharges that are among those of greatest concern in the Central Valley are pesticides, nutrients, salts, sediments, and specific toxicants such as selenium and boron. While there are a number of other potential pollutants of concern, such as total organic carbon (TOC), the degree of understanding of their impacts and amounts derived from various agricultural sources is poorly understood.

That type of information must first be obtained before BMPs to control their impacts can be developed.

Selenium, TDS, Boron

A special situation occurs in the Grasslands area of the Central Valley, where the discharge of selenium, total salts (TDS) and boron by irrigated agriculture is of concern in parts of the Mud Slough and Salt Slough watersheds in the San Joaquin River watershed. Agricultural interests in this area have investigated the agricultural practices that result in elevated selenium releases. They are associated with the management of subsurface drain water arising from a perched water table that results from the practice of irrigated agriculture in the area. The subsurface drains transport selenium from the perched groundwater to surface waters. The selenium associated with subsurface drain waters is being managed through water management techniques.

At this time, consideration is being given to various irrigation and stormwater runoff water management approaches for controlling the discharge of salts and some other potential pollutants derived from agricultural lands. This is an evolving area of concern related to complying with the TDS TMDL that is being adopted by the CVRWQCB.

Managed Wetlands

Substantial areas of the Central Valley are devoted to federal and state wildlife refuges and duck clubs. These areas are managed wetlands where the managers control water additions and releases. Water releases from these managed wetlands contain a variety of potential pollutants, such as TDS, total organic carbon (TOC), nutrients (N and P), and other constituents. It is possible that operators of managed wetlands for wildlife habitat will need to adopt altered water-management practices to control the adverse impacts of chemical constituents in the wetlands discharges.

The Sacramento-San Joaquin River Delta serves as the domestic water supply for about 22 million people in California. Water utilities that use Delta water as a water supply source experience water quality and water treatment problems due to constituents such as TOC, nutrients that develop into algae, and TDS that impair wastewater recharge. The San Joaquin River watershed and the Delta have been shown to be significant sources of pollutants that impair the use of Delta waters for domestic water supply purposes. There is need to understand the agricultural practices within the Delta watershed and the Delta that lead to excessive concentrations of pollutants that impair the use of Delta water for domestic water supply purposes, and develop management practices to control the constituents of concern at their source. At this time there is essentially no information on the control of TOC in agricultural and managed wetland stormwater runoff and discharges.

The growing of rice in the Sacramento River watershed has led to problems with adverse water quality impacts of chemicals (herbicides) used in rice farming in waterbodies that receive water releases from rice fields. BMPs were developed by the rice industry to control these water quality problems based on an understanding of the aquatic chemistry of the herbicides, which led to holding the rice field drainage water for a sufficient period of time to allow the chemicals added to the fields that were causing downstream water quality problems to decay sufficiently to control the chemical-caused water quality problems.

OP Pesticides

Since extensive work has recently been done on the potential BMPs that could be used to control the concentrations of organophosphate (OP) pesticides, such as diazinon and chlorpyrifos, in stormwater runoff from irrigated agriculture, a summary of this work and conclusions developed from it, as well as references to recently developed reports, are provided herein. It has been found that while there are a number of potential management practices that could reduce/eliminate the discharge of OP pesticides from agricultural lands, at this time there is a lack of quantitative information on the efficacy and cost of these management practices.

Sediments, Turbidity

The discharge of sediments associated with agricultural land erosion is an issue of particular concern in some areas of the Central Valley, especially on the west side of the San Joaquin River. Progress is being made in controlling erosion through improved agricultural practices as well as through the use of organic polymers (PAM).

Pathogens

Pathogen indicator organisms and human pathogens are receiving increased attention as a cause of water quality impairment for the use of waters for contact recreation or domestic water supplies. The US EPA is requiring that states adopt *E. coli* or enterococcus as a fresh-water indicator organism water quality standard to evaluate the suitability of a water for contact recreation. This will lead to greater monitoring of waterbodies for pathogen indicators such as *E. coli*. Such monitoring will likely show that agricultural lands are significant sources of these organisms. This in turn can lead to 303(d)-listed waterbodies for which management practices will need to be developed to control the discharges/releases of *E. coli* from agricultural lands. At this time there is limited understanding of the agricultural practices that lead to elevated concentrations of *E. coli* and therefore the management practices that need to be implemented to prevent the pollution of waterbodies by *E. coli* in stormwater runoff and tailwater discharges from agricultural activities.

DO Problems

The San Joaquin River Deep Water Ship Channel (DWSC) near Stockton, California, experiences low dissolved oxygen concentrations that violate water quality standards. This has led to the DWSC being listed as a Clean Water Act 303(d) impaired waterbody for which a TMDL must be developed to control violations of the DO water quality standard. Studies have shown that one of the major sources of oxygen demand for the DWSC is algae that develop in the San Joaquin River watershed based on nutrient discharges from agricultural lands. There is need to develop management practices that can be used to control nitrogen and phosphorus discharges from agricultural lands that develop into algae that are transported to the DWSC where they die and decompose, consuming oxygen in the process.

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.

Organochlorine Pesticides, PCBs, Dioxins/Furans

Eleven waterbodies in the Central Valley are listed as Clean Water Act 303(d) impaired because of excessive bioaccumulation of organochlorine "legacy" pesticides, PCBs or dioxins/furans in edible fish tissue. These chemicals are called OCls in this report. The legacy pesticides include DDT, chlordane, dieldrin, toxaphene and other chlorine-based pesticides that were banned 10 or more years ago because of adverse impacts on birds and other wildlife. These pesticides are regulated as human carcinogens. The OCls tend to bioaccumulate in edible fish tissue, and therefore are a threat to those who use as food fish containing elevated concentrations of OCls. They also tend to be strongly sorbed by soils and aquatic sediments.

Lee and Jones-Lee (2002a) have recently reviewed the existing database on OCls in Central Valley waterbody fish and other aquatic organisms. They have recommended an approach for managing the excessive bioaccumulation of the OCls in edible Central Valley fish. The recommended approach involves determining the amount of the OCls that are contributed to the 303(d)-listed waterbodies from the waterbodies' watersheds. If current stormwater runoff/discharges are still contributing OCls to the waterbody then management practices should focus on controlling the OCl-containing soils at their source. The other component of the recommended OCl management program is to identify the in-waterbody sediments that are contributing OCls to fish that are bioaccumulating excessive OCls. This management practice could require removal/burial of the OCl-containing sediments.

Sediment Toxicity

It is likely that aquatic sediment toxicity will be found in Central Valley waterbodies that is due to discharges of pesticides and/or nutrients derived from irrigated agriculture runoff/discharges. Management of sediment toxicity will require identification of the cause of the toxicity and then its origin. This can lead to the development of appropriate management practices to control the sediment toxicity.

Science of BMPs

Information is presented in this report on developing management practices based on the basic physics, chemistry, hydrology and biology that govern the mechanisms of potential pollutant removal. It is suggested that those developing agricultural runoff/discharge management practices become familiar with the water and wastewater treatment methodologies as well the development of urban and highway stormwater runoff BMPs. Following this approach would lead to improved agricultural BMPs.

Integrated Approach

It is recommended that the water quality stakeholders (agricultural interests, regulatory agencies, environmental groups, and the public) in each of the major tributaries of the San Joaquin River and Sacramento River watersheds, as well as the mainstem of each river, organize an integrated water quality monitoring program to define the potential water quality problems in each watershed and downstream thereof that are caused by constituents derived from the watershed. This monitoring program should follow the approach recommended by Lee and Jones-Lee (2002a) for conducting a comprehensive watershed-based NPS water quality evaluation. Also, the stakeholders in various parts of the Delta (south, mid, northeast) should conduct comprehensive water quality monitoring programs in their part of the Delta. The focus of these monitoring programs should be on determining whether regulated potential pollutants exist in the State's waters within the watershed at concentrations that exceed CVRWQCB water quality objectives. An Evaluation Monitoring (Jones-Lee and Lee, 1998a) approach should be used which focuses on determining the impacts of chemical constituents and pathogen-indicator organisms on the beneficial uses of waters within the watershed.

The results of these monitoring programs should be used to define the constituents that cause significant water quality use impairment in the watershed or parts thereof. Based on this information, the stakeholders in the watershed should organize an integrated management practice (BMP) evaluation program to determine the degree of control of the constituents of concern that can be achieved at various costs. This information should then be used by the stakeholders to formulate a technically valid cost effective NPS and point source management program to protect the designated beneficial uses of the waterbodies in the watershed as well as downstream.

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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)

Definitions - Terminology[1]

A major problem within the water quality management field is a lack of common understanding of water-quality-related terminology relative to regulatory requirements and appropriate evaluation of water quality. This lack of understanding, especially as it relates to developing technically valid, cost-effective water pollution control programs, leads to over-regulation of wastewater discharges and stormwater-runoff-associated constituents for which there are water quality criteria/standards. It also leads to under-regulation of real, significant water quality use impairments for the unregulated constituents for which there are no water quality criteria/standards. It is important to use such terms as "pollutant," "pollution," "water quality," "water chemistry," etc., in accord with legal and technically correct usage to eliminate the inappropriate characterization of a water quality evaluation situation. Presented below are definitions of many of these issues that are discussed in this report.

Administrative Exceedance

An "administrative exceedance" of a water quality standard occurs when concentrations of a constituent are present in waters at concentrations above the standard without adverse impacts to aquatic life and other beneficial uses. For example, nontoxic forms of copper can be present in a waterbody above a water quality standard that is based on copper toxicity under worst-case exposure conditions without adverse effects on aquatic life.

Aquatic Life Adverse Impact

In order for a chemical constituent to be adverse to the beneficial uses of a waterbody, and therefore be a pollutant, it is necessary that the chemical constituent cause an altered number and/or altered types/characteristics of desirable forms of aquatic life.

Aquatic Chemistry

"Aquatic chemistry" is the physical, chemical factors/reactions that control the distribution of chemical species that impact how a chemical affects water quality-beneficial uses. It includes the transport (advection and mixing) and transformations-reactions (kinetics and thermodynamics) that control the concentrations of chemical species in a waterbody. Aquatic chemistry is not a list of the concentrations of chemical constituents found in a water or sediment sample. Such a list is a summary of chemical characteristics, not chemistry.

Aquatic Toxicity

"Aquatic toxicity" is assessed by determining the effects of a chemical or water or waste sample on a test organism. Typically it is assessed through the use of a standardized toxicity test. The term "bioassay" is sometimes used synonymously with "toxicity test." This usage is inappropriate.

Benthic Organism Assemblages

"Benthic organism assemblages" are the macroinvertebrates that live within or upon aquatic sediments. The numbers and types of benthic organisms associated with the sediment is

1 Derived from Lee and Jones-Lee (1999).

an important indicator of water pollution/water quality impairment when appropriately evaluated relative to aquatic life habitat characteristics of the waterbody.

Best Professional Judgment Triad Weight of Evidence Water Quality Evaluation

"Best Professional Judgment (BPJ) Triad Weight of Evidence (WOE) water quality evaluation" is becoming recognized as the approach that should be used to determine whether the beneficial uses of a waterbody are impaired by a particular chemical or group of chemicals. A BPJ Triad WOE involves an expert panel's integration of the aquatic toxicity/bioaccumulation, aquatic organism assemblage, and aquatic chemistry information to determine the degree of impairment that occurs in a waterbody due to discharges of potential pollutants.

Cause of Aquatic Life Adverse Impacts

The association (cooccurance) of elevated concentrations of a constituent in water and/or sediments with aquatic life toxicity or altered organism assemblages is not a valid basis for assessing the cause of adverse impacts. Site-specific studies involving assessing cause and effect must be used to determine if chemical constituents in water or sediments are responsible for aquatic-life-related adverse impacts.

Excessive Bioaccumulation

"Excessive bioaccumulation" of chemicals occurs when the tissue residue-body burden of the chemical within edible aquatic organisms exceeds US EPA or other risk-based guidelines.

Pollutant

A "pollutant" is a chemical constituent that impairs the designated beneficial uses of a waterbody.

Pollution

"Pollution" is defined in the Clean Water Act as an impairment of the beneficial use(s) of a waterbody. Finding chemical constituents in elevated concentrations in the water column or sediments is not "pollution" unless these constituents are impairing the designated beneficial uses of the waterbody.

Water Quality

"Water quality" should be assessed based on the characteristics of the water relative to the beneficial uses of the water. "Water quality" is not, as frequently used, a list of chemical constituent concentrations. In order to reliably assess whether the concentration of a constituent(s) impairs the water quality – beneficial uses of a waterbody, it is necessary to evaluate on a site-specific basis whether the constituent is present in toxic/available forms at a critical concentration for a sufficient duration to be significantly adverse to aquatic life that are important to the beneficial uses of the waterbody, or adversely impacts other beneficial uses of a waterbody.

Water Quality Assessment

A "water quality assessment" is an evaluation of the beneficial use impairment that is occurring, or could potentially occur, due to the presence of a particular chemical(s) or other constituent. It is not an assessment of the frequency of exceedance of a water quality standard.

Water Quality Standard Compliance

"Water quality standard compliance" is based on an assessment of the frequency of exceedance of a water quality standard in ambient waters receiving the discharge/runoff. Such compliance does not ensure that the beneficial use of the waterbody is being protected or that significant over-regulation is not occurring.

Review of Irrigated Agricultural Runoff/Tailwater Discharges Water Quality Management Practices

With increasing attention being given to controlling the water quality impacts of chemical constituents in stormwater runoff and tailwater discharges from irrigated agriculture, there is need for information on cost-effective control programs to manage pollutant discharges from irrigated agriculture. This situation is becoming increasingly important in the Central Valley of California, especially in the San Joaquin River watershed and the Delta. Generally, agricultural land runoff/discharges are to be controlled through the application of best management practices (BMPs). Table 1, from Appendix A in this report, presents a list of the constituents that are or could be subject to TMDLs to control their export from irrigated agriculture in the San Joaquin River watershed.

Table 1
San Joaquin River Watershed TMDLs

Current TMDLs Being Implemented

- Selenium
- Salinity, Total Dissolved Solids
- Boron
- OP Pesticides (Diazinon, Chlorpyrifos)
- Oxygen Demanding Substances, (BOD, Ammonia, Organic N)

Pending TMDLs

- Organochlorine Pesticides, (DDT, Chlordane, Dieldrin, Toxaphene, etc.)
- PCBs
- Mercury
- Unknown-Caused Toxicity
- Toxicity to Algae (Herbicides)

Potential Future TMDLs

- Nutrients, Excessive Fertilization (Nitrogen and Phosphorus Compounds)
- High pH, Low DO caused by Excessive Fertilization (Photosynthesis)
- Alternative Pesticides to OP Pesticides
- Total Organic Carbon, Trihalomethanes in Domestic Water Supplies
- Excessive Sediment, Erosion, Turbidity
- Pathogen-Indicator Organisms, *E. coli*
- Sediment Toxicity, Pesticides, Nutrients/Algae/Sediment Ammonia
- Temperature (?)
- Dioxins/Furans, Combustion Residues (?)

Background information on the constituents listed in this table is provided in Appendix A (Lee and Jones-Lee, 2002b). Some of the constituents listed in Table 1 are of water quality concern in the Sacramento River watershed as well. These are the constituents that have been found or are likely to be found in Central Valley irrigation runoff/discharges at sufficient concentrations to impair the beneficial uses of receiving waters for the runoff/discharges. A summary of the current status of management practices (BMPs) for irrigated agricultural runoff/discharges in the Central Valley of California for the constituents listed in Table 1 is presented below.

Conceptual Model of Irrigated Agriculture Water Quality Management Practices Selection/Evaluation

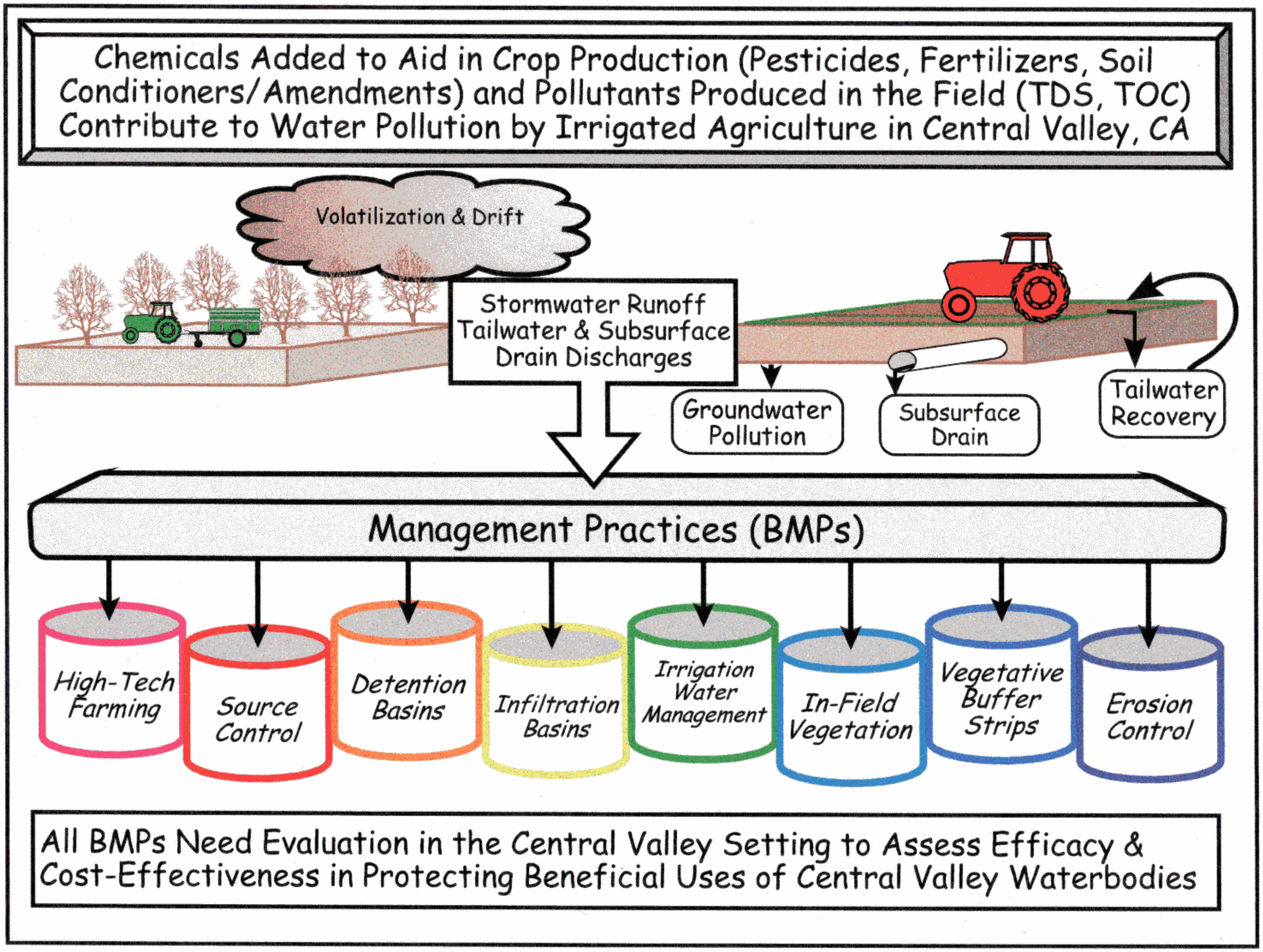
Figure 1 presents a diagram of the agricultural water quality management practices selection and evaluation process. For an agricultural field there are a variety of chemicals (pesticides, fertilizers, soil amendments, etc.) that are added to an area to enhance crop production. Each of these chemicals and their transformation products has the potential to be present in stormwater runoff, tailwater discharges to surface waters, and infiltrating water at sufficient concentrations to pollute (impair the beneficial uses of) surface and/or ground waters. In addition, a variety of chemical compounds are generated on agricultural lands that can also be pollutants (such as TDS, TOC, etc.) to surface and ground waters. Also, some of the applied chemicals can be volatilized/released/transported to the atmosphere and therefore have the potential to cause water pollution at the location where there is precipitation/fallout of the agricultural chemicals. The chemicals of concern in the Central Valley agricultural releases are listed in Table 1.

For each of the chemicals and pathogen indicator organisms that potentially could be present in runoff/discharges from agricultural areas, there are a variety of potential management practices (BMPs) that can reduce/control the concentrations of potential pollutants in runoff/discharges. There are several types of BMPs for the control of water quality impairments caused by agricultural stormwater runoff/discharges. One of these is devoted to source control. Through adjusting the rate of application, time of application, method of application, etc., of chemicals of concern, it may be possible to reduce the losses/discharges of the chemicals of concern. As an example, as discussed herein, there is potential for altered application of diazinon as a dormant spray in orchards to reduce the stormwater runoff associated with aquatic life toxicity.

The source control management practices include replacement of one chemical of concern such as a pesticide with another that has less potential to be present in runoff and discharges or has less potential to be adverse to receiving water quality. The substitution of pyrethroid pesticides, which are less mobile, for OP pesticides has the potential to reduce the aquatic life toxicity in stormwater runoff from dormant-sprayed orchards. Just the opposite can also occur, however, where the substituted chemical causes even greater water quality problems than the original chemical. The greater toxicity of the pyrethroid pesticides, especially to fish, could cause greater toxicity in the receiving waters for stormwater runoff for pyrethroid-pesticide-treated agricultural areas.

With increasing attention being given to protecting the sanitary quality of surface waters for contact recreational use, there is need to define the sources of pathogen-indicator organisms, especially *E. coli,* in agricultural land stormwater runoff and tailwater discharges. Some agricultural practices such as the use of manure and sewage sludge (biosolids) on agricultural lands can lead to increased *E. coli* discharges in runoff/tailwater discharges. Since *E. coli* can also be derived from wild animals, it will be important to gain an understanding of the sources of *E. coli* in agricultural land runoff/discharges and develop management practices to control excessive discharges of pathogen-indicator organisms.

Figure 1. Conceptual Model of Agricultural Water Quality Management Practices.



An agricultural water quality management practice that shows considerable promise to reduce the water quality impacts of discharges from agricultural lands is precision (high-tech) farming. Through analysis of soil characteristics and small regional crop fertilizer and pesticide needs, it is possible to reduce runoff and losses of chemicals applied to farm land and improve crop yield at a reduced cost for chemicals. Experience in other areas with precision farming indicates that this approach may be cost-effective for controlling chemicals in farm land runoff/discharges.

Agricultural management practices involving altered irrigation water management have the potential to reduce water quality impacts of chemicals added to agricultural lands or generated on agricultural lands that cause water quality problems in irrigation tailwater. The use of drip irrigation rather than furrow or flood irrigation can greatly reduce/eliminate tailwater discharges and therefore the loads of chemicals of concern in irrigation discharge waters to receiving waters. Tailwater recovery systems can also potentially reduce the discharges of potential pollutants and improve water use efficiency.

Subsurface drain waters associated with irrigated agriculture in some parts of the San Joaquin River watershed (Grassland area) have been found to contribute several pollutants (selenium, boron, TDS, nutrients, etc.) to Central Valley waters. The Grassland area farming interests have found, through a detailed monitoring program of water and chemical concentrations, that they can control selenium discharges to achieve the regulatory limits. Similar approaches may need to be used for the other pollutants discharged from farming areas with subsurface drains.

Substantial areas of the Central Valley are devoted to federal and state wildlife refuges and private duck clubs. These areas are managed wetlands where the area managers control the addition and discharge of water from the area. The discharges from these wetland areas can contain elevated total dissolved solids, total organic carbon, nutrients and other potential pollutants. The management of discharges from these wetland areas may require altered water management practices from the current practices.

Rice farmers in the Sacramento Valley were able to solve the problem of aquatic life toxicity caused by herbicides used to control weed growth in rice fields by holding the field water until the chemical of concern had decayed sufficiently to eliminate the toxicity to aquatic life in the receiving water for rice field discharge waters. There is concern, however, that this practice may be leading to groundwater pollution under the rice field. It is important that the in-field irrigation water management does not lead to greater groundwater pollution through providing greater infiltration of the irrigation waters and their associated chemicals. Of particular concern are BMPs that involve holding the water on the field, as well as the use of infiltration basins to reduce surface water runoff/discharges.

Erosion of farm land is a significant cause of water quality impairment in some parts of the Central Valley. Erosion leads to excessive turbidity in agricultural land runoff receiving waters. The suspended solids in agricultural land runoff also result in loss of aquatic life benthic habitat and, at some locations, shoaling, which interferes with navigation of a waterway. Modified farming and water conveyance practices can reduce erosion. Some success is being achieved in the Central Valley in erosion control through the use of organic polymers (PAM) which tend to bind the soil.

Discharge water treatment management practices such as detention basins, field cover crop-vegetation, vegetative buffer strips and grassy swales, are commonly considered as agricultural water quality BMPs that can be used to "treat" the runoff/discharge waters from agricultural fields. While there has been some evaluation of the efficacy and cost of the "common" agricultural treatment BMPs in other parts of the country, this information is lacking in the Central Valley.

Provided below is a discussion of many of the agricultural water quality management practices that have the potential to reduce the impact of irrigated agriculture stormwater runoff and tailwater/subsurface drain water discharges to Central Valley waterbody water quality-beneficial uses. As discussed, there is limited quantitative information on the efficacy, factors influencing the management practice efficacy, and cost-effectiveness of standard practices in controlling water quality impairment within the Central Valley. Guidance is provided on a recommended approach to cost-effectively manage the water quality problems caused by stormwater runoff and discharges from Central Valley agriculture.

Management Measures to Control Nonpoint Source Pollution from Agriculture

The US Committee for Irrigation and Drainage (USCID, 1998) held a conference in 1997 devoted to "Best Management Practices for Irrigated Agriculture and the Environment." This conference was held in Fargo, North Dakota. Most of the papers presented at the conference were concerned with agricultural water quality BMPs for upper Midwest conditions. While a couple of the papers presented at this conference (discussed below) have relevance to California agriculture, the majority of the information provided on the efficacy of the BMPs discussed at this conference have limited applicability to Central Valley irrigated agriculture because of the significantly different climatic regime and agricultural practices in the Central Valley compared to the Midwest and East.

The US EPA contracted with the North Carolina State University (NCSU, 2000) Water Quality Group in Raleigh to develop a review of "National Management Measures to Control Nonpoint Source Pollution from Agriculture." This review was published in draft form on August 31, 2000. This report has recently been finalized as a US EPA (2002a) document. It provides substantial information pertinent to the national situation with respect to the current state of information on developing and evaluating water quality BMPs for agriculture. The report is available online at www.epa.gov/owow/nps/agmm/. Excerpts from this publication are presented below.

The US EPA (2002a) uses "management measures" rather than the term "BMPs" to describe control programs, based on the uncertainty as to what is the "best" management practice. In this review, "management measures," "management practices," and "BMPs," are all used synonymously.

The US EPA (2002a) indicated that the National Resources Conservation Service (NRCS) maintains a National Handbook of Conservation Practices (USDA-NRCS, 1977), updated continuously, which details nationally accepted management practices. This handbook is available at the USDA/NRCS website (www.ncg.nrcs.usda.gov/practice_stds.html).

The US EPA (2002a) states that,

"Management practices control the delivery of nonpoint source (NPS) pollutants to receiving water resources by

- *minimizing pollutants available (source reduction);*
- *retarding the transport and/or delivery of pollutants, either by reducing water transported, and thus the amount of the pollutant transported, or through deposition of the pollutant; or*
- *remediating or intercepting the pollutant before or after it is delivered to the water resource through chemical or biological transformation."*

Presented below is information derived from the US EPA (2002a) report that provides information pertinent to the general approaches that have been or can be used for managing certain types of chemical constituents which are potential pollutants in agricultural stormwater runoff/tailwater discharges. Also provided is the available information on the application of these approaches to Central Valley agriculture.

Pesticides

Pesticides include insecticides, herbicides, miticides and fungicides. These chemicals are frequently used by agriculture to control pests that damage crop production and characteristics. They are of particular concern, since some forms of desirable aquatic life are highly sensitive to pesticide toxicity. The US EPA (2002a) report lists the following as management measures for pesticides. It also provides a discussion of each of these measures and a summary of effectiveness that has been found in other parts of the country.

From US EPA (2002a):

"Management Measure for Pesticides

To reduce contamination of ground and surface water from pesticides:

1. *Inventory pest problems, previous pest control measures, and cropping history.*
2. *Evaluate the soil and physical characteristics of the site including mixing, loading, and storage areas for potential leaching or runoff of pesticides. If leaching or runoff is found to occur, steps should be taken to prevent further contamination.*
3. *Use integrated pest management (IPM) strategies that*
    - *apply pesticides only when an economic benefit to the producer will be achieved (i.e., applications based on economic thresholds) and*
    - *apply pesticides efficiently and at times when runoff losses are least likely.*
4. *When pesticide applications are necessary and a choice of registered materials exists, consider the persistence, toxicity, runoff potential, and leaching potential of products in making a selection.*

5. *Periodically calibrate pesticide application equipment.*
6. *Use anti-backflow devices on the water supply hose, and other safe mixing and loading practices such as a solid pad for mixing and loading, and various new technologies for reducing mixing and loading risks."*

OP Pesticides. The control of the organophosphate (OP) pesticides diazinon and chlorpyrifos present in stormwater runoff from dormant-sprayed orchards in the Central Valley is a topic of investigation by the Sacramento River Watershed Program OP Focus Group/Agricultural Practices Workgroup. This Group (SRWP, 2002a,b,c; CVRWQCB, 2002a) has developed several reports devoted to a review of the literature on potential BMPs that can be used to control the runoff of diazinon from treated orchards. Information developed by this group and others is summarized below.

Ross, *et al.* (1997) reported on the results of a study devoted to reducing OP pesticide and other pesticide runoff from dormant-sprayed orchards in the Central Valley. They investigated the use of cover crops to control runoff of pesticides from a peach orchard. Cover crops reduced pesticide runoff by as much as 74% over non-vegetated areas.

Werner, *et al.* (2002) and Zalom, *et al.* (2002) have investigated the movement of diazinon and esfenvalerate from orchards which were sprayed during the dormant season with these pesticides. They measured the toxicity of the runoff to *Ceriodaphnia* and fathead minnow larva. They found that ground cover affected the amount of runoff in some rainfall runoff events, but not all. Diazinon concentrations were lower in samples of runoff taken from vegetated areas compared to those taken from bare ground areas. Diazinon was apparently responsible for toxicity to *Ceriodaphnia* in the runoff waters. Diazinon was detected in runoff from all samples even with buffer rows intercepting the runoff. They attributed this to drift of the applied pesticides. Esfenvalerate could not be detected in any runoff sample.

Zalom, *et al.* (2001) investigated alternative control treatments and timing for San Jose scale and peach twig borer in almond orchards in the Central Valley. They compared treatments involving diazinon plus oil, esfenvalerate plus oil, and horticultural mineral oil alone to untreated areas. They also examined the effects of treatment timings of spinosad. They found that esfenvalerate plus mineral oil gave better control of San Jose scale crawlers than did diazinon plus mineral oil. They point out, however, that while pyrethroid pesticides such as esfenvalerate are a promising alternative approach, the pyrethroids have been associated with pest resistance and the suppression of predatory mites. They found that horticultural mineral oil alone provided significant control of San Jose scale, but that this treatment was not as effective as esfenvalerate treatment.

The study also indicated that the timing of application of diazinon plus mineral oil dormant spray can be moved to mid-December without significantly affecting efficacy against San Jose scale and peach twig borer. Application earlier in the dormant season could be advantageous for reducing the amount of diazinon runoff present in stormwater runoff from the orchard.

The CVRWQCB (Azimi-Gaylon, *et al*., 2002) has developed a draft implementation framework report for the control of diazinon and chlorpyrifos in the San Joaquin River watershed. This report contains a section devoted to evaluation of agricultural practices that *"… are likely to be effective in reducing offsite movement of diazinon and chlorpyrifos into surface water."* The following are the indicated major types of agricultural practices that were listed as being potentially effective in controlling diazinon runoff/releases from dormant-sprayed orchards and agricultural fields treated with diazinon/chlorpyrifos during the growing season:

- *"Pesticide application practices*
- *Pest management practices*
- *Vegetation management practices*
- *Field crop management practices*
- *Water management practice."*

The discussion of these practices focuses on how they may be effective in controlling the concentrations of diazinon and chlorpyrifos in the receiving waters for stormwater runoff and irrigation tailwater releases. Many of the same practices are applicable to the runoff/discharges of other constituents, such as nutrients and other chemicals that are added to agricultural lands that, in turn, can be present in runoff/releases from these lands and can be adverse to the beneficial uses of the receiving waters for the releases/discharges.

In evaluating a potential BMP for control of constituents derived from agricultural lands, it is important to clearly distinguish between the various goals that could be used to establish the BMP. There are basically two types of goals that need to be considered. One is an interim goal, where some progress toward reducing the magnitude of the constituents' runoff/release is being made, and the other is the ultimate goal of having to control these discharges/releases of potential pollutants so that they do not cause or contribute to violations of water quality standards (objectives)/impairment of beneficial uses more than once every three years. The Azimi-Gaylon, *et al*. (2002) discussion focuses on *"… agricultural management practices that are likely to be effective in reducing offsite movement of diazinon and chlorpyrifos into surface waters."* [Emphasis added.] While this is the approach that the CVRWQCB staff are advocating as the initial phase of the San Joaquin River watershed OP pesticide TMDL implementation, ultimately, as discussed herein, many of the management practices discussed by Azimi-Gaylon, *et al*., will not be expected to achieve the ultimate goal of controlling OP pesticides in runoff/discharges so that they do not cause or contribute to violations of CA Department of Fish and Game proposed water quality criteria at the point where the agricultural runoff/discharge enters the State's waters.

An important issue that needs to be evaluated in developing BMPs for potential pollutant runoff/discharges from agricultural lands is whether the BMP that might be adopted for the initial "reducing load" phase of BMP implementation would be effective when the ultimate goal of having to prevent violations of water quality objectives in the receiving waters is implemented through the BMP ratcheting-down process. It could, in the long run, be more cost-effective to use a more effective BMP initially than some of those listed by Azimi-Gaylon, *et al*., as initial-phase, load-reduction BMPs. There is need to consider the overall goals and economics of various BMPs relative to these goals. One of the large unknowns in this matter is the rate at which the BMP ratcheting-down process will be implemented. As discussed elsewhere in this report, BMP ratcheting-down is well on its way in urban stormwater runoff water quality management. It will, ultimately, become a key component of agricultural land stormwater runoff water quality management.

Klassen (2002) has recently reviewed the approaches that are being developed to control the organophosphorus pesticides in the Sacramento and San Joaquin River watersheds. He reviewed a number of the issues that have evolved out of the SRWP OP Focus Group, which have the potential to reduce the amount of diazinon and chlorpyrifos present in stormwater runoff and irrigation discharge waters, as well as the aerial drift of pesticides associated with their application. He outlined five strategies for accomplishing reduced pesticide runoff/discharges:

- Strategy 1 – Dormant Diazinon and Oil Spray
- Strategy 2 – No Dormant Treatment or Dormant Oil Only Treatment
- Strategy 3 – Alternate Year Dormant OP Pesticide with Yearly Oil Spray
- Strategy 4 – Dormant Spray (Non-OP Pesticides) and Oil
- Strategy 5 – Spinosad and Oil as Dormant Spray

Klassen (2002) has provided a brief summary of the potential advantages and disadvantages of each of these strategies. He has also discussed the potential for vegetation to be effective in controlling OP pesticide discharges/runoff from the perspective of both benefits and drawbacks. He provides a good overview of the potential approaches that are being considered for controlling diazinon and chlorpyrifos runoff/discharges. At this time, however, there is essentially no information on the effectiveness and cost of any of these potential management practices.

Additional information on the details of the management measures discussed by Azimi-Gaylon, *et al.* (2002) and Klassen (2002) is provided in their papers and in SRWP (2002a,b,c,d). The latter contains a comprehensive list of references to the literature that serves as the basis for these reviews.

Fawcett and Tierney (2001) have presented a review of the literature on the use of conservation buffers for "trapping" diazinon in stormwater runoff from agricultural fields. Conservation buffers are areas or strips of land with maintained permanent vegetation. These vegetative buffers are often advocated as a management approach to control soil, water, nutrients and pesticides in agricultural land runoff. The USDA NRCS (2000) has published a review, "Conservation Buffers to Reduce Pesticide Losses," of the ability of conservation buffers to trap and degrade pesticides in field runoff. Fawcett and Tierney (2001) state that conservation buffers trap pesticides in surface runoff by trapping eroded sediment carrying adsorbed pesticide, and by increasing infiltration of water into buffer soil where dissolved pesticides can be adsorbed and degraded. Their review utilizes information from the USDA NRCS (2000), as well as other literature, to evaluate the potential for conservation buffers to prevent diazinon in agricultural field runoff from entering surface waters. Based on their review of K_{oc} values (organic carbon normalized partition coefficients), they conclude, *"Thus, diazinon would be categorized as a highly adsorbed pesticide, and would be transported primarily adsorbed on eroded sediment,* *with smaller amounts transported in the water phase."* However, Ross, *et al.* (1997) found, in their study of diazinon losses from Central Valley orchards, that 44% of the diazinon was lost from the field in the dissolved phase.

Lee and Taylor (1999) and Lee, *et al.* (2001) were involved in a large study of diazinon and chlorpyrifos stormwater runoff from various types of land use in the Upper Newport Bay watershed in Orange County, CA. Several hundred samples of stormwater runoff had been collected over a several-year period in the mid- to late 1990s. They found that diazinon was primarily transported in the dissolved phase. They also found, after the samples were allowed to stand for several days and the supernatant was tested for toxicity, that stirred and settled samples had about the same toxicity to *Ceriodaphnia*. Similar results have been found by several commercial laboratories (Pacific EcoRisk and AquaScience). Therefore, the Fawcett and Tierney conclusions on diazinon being strongly adsorbed to particles and therefore readily removed in buffer strips or other vegetative areas are not reliable.

In summary, it has been found that there is limited quantitative literature/experience devoted to the efficacy/cost of management measures for OP pesticides that is applicable to the Central Valley of California. This is an area that needs research. The SRWP OP Focus Group (2002d) has developed a list of research priorities for developing cost-effective management practices for controlling diazinon in stormwater runoff from dormant sprayed orchards. At this time the most promising of the BMPs is through source control, either through altered application practices or the substitution of other pesticides. The US EPA (2002b) recently determined that diazinon and chlorpyrifos represent significant ecological risks, and that the continued use of these pesticides for certain agricultural practices will require reregistration. This action by the US EPA may result in reducing diazinon and chlorpyrifos as a cause of water quality problems in the Central Valley.

Other Pesticides. Moore, *et al.* (2001a,b) have discussed the use of vegetated agricultural drainage ditches to remove contaminants present in agricultural runoff. They investigated an agricultural drainage ditch located in the Mississippi Delta for removal of atrazine, and lambda-cyhalothrin. They found that the vegetation in the drainage ditch was effective in removing these pesticides from the water passing through it. Moore, *et al.* (2001a,b) recommend that vegetated drainage ditches be considered as a BMP for managing potential pollutants in agricultural runoff. The effectiveness of vegetated agricultural drainage ditches in the Central Valley for the removal of pesticides, nutrients and other potential pollutants of concern needs to be investigated to determine if they can be an effective management measure for agriculturally derived pollutants.

It is important not to assume that buffer strips (conservation buffers) that are used in the south, Midwest, and eastern US will be as effective in removing potential pollutants in the Central Valley as they are in these other areas. The ability to maintain dense vegetation of the type that can readily be developed in the southern, Midwestern, and eastern US will be significantly different in the Central Valley. At this time it is unclear as to how effective buffer strips and other vegetative areas will be in controlling pesticides and other agriculturally derived pollutants in runoff in the Central Valley setting.

Erosion Control-Sediment

Suspended Sediment/Turbidity. Excessive erosion turbidity is a significant water quality problem within parts of the San Joaquin River watershed. However, neither the San Joaquin River nor the Delta is listed as a 303(d) impaired waterbody due to sediments, erosion or turbidity. The US EPA (2002a) lists several approaches for erosion control. Suggested approaches for control of both wind and water erosion are presented. US EPA (2002a) states,

> ***"Management Measure for Erosion and Sediment***
>
> *Apply the erosion component of a Resource Management System (RMS) as defined in the Field Office Technical Guide of the U.S. Department of Agriculture—Natural Resources Conservation Service (see Appendix B) to minimize the delivery of sediment from agricultural lands to surface waters, or*
>
> *Design and install a combination of management and physical practices to settle the settleable solids and associated pollutants in runoff delivered from the contributing area for storms of up to and including a 10-year, 24-hour frequency."*

The NCSU (2000) draft report contains a discussion of the use of polyacrylamides for erosion and infiltration management. This information was not included in the US EPA (2002a) report. It is included herein because of the importance of erosion control in the SJR westside tributaries.

> ***"Polyacrylamide Application for Erosion and Infiltration Management***
>
> *Polyacrylamide (PAM) is a water soluble polymer produced for agricultural use to control erosion and promote infiltration on irrigated lands. PAM comes in many formulations which should not be confused. The super water-absorbent PAM used to increase soil water holding capacity is not the PAM used for erosion control.*
>
> *When applied to soils, erosion-prevention PAM forms a gel that decreases soil bulk density, absorbs water, and binds fine-grained soil particles within the top 1/16 in. (1-2 mm) of soil. It is not only used for erosion control, but it is also employed in municipal water treatment, paper manufacturing, food and animal feed processing, cosmetics, friction reduction, mineral and coal processing, and textile production.*
>
> *Studies using erosion-prevention PAM have shown a 94% reduction of sediment loss in irrigation runoff, although there is some variability in results due to differing application techniques and management practices. At the same time, PAM has resulted in some cases in higher crop yields, improved crop emergence, and decreased soil crusting. However, long-term, off-site impacts of widespread application of PAM on water quality and wildlife have yet to be determined. Although limited use of PAM may be the best solution for erosion in some cases, other erosion control practices with known environmental consequences may be better choices in general to prevent potential environmental harm.*
>
> <u>*Availability and Application*</u>
>
> *Erosion-prevention PAM is available in blocks or cubes, or as a powder, aqueous concentrate or emulsified concentrate. Each form has benefits and drawbacks that would alter efficacy in different settings and with different application methods. Additional factors that affect PAM's effectiveness include irrigation inflow rate, duration of furrow*

exposure, and soil salinity. Erosion prevention PAM costs range from $3 - $8 per pound, depending on the application form purchased, and is typically effective at applications of 1 lb. per crop-acre with each treated irrigation (Sojka, 1999). Amounts applied per crop-acre can be reduced with repeat irrigations.

Application rates of PAM recommended by the Natural Resources Conservation Service (NRCS) and Agricultural Research Service (ARS) are 10 ppm in the irrigation inflow during the furrow-advance period (only). ARS has reported results using the following application methods:

- *adding dry granules to the irrigation water in a gated irrigation pipe*
- *adding a stock solution to furrow heads*
- *placing 1/2 to 1 oz. powder patches directly on the soil immediately below furrow inlets*

The NRCS and ARS encourage adjustment of furrow irrigation practices to take advantage of the erosion-abating and infiltration-enhancing properties of the PAM practice. These adjustments include increasing the irrigation inflow rate, resulting in shortened advance times and preventing leaching from over-irrigation of the near end of the field.

Environmental Pros and Cons

PAM can provide several benefits to the environment (Table 1). PAM practices undoubtedly improve surface water quality by decreasing suspended sediments and the phosphorus, nitrogen, pesticides, pathogens, salts, BOD, and eutrophication that are usually associated with sediment loading. PAM also improves crop vigor by enriching soils and ensuring against drought stress.

Table 1. PAM's beneficial effects on the environment and crop production (Sojka and Lentz, 1996)

What PAM does	***Environmental Benefit***
Decrease sediment loading	*Decrease turbidity* *Improve clarity* *Decrease P, N, pesticides, salts, pathogens* *Decrease BOD, eutrophication*
Lower soil bulk density	*Increase infiltration* *Decrease runoff* *Improve soil tilth* *Decrease compaction*
Binds fine soil particles	*Decrease wind erosion* *Accelerates clarification* *Prevents erosion*
Increase soil water storage	*Decrease need for irrigation* *Decrease plant stress* *Improve plant vigor*

However, PAM may detrimentally affect groundwater quality by increased leaching of fertilizer, pesticides, animal waste and pathogens as a result of improved infiltration (Table 2). Additionally, crops may suffer nutrient stress if nutrient supplies are not adjusted for increased leaching.

Although management practices can partially mitigate these effects, the impact of PAM practices on water quality and wildlife are still unknown. Questions have arisen as *to PAM=s* [sic] *environmental toxicity. Anionic PAM, the form found most often in erosion control products, has not been proven to be toxic to aquatic, soil or crop species.*

Table 2. PAM's potential detrimental effects on the environment and crop production (Sojka and Lentz, 1996)

What PAM does	***Potential Detrimental Effect***	***Preventative Measures***
Improve infiltration	*Leaching of nutrients, pesticides, and pathogens to groundwater* *Nutrient shortage for plant uptake*	*Increase irrigation flow rate to prevent over-irrigation of near end of field* *Monitor levels of fertilizer in soil*
Bind fine soil particles	*Soil crusting, impaired seedling emergence, decreased infiltration, increased erosion*	*Careful application and monitoring*
Unknown effects on fish and wildlife	*Toxicity, habitat alteration ?*	*Use as directed?*

The molecule is too large to cross membranes, so it is not absorbed by the gastrointestinal tract, is not metabolized, and does not bioaccumulate in living tissue. Cationic water-absorbent PAM (the form not used for erosion control in agriculture) has been shown to be toxic to fish due to its affinity to anionic hemoglobin in the gills. PAM's effect on biota is buffered if the water contains sediments, humic acids, or other impurities (Barvenik et al., 1996).

Most of the concern for PAM toxicity has arisen because of acrylamide (AMD), the monomer associated with PAM and a contaminant of the PAM manufacturing process. AMD has been shown to be both a neurotoxin and a carcinogen in laboratory experiments. Current regulations require that AMD not exceed 0.05% in PAM products. At the application rates prescribed by the NRCS, the concentration of AMD in outflow waters is several orders of magnitude less than what is considered toxic. Although there seems to be little risk from AMD as a result of prescribed application of PAM, it is uncertain what effects may result from spills, over-application, or other unforeseen accidents. According to the ARS, AMD decomposes in 18 to 45 hours in biologically active environments (Barvenik et al, 1996).

Conclusion

Limited applications of PAM may be an effective solution for erosion on irrigated lands. However, PAM should not be used to the exclusion of other techniques such as conservation tillage, sediment basins, and drip and sprinkler irrigation, which provide erosion control without active human monitoring and continue effectiveness when not irrigating. Responsible application and monitoring practices will help to ensure that adverse environmental effects from PAM are minimized."

McElhiney (pers. comm., 2002), District Conservationist, USDA Natural Resources Conservation Service, Modesto, CA, has provided information on the use of PAM in the San Joaquin River westside watershed. He has indicated that, while there is limited documentation, it is his finding that the use of PAM is highly effective in erosion control and improved infiltration and crop yields. He provides the following websites for additional information:

http://kimberly.ars.usda.gov/pampage.shtml, www.ca.nrcs.usda.gov/fotg,
http://ucce.ucdavis.edu/counties/cestanislaus/Custom_Program95/A_Team_Approach_to_Water_Quality.htm

The Yolo County Resource Conservation District (Yolo RCD, 2002) has conducted studies on the use of various approaches for controlling sediment discharges from irrigated agricultural fields in Yolo County. This information is presented in the Nutrient section of the report. Also discussed in the Nutrient section is information on the control of sediment from irrigated agriculture in the Salton Sea watershed.

Irrigation Water Management for Selenium, TDS and Boron

US EPA (2002a) devotes a chapter to Irrigation Water Management. They list the following as management measures for irrigation water. This discussion includes a section on the use of runoff or tailwater.

"Management Measure for Irrigation Water

To reduce nonpoint source pollution of ground and surface waters caused by irrigation:

(1) Operate the irrigation system so that the timing and amount of irrigation water applied match crop water needs. This will require, as a minimum: (a) the accurate measurement of soil-water depletion volume and the volume of irrigation water applied, and (b) uniform application of water

(2) When chemigation is used, include backflow preventers for wells, minimize the harmful amounts of chemigated waters that discharge from the edge of the field, and control deep percolation. In cases where chemigation is performed with furrow irrigation systems, a tailwater management system may be needed.

The following limitations and special conditions apply:

(1) In some locations, irrigation return flows are subject to other water rights or are required to maintain stream flow. In these special cases, on-site reuse could be precluded and would not be considered part of the management measure for such locations. In these locations, improvements to irrigation systems and their management should still occur.

(2) By increasing the water use efficiency, the discharge volume from the system will usually be reduced. While the total pollutant load may be reduced somewhat, there is the potential for an increase in the concentration of pollutants in the discharge. In these special cases, where living resources or human health may be adversely affected and where other management measures (nutrients and pesticides) do not reduce concentrations in the discharge, increasing water use efficiency would not be considered part of the management measure.

(3) In some irrigation districts, the time interval between the order for and the delivery of irrigation water to the farm may limit the irrigator's ability to achieve the maximum on-farm application efficiencies that are otherwise possible.

(4) In some locations, leaching is necessary to control salt in the soil profile. Leaching for salt control should be limited to the leaching requirement for the root zone.

(5) *Where leakage from delivery systems or return flows supports wetlands or wildlife refuges, it may be preferable to modify the system to achieve a high level of efficiency and then divert the 'saved water' to the wetland or wildlife refuge. This will improve the quality of water delivered to wetlands or wildlife refuges by preventing the introduction of pollutants from irrigated lands to such diverted water.*

(6) *In some locations, sprinkler irrigation is used for frost or freeze protection, or for crop cooling. In these special cases, applications should be limited to the amount necessary for crop protection, and applied water should remain on-site."*

Tailwater Return Systems. One of the BMPs that is receiving increased attention in the Central Valley is the use of a tailwater recovery system to conserve water and/or to reduce discharges of pollutants. While tailwater recovery systems have been used for many years, there is essentially no information on the water quality aspects of tailwater recovery systems. A review is presented below on what is known about these systems with respect to how they impact various types of potential pollutants that are derived from irrigated agriculture in the Central Valley.

Burt (1995) discussed several aspects of tailwater recovery systems in The Surface Irrigation Manual. This manual is primarily concerned with the hydraulics of water movement and the interactions with soils under the various approaches that are used for irrigating crops. Burt is the director of the Irrigation Training and Research Center at California Polytechnic State University (Cal Poly) in San Luis Obispo, California. Burt describes return flow (tailwater recovery/return systems), where the typical physical layout includes:

- *"Small sump which has essentially no storage capacity. The pump intermittently and automatically returns tailwater to the supply pipe or ditch.*
- *Large sump which stores all of the runoff from one irrigation set. The pump is manually turned on to empty the sump at the beginning of the next irrigation set.*
- *Small recirculating sump (below ground level) at the bottom of the field, combined with a reservoir (above the ground level) at the top of the field. Tailwater is immediately returned to the reservoir, which acts as a buffer for both the tailwater and supply water."*

Burt describes tailwater quality as *"generally lower than the source water."* The primary constituents which are added to the water are sediment, salinity, nutrients, various plant diseases and insects (including nematodes). While not mentioned by Burt, tailwater recovery systems would be expected to have pesticides and herbicides. Boron and selenium would be constituents of concern in tailwater recovery systems in some parts of the San Joaquin River watershed.

Burt describes tailwater recovery systems as having a higher initial cost and operation and maintenance cost. The primary benefits of tailwater recovery systems are improved irrigation water efficiency and reduced labor costs in managing irrigation. Burt also lists, as a potential benefit, less salt problems with tailwater recovery systems. He states, *"Tailwater return systems allow irrigators to obtain more even times along the furrow, and thereby provide better salt leaching in the lower half of the field. The same can also be true for border strip systems."*

Another benefit listed by Burt is less drainage problems, which is related to being able to distribute the water more effectively in the field. Finally, tailwater recovery systems can be of benefit in obtaining a more uniform crop yield. Burt provides information on the design of tailwater recovery systems, considering such issues as runoff rates and volumes (i.e., how big should the pump and sump be) and the storage and disposal of tailwater runoff. Burt provides information on the various types of tailwater recovery systems, such as:

- small sump with very little storage,
- large sump with storage,
- operation of tailwater recovery systems with and without border strips.

Burt does not provide data on the chemical characteristics of tailwater recovery systems. It is this type of data that is needed to judge how tailwater recovery systems can affect the water quality impacts of tailwater discharges from irrigated agriculture. In many tailwater recovery systems it would be expected that there would be a buildup of some constituents in the tailwater, which would result in a more concentrated tailwater discharge that ultimately will take place in many tailwater recovery systems. It would be expected that there would be a considerable range of concentrations of constituents in various tailwater recovery systems, depending on the type of tailwater recovery system used, the type of soil, its physical characteristics, crops grown, irrigation methods, etc.

Burt's manual contains a chapter on what is called "Fertigation." "Fertigation" is defined as simultaneously conducting irrigation and fertilization, where the fertilizer is applied with the irrigation water. This approach is also used to apply pesticides in some irrigation practices. Burt provides a fairly detailed discussion of the advantages and disadvantages of applying nutrients and pesticides with the irrigation water. This approach is commonly used for application of anhydrous ammonia.

Broner (2001), of Colorado State University Cooperative Extension, provides a discussion of "Tailwater Recovery for Surface Irrigation." He indicates, as "Quick Facts" about tailwater recovery systems:

- *"Use of tailwater can offer substantial savings in irrigation power consumption if the water supply is groundwater.*
- *A tailwater recovery system increases yields because of higher irrigation efficiencies.*
- *A tailwater recovery system will not save all the tailwater, but it can increase irrigation efficiency by 30 percent.*
- *Disadvantages are the loss of the area required for a reuse pit and periodic maintenance of the pump and return facilities."*

Broner provides additional details on the development of tailwater recovery systems, including costs, which are presented below:

"In general, return-water recovery systems cost from $150 to $225 per acre. System cost is composed of earth work cost, pipeline installation cost and pump assembly cost. Cost of a particular tailwater recovery system can be estimated using the following prices: $0.70 per cubic yard of earth work and $4.80 per foot for a 10" PVC high pressure pipeline installation. Add the cost of pump and power source, if needed, to the system cost. The local NRCS office can provide cost estimates and help in designing a system.

Floating tailwater pump assemblies cost from $1,500 to $3,000 or more depending on the size, make and power source. Generally, single-phase electric motors are more expensive to purchase and operate than triple-phase motors. Also consider the cost of providing electrical service. Costs for gasoline or tractor-driven pumps can vary considerably. Include anticipated costs and availability of fuel for at least 10 years in the economic analysis of internal combustion power sources.

Excavation of tailwater pits often can be done by the irrigator with farm or rental equipment. Commercial contractors charge $.07 per cubic yard. Concrete lining of a tailwater pit may cost from $4 to $6 per square yard of surface depending on thickness and reinforcing. Concrete should be sulfate-resistant for most areas in Colorado.

Open discharge (surface irrigation) return-water pipeline should probably be about 80 psi rated PVC plastic for maximum durability and least cost. In some instances 50 psi rated PVC plastic pipe can be used. Fifty feet (low head) pressure rated plastic pipe is not recommended. Costs of pipe and installation vary significantly with location. Obtain local cost estimates from a NRCS office.

Return-flow pipelines that are used for sprinklers usually are Class 160 or Class 200 plastic pipe. Steel or concrete pipe usually is not competitive with plastic pipe for these uses, due to installation and/or materials costs. As with most products, the economics can vary significantly from area to area and year to year. Request quotations from several sources."

The costs cited above were applicable to the Front Range of Colorado. They would need to be adjusted for Central Valley conditions. Information of this type is presented below in connection with the Yolo County RCD tailwater recovery system studies. Broner (pers. comm., 2002) was asked about information on the chemical characteristics of waters in tailwater recovery systems. He indicated that he was not aware of any data of this type. Further information from the Yolo County RCD evaluation of BMPs is presented in a subsequent section of this report.

Selenium. A special situation occurs in the Grassland area of the Central Valley, where the discharges of selenium, total salts and boron by irrigated agriculture are of concern in parts of the Mud Slough and Salt Slough watersheds in the San Joaquin River watershed. Agricultural interests in this area have investigated the agricultural practices that result in elevated selenium releases (McGahan and Falaschi, 2002). They are associated with the management of subsurface drain water arising from a perched water table that results from the practice of irrigated agriculture in the area. The subsurface drains transport selenium from the perched groundwater to surface waters. The selenium associated with subsurface drain waters is being managed through water management techniques. Similar approaches will likely be used to manage the elevated total salts and boron present in water releases from the Grassland area.

Ayars and Christen (2002) discuss best management practices for controlling subsurface drainage systems, focusing on how the systems can be designed to minimize salt, trace elements, pesticides and fertilizers in the drain water. They point out that BMPs have been developed for irrigated agriculture to address problems related to nitrate losses in irrigation and erosion losses from irrigated areas. They discuss the situation that occurred in Australia, where, through design of the subsurface drain system, they were able to reduce the leaching/transport of potential pollutants from the soils through which the drainage water passes.

TDS and Boron. Grober (2002) presented a discussion of an "Implementation Framework" for the salt and boron TMDL for the Lower San Joaquin River. Grober listed the methods for controlling salt and boron in the San Joaquin River. These include:

"1) Reduce salt imports to the basin
2) Provide more water
3) Control/reduce salt discharges
4) Export more salt out of basin (disposal)
5) Real time water quality management"

With respect to reduced salt discharges, the areas of concern are:

"Agricultural drainage
– surface drainage (tailwater)
– Subsurface drainage (tilewater)
Managed wetlands
Municipal and industrial sources
– Wastewater treatment plants"

Grober (2002) lists the following methods for controlling salt discharges:

"Water conservation
Tailwater/tilewater recovery
Sequential reuse and volume reduction
Integrated on farm drainage management
Evaporation ponds
Water treatment
Land retirement
Reduce municipal and industrial sources of salt"

Additional information on these issues is provided at
http://wwwdpla.water.ca.gov/agriculture/drainage/implementation/hq/title.htm

Grober (2002) has provided additional discussion of the various approaches for controlling salt discharges. These are also effective in controlling boron discharges. At this time there is limited information on the costs and effectiveness of these various approaches for controlling salt discharges in the San Joaquin River watershed.

Quinn and Hanna (2002) have reported on the results of the monitoring of salt discharges from managed wetlands in the Grassland Water District area. They point out that, through a monitoring program, the salt discharges from these managed wetlands could be reduced through water management during periods when they would contribute to exceedance of a TMDL goal for salts in the San Joaquin River.

Total Organic Carbon

Table 1 lists total organic carbon (TOC) as a constituent of potential concern in agricultural runoff in the San Joaquin River watershed. As discussed in Appendix A, TOC is of concern because of its interactions with water supply disinfectants which can lead to trihalomethane (THM) formation. THMs are regulated as carcinogens in drinking water. While Woodard (2000) has shown that there is appreciable TOC derived from the San Joaquin River watershed, at this time, there is essentially no quantitative information on the source of the TOC that causes the San Joaquin River to be a significant source of TOC for the Delta. Agricultural land runoff, tailwater discharges and drainage from wetlands are all potentially significant sources of TOC.

Lee and Jones (1991a) report that about half of the TOC that is present in the water exported from the Delta by the State Project is derived from in-Delta sources associated with leaching of the peat soils used for Delta farming. The other half of the TOC exported from the Delta is derived from Delta watershed sources, primarily the San Joaquin River watershed. Lee and Jones (1991a) have reviewed the literature on TOC sources, where they report that agricultural land runoff has been found in other areas to be a significant source of TOC. The managed federal and state wildlife refuges and private duck clubs in the Central Valley are likely at times significant TOC sources for the Sacramento and San Joaquin Rivers. An area of concern as a potential TOC source in the Sacramento River watershed is the discharge of water from rice fields. Additional work needs to be done on defining TOC sources for waterbodies within the Central Valley before it will be possible to meaningfully control excessive TOC in some Central Valley waterbodies that is derived from agricultural sources.

Contact Recreation Sanitary Quality

The US EPA and the state of California are both working to improve water quality for contact recreation. It has been known for many years that total coliforms and fecal coliforms are unreliable indicators of potential disease associated with contact recreation in waterbodies that are contaminated with fecal material from humans and animals. The CVRWQCB has adopted the US EPA's (2002c) recommended *E. coli* criterion as a more reliable indicator organism for assessing the sanitary quality of waterbodies for contact recreation. The finalization of establishing *E. coli* as the basis for a CVRWQCB Basin Plan water quality objective for contact recreation is under review by the SWRCB and the Office of Administrative Law. At this time, there is limited information on the presence of *E. coli* in agricultural stormwater runoff/tailwater discharges. Of particular concern are situations where animal manure and/or domestic wastewater sludge (biosolids) are used as fertilizers or disposed of on agricultural lands. Studies need to be done to define the sources of *E. coli* in agricultural land runoff/discharges that impair contact recreation in the receiving waters for runoff/discharges from agricultural lands. These studies can potentially lead to control practices for *E. coli* in agricultural land runoff/discharges that cause violations of the *E. coli* water quality objective.

Organochlorine Pesticides, PCBs, Dioxins/Furans

Eleven waterbodies in the Central Valley are listed as Clean Water Act 303(d) impaired because of excessive bioaccumulation of organochlorine legacy pesticides, PCBs or dioxins/furans in edible fish tissue. These chemicals are called OCls in this report. The legacy pesticides include DDT, chlordane, dieldrin, toxaphene and other chlorine-based pesticides that were banned 15 or more years ago because of adverse impacts on bird reproduction. These pesticides are regulated as human carcinogens. The OCls all tend to bioaccumulate in edible fish tissue. They also tend to be strongly sorbed by soils and aquatic sediments. Lee and Jones-Lee (2002a) have recently reviewed the existing database on OCls in Central Valley waterbody fish and other aquatic organisms. They have reported that there are a number of waterbodies in the Central Valley that are not 303(d) listed as having fish with excessive OCls. Further studies may result in additional 303(d) listings for excessive bioaccumulations of OCls in edible fish in the Central Valley.

Lee and Jones-Lee (2002a) have recommended an approach for managing the excessive bioaccumulation of the OCls in edible fish in Central Valley waterbodies which involves determining the amount of the OCls that are contributed to the OCl 303(d) listed waterbodies from the watershed. If current stormwater runoff and discharges from agriculture and/or other areas are still contributing OCls to a listed waterbody, then management practices focusing on controlling the OCl-containing soils/sediments at their source is the recommended approach. This approach is based on the finding that the OCls are primarily transported in land runoff associated with soil/sediment particles. Controlling the erosion of the soils/sediments that contain elevated concentrations of the OCls potentially can reduce continued contribution of OCls to waterbodies from their watershed.

The other component of the recommended OCl management program is to identify the in-waterbody sediments contributing OCls to fish through the food web that are bioaccumulating to excessive concentrations. This management practice will likely require removal/burial of the OCl-containing sediments that are significant sources of OCls for the waterbody fish.

PCBs and dioxins/furans are typically derived from industrial sources. The management of PCBs and dioxin/furans that are bioaccumulating to excessive levels in edible fish requires that the waterbody external OCl sources be identified and controlled at the source. A similar approach to that recommended for the legacy OCl pesticides that are derived from the waterbodies' sediments should be used to control excessive bioaccumulation of the PCBs and dioxins/furans in the waterbodies' fish. In both cases it will be important to use the US EPA standard sediment aquatic organism bio-uptake testing to determine if the chemically measured sediment OCl is bioavailable. A waterbody-specific sediment biota accumulation factor should be developed from these measurements. Additional information on these issues is provided by Lee and Jones-Lee (2002a and Lee *et al.* 2002).

Sediment Toxicity

It is likely that, based on studies conducted in other areas, aquatic sediment toxicity will be found in Central Valley waterbodies that is due to discharges of pesticides and/or nutrients derived from irrigated agriculture runoff/discharges. Aquatic sediment toxicity would likely be a violation of the CVRWQCB Basin Plan narrative toxicity objective of no toxics in toxic amounts. The US EPA has recently announced that it is developing a sediment quality management program that will address the control of sediment toxicity. The Agency has published several discussions of its sediment quality management strategy which are available at its website, such as http://www.epa.gov/ost/cs/manage/strat10.html. The US EPA website contains information on assessing sediment toxicity ("Sediment Contamination Assessment Methods: Validation of Standardized and Novel Approaches") at:
http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/77

While some pesticides become nontoxic when associated with sediment, there are situations where the sorbed pesticides on sediments are bioavailable/toxic. Nutrients that develop into algae that become part of the sediments are a common cause of sediment toxicity. The decomposition of the algae leads to the release of ammonia and hydrogen sulfide that causes aquatic life toxicity in many sediments. Management of sediment toxicity will require identification of the cause of the toxicity and then, through forensic studies, its origin. This can lead to the development of appropriate management practices to control sediment toxicity.

Other Constituents

Table 1 lists several other constituents as a cause of pending TMDLs. These include mercury, unknown-caused toxicity and toxicity to algae. These are problems within the San Joaquin River watershed which could lead to the development of TMDLs. The control of mercury from various sources that bioaccumulates to excessive levels in fish is under investigation by the CVRWQCB and others. Mercury runoff from soils is being found to occur in some parts of the Central Valley where there is no known previous use of mercury in the area. It is unknown whether this occurs to any significant extent from agricultural lands in the Central Valley. Within a few years, BMPs for the control of mercury bioaccumulation in fish should be developed, which may have applicability to agricultural lands where elevated mercury concentrations are present in runoff.

The standard US EPA three-species toxicity tests include the use of an alga, *Selenastrum*, as a test organism. Some waters within the Central Valley have been found to be toxic to *Selenastrum*. Until recently the cause of this toxicity was unknown. Miller, *et al.*(2002) have completed a study which has shown that diuron, a herbicide which is used along roadways, is a cause of at least part of this algal toxicity. At this time, additional studies need to be done to define other causes of the unknown-caused toxicity in Central Valley waterbodies. When the causes are known, though forensic studies to define the source of the toxicity, it will be possible then to develop management programs to control it, which will likely involve source control. Prather, *et al.* (undated) have discussed various methods for controlling herbicide runoff from areas of application. Such practices as delaying herbicide application until after the typical rainfall runoff period, using a lower rate of application, injecting herbicides into irrigation water, the use of post-emergent herbicides and the use of cover-crops and filter strips are all methods that are suggested by Prather, *et al.* (undated) for reducing herbicide runoff.

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.

US EPA (2002a) 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 features based on environmental hazards or concerns, such as:*
   - *Sinkholes, shallow soils over fractured bedrock, and soils with high leaching potential;*
   - *Subsurface drains (e.g., tile drains);*
   - *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 US EPA (2002a) 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 (2002a) 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

<u>The Precisely Tailored Practice</u>

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.

* * *

<u>The Computer-Aided Approach</u>

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.

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.

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. 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.

Overall State of Development of Agricultural Water Quality Management Practices

Overall, it can be concluded that, at this time, there is limited reliable quantitative information on the ability of various so-called best management practices for control of potential pollutants in irrigated agriculture stormwater runoff and tailwater discharges. Studies of the type that are needed to determine the efficacy of various potential water quality BMPs and their cost of development and operation have not been done. Without this information it is not possible to assess the ability to control pesticides, nitrogen, phosphorus, sediments, salts, TOC and other constituents in irrigated agriculture stormwater runoff and tailwater releases. Further, the lack of reliable efficacy and cost information causes significant problems for the agricultural community, since they are not in a position to reliably discuss the economic burden of control of potential pollutants in runoff/discharges from their fields to a certain degree. This information is essential for formulating and implementing an overall management program to control the significant water quality impacts of Central Valley irrigated agriculture stormwater runoff and tailwater/subsurface drain water discharges.

Urban Stormwater Runoff Water Quality BMP Performance

While there has been limited quantitative work done in evaluating the efficacy of various types of BMPs, such as detention basins, grassy swales, etc., in agricultural runoff situations, there has been considerable work done on urban runoff, using the same types of BMPs as are normally considered for agricultural runoff. Taylor (2000) has summarized this information, which is presented below.

Overview of Conventional Stormwater Runoff Water Quality BMP Characteristics and Performance

This section is based on a review by Scott Taylor of RBF Consultants, Irvine, CA (Taylor, 2000), as published in the *Stormwater Runoff Water Quality Science/Engineering Newsletter,* Dr. Anne Jones-Lee, editor.

"Introduction

The cost and effectiveness of structural or treatment control BMPs is becoming the subject of increased interest as urban storm water dischargers face permit requirements that include "BMP ratcheting down" clauses and TMDL waste load allocations. Stormwater's high volume, intermittent nature and variable quality make treatment a tremendous challenge. Conventional structural BMPs can be a useful element in the management of stormwater quality but they are not a panacea to achieve water quality standards.

Structural BMPs should be used when it is determined that they will be "cost effective." A cost effective application is one that accomplishes the project goals for the least cost while also providing a benefit that exceeds the cost. Most current conventional structural BMPs will not remove the dissolved fraction of a constituent-potential pollutant. In most instances it is the dissolved form of the constituent that can be responsible for beneficial use impairment in downstream receiving waters. Consequently, the conventional structural BMP "tool kit" available to the stormwater manager cannot independently achieve the goal of compliance with water quality standards.

Stormwater runoff water quality management programs must be a carefully crafted combination of non-structural and structural BMPs designed to address targeted constituent control requirements. Routine achievement of water quality standards will require more receiving water quality monitoring and evaluation to provide the basis for BMP development. Changes in urban planning and design will also be required to address peak flow and volume increases that occur with urbanization.

Structural BMPs

The primary urban structural BMPs currently in use in the southwest are:

- *Drain inlet inserts*
- *Extended detention basins*
- *Biofilters*
- *Media filters*
- *Infiltration*

There are also other proprietary BMPs that use the principles of settling and filtration to remove chemical constituents and gross pollutants. Some of the benefits and pitfalls for each type of BMP are discussed below.

Drain Inlet Inserts

Drain inlet inserts are a proprietary BMP that are generally easily installed in a drain inlet or catchbasin to treat stormwater runoff. Three basic types of inlet inserts are available: the tray type, bag type and basket type. The tray type allows flow to pass through filter media residing in a tray located around the perimeter of the inlet. Runoff enters the tray and leaves via weir flow under design conditions. High flows pass over the tray and into the inlet unimpeded.

The bag type of insert is constructed from a fabric and is placed in the drain inlet around the perimeter of the grate. Stormwater runoff must pass through the "bag" prior to discharging to the drain outlet pipe. Overflow holes are usually provided to pass larger flows without causing a backwater at the grate.

The basket type of inlet consists of a wire mesh that is placed around the perimeter of the inlet in an installation similar to the tray type device. The wire mesh operates similar to the bag type insert, screening larger materials from the runoff. Some basket type inserts also incorporate filter media similar to the tray type insert.

Drain inlet inserts have generally performed poorly in tests for several reasons. First, the detention or contact time with the insert "media" is very short. Second, there is little storage area available for material that is removed from the flow. The device can act as a temporary storage location, retaining solids as flow decreases, but then may allow resuspension when flow (and velocity) subsequently increases. Lastly, inserts require a high degree of maintenance and must be monitored closely during rain events to ensure that the unit is not clogged or bypassing flow. Such a level of maintenance is not practical for most installations.

Bag and basket type drain inlet inserts can be effective in removing gross pollutants (trash), but must be well maintained. For areas with a limited number of inlets where trash removal is the desired objective, inserts can be a useful BMP. Tray type inserts are generally not effective in trash or solids removal.

Extended Detention

Extended detention basins are a relatively popular BMP since the design is well documented from flood control engineering, and extended detention may be incorporated as an element into flood control detention basins. Extended detention employs a relatively longer *drain time than conventional detention used for peak flow control. An average hydrograph detention time of 24 hours is desired. This can be achieved by using a full basin drain time of at least 48 hours, with no more than 50 percent of the water quality volume draining in the first 24 hours (Barrett, 1999). Sedimentation in the basin is the primary removal mechanism.*

Extended detention basins can be relatively effective in removing solids (including gross pollutants) but are relatively ineffective in removing dissolved constituents and bacteria. The application of extended detention must include a review of the downstream receiving channel to ensure that problems are not created by their use through increased erosion of the channel..

Careful consideration should be given when installing extended detention basins upstream of an alluvial channel. The stability of an alluvial channel depends in large part on the quantity of bed material load that is transported by the stream, as well as the frequency and duration of the bankfull discharge. Extended detention basins are effective in removing the bed material load from natural channels. Channel stability problems and channel scour can result from the misapplication of this BMP. Extended detention is a useful BMP where particulate removal is a desired objective for the downstream receiving water. Extended detention requires moderate maintenance as compared to other BMPs.

Biofilters

Biofilters consist of dense vegetation designed to "filter" runoff as it passes through the BMP. The detention or "residence" time is generally insufficient for a significant portion of the runoff volume to be infiltrated, however, infiltration can be significant for storms smaller than the design storm for biofilters in soils with good infiltration characteristics. Biofilters can be effective in removing particulates from runoff.

Biofilters are an attractive BMP in that they can be incorporated into many projects with relatively little site modification. Conveyance structures that are normally paved can sometimes be replaced with vegetation. Buffer "strips" can be provided where sheet flow leaves paved areas. Biofilter swales are generally designed with a flow velocity of less than 1 foot per second and are installed in a location with enough length to provide a residence time of at least 5 minutes (the length of the swale divided by the average flow velocity) (WEF/ASCE, 1998). Biofilter strips treat sheet flow and their width is a function of the contributing drainage area, but the strips should be at least 12 feet wide (Barrett, 1999).

Swales and strips must be designed to withstand flow rates that exceed the water quality design velocity to ensure they are not damaged during high flows, or cause upstream flooding. Certain types of well-established vegetation can be sustained in flow velocities of up to about 8 feet per second with a more typical value being 4 to 5 feet per second. In the southwest, vegetation that does not require irrigation may be prudent to reduce water consumption. Biofilters can serve as a pretreatment device prior to infiltration or in situations where extended detention is desirable but insufficient area is available. Biofilters require a moderate maintenance schedule as compared to other BMPs.

Media Filters

There are a variety of media filters currently in use including sand, compost, sand peat and perlite/zeolite. Perlite/zeolite and compost filters are proprietary. The use of compost has declined since nutrients are released from this media. Sand filters enjoy the most widespread application. Slow sand filtration is a relatively old technology largely abandoned by the US water industry several decades ago in favor of rapid sand filtration. Sand filters are generally limited to low turbidity waters and operate through a combination of straining and adsorption. Sand filters are among the most efficient conventional treatment devices achieving good removal of particulates and modest removals of bacteria and dissolved metals.

Sand filters are designed with a sedimentation chamber to store all or part of the water quality volume, followed by the sand bed. The purpose of the sedimentation chamber is to remove the settleable solids that could otherwise rapidly clog the filter. The sand bed is designed for a filtration rate of about 3.5 ft/day (Barrett, 1999) but generally operates at the rate limited by the release from the sedimentation chamber. Various configurations are available including the Austin design, the Delaware design and the Washington D.C. design. Sand filters require relatively higher maintenance as compared to other BMPs.

Infiltration

Infiltration of stormwater is a zero discharge solution infiltrating the entire design water quality volume to the surrounding soil. Infiltration is a popular BMP in areas that have relatively permeable soils. Significant questions remain as to the potential impacts on groundwater quality from the infiltration of stormwater. [The US EPA (1983) Nationwide Urban Runoff Program (NURP) study concluded that most pollutants of importance in urban runoff are intercepted during the process of infiltration and quite effectively prevented from reaching the groundwater aquifers underlying recharge basins.] *Consequently, storm water infiltration devices should always include a groundwater monitoring element. Soils that are conducive to infiltration are also relatively poor in filtering and adsorbing contaminates that could otherwise enter an aquifer.*

Infiltration devices have a poor performance record due to clogging. Current guidelines call for minimum soil permeability rates of about 0.52 in/hr (Schueler and Claytor, 1998) for infiltration to be considered feasible. Generous safety factors should be used (by increasing surface area) and the depth to the groundwater table, seasonally adjusted, must be well documented (10 feet separation to the invert of the infiltration device is recommended). If soil permeability does not allow the use of infiltration, retention and irrigation may be considered. The design water quality volume is stored and subsequently pumped through an irrigation system. Additional information on infiltration as a stormwater BMP has been provided by Lee, et al. (1998) and Taylor and Lee (1998).

Conventional Structural BMP Performance

The volume of available performance data (constituent removal) for conventional structural BMPs is rapidly increasing. Removals of commonly monitored constituents can be estimated with good accuracy using tools such as ASCE's BMP database (ASCE, 2000, 2002). Table 4 provides estimated removals for selected categories of constituents for the BMPs *discussed above. Note that the values are generalized and total (particulate and dissolved) for nutrients, pesticides and metals.*

Table 4
Percentage Reduction in Storm Water Load by BMP

Runoff Control	*Solids*	*Nutrients*	*Pesticides*	*Metals*	*Bacteria*
Drain Inlet Insert	*10*	*5*	*5*	*5*	*5*
Ext. Detention Basin	*75*	*25*	*25*	*50*	*40*
Vegetated Swales	*70*	*30*	*30*	*50*	*0*
Filter Strips	*85*	*40*	*40*	*63*	*0*
Media Filters	*85*	*40*	*40*	*70*	*55*

Source: Barrett (1999)

Capital Cost

The capital cost of conventional BMP installation varies widely depending on site conditions. The primary factor is whether the BMP will be implemented as a part of new construction or is a retrofit project. Generalized costs for selected BMPs are provided in Table 5 for new construction and retrofit on a dollar per tributary acre basis assuming a one-inch capture from the contributing watershed. Construction cost data is site specific, and the values given in Table 5 are based on one-inch capture volume and should be considered valid for planning purposes only. Future versions of the ASCE (2000, 2002) BMP database (discussed below) will include cost data for various devices.

Table 5
Generalized Capital Cost for Conventional BMPs

Runoff Control	*New Construction*	*Retrofit Construction*
Drain inlet insert	*1,000 $/ac*	*1,000 $/ac*
Ext. Detention Basin	*10,000 $/ac*	*25,000 $/ac*
Vegetated Swales	*10,000 $/ac*	*30,000 $/ac*
Filter Strips	*17,000 $/ac*	*37,000 $/ac*
Infiltration Basin	*20,000 $/ac*	*38,000 $/ac*
Media Filters	*27,000 $/ac*	*55,000 $/ac*

Source: Barrett (1999)

Operation and maintenance costs are also difficult to estimate on a general basis since variables such as maintenance access and constituent load are site-specific. Table 6 gives general maintenance costs for conventional BMPs on an annual basis.

Widespread Implementation

Structural Best Management Practices (BMPs) and non-structural BMPs are applied to various types of land uses according to their compatibility with the given land use, and the type of constituents of concern in the runoff. Numerous studies have been completed discussing siting criteria and constituent removal efficiencies for BMPs. There are fewer works assessing BMP effectiveness on a watershed basis, specifically in relationship to the ability of a conventional BMP system to achieve compliance with water quality standards. There is even less research *defining the relationship between structural BMPs and receiving water quality. Currently, compliance with water quality standards is presumptive, given a "comprehensive" BMP installation program and adequate maintenance for the program.*

Table 6
Generalized Maintenance Cost for Conventional BMPs

Runoff Control	***Maintenance Cost (per year)***
Drain inlet insert	*$ 500*
Ext. Detention Basin	*3% construction cost*
Vegetated Swales	*$ 5/foot*
Filter Strips	*$ 1/square foot*
Infiltration Basin	*3% construction cost*
Media Filters	*5% construction cost*

Receiving Water Impacts

There are very little published evaluations of the benefits of conventional urban water quality BMPs for receiving waters water quality-beneficial uses. Maxted and Shaver (1997) published a work entitled, 'The Use of Retention Basins to Mitigate Stormwater Impacts on Aquatic Life." In this paper, the authors reviewed eight watersheds, two of which had been retrofitted with "stormwater" controls.

The study looked at watersheds with either detention or retention ponds. The facility generally had to control peak flows from storms with recurrence intervals of 2, 10 and 100 years, as well as provide detention or retention of the first inch of runoff from the watershed. Further, the BMPs had to be a least two years old to avoid construction-related stream impacts. Watersheds with at least 20 percent impervious cover were studied.

The results of the study indicate that the sites with the BMPs did not appear to improve the biological conditions in the receiving waters. The degree of urbanization did not appear to affect the biological conditions at the sites (Maxted and Shaver, 1997). The authors stress that complexity of the system under study could not be adequately understood using a single data set. The conclusions of the paper stress the need for additional monitoring of BMP sites to develop the information needed to improve BMP design. The authors also pointed to the need to focus on receiving water impacts rather than load reduction (of constituents) from the watershed. Aquatic life impacts are based on constituent concentration/duration of exposure, rather than the average annual load of a constituent.

Advanced Treatment

Advanced treatment controls for urban stormwater runoff are becoming a source of greater interest with the advent of water quality-based effluent limits (WQBELs). Advanced treatment controls may include ion-exchange, reverse osmosis, disinfection, or ultrafiltration. None of these technologies has been tested on a prototype scale for stormwater and their cost and effectiveness is unknown with respect to application to urban area stormwater runoff treatment. Ozone and UV disinfection systems have been developed for stormwater runoff applications but limited data on their effectiveness has been published.

Advanced treatment may be a last resort option in existing urban areas faced with Total Maximum Daily Load (TMDL) waste load allocations (WLAs), as well as when compliance with water quality standards in the stormwater runoff is required. Further study will need to be done to determine the capital and operation and maintenance cost for these devices, as well as the impacts to downstream receiving waters as a result of their operation. Many advanced treatment processes, such as reverse osmosis and ion exchange, result in a brine that must be disposed of to the sanitary sewer or other location. Flow equalization and pretreatment would also be a necessity for these processes.

Urban Stormwater Runoff BMP Issues

Taylor's discussion of the characteristics/efficacy and costs of conventional urban BMPs provides information that is pertinent to appropriate selection of BMPs in accord with current regulatory requirements. It is clear that the conventional BMPs discussed by Taylor were not selected based on demonstrated or even expected performance for protection/enhancement of the water quality-beneficial uses of the receiving waters for the stormwater runoff BMP-treated waters. Except for possible control of suspended solids arising from erosion within the watershed, conventional urban BMPs are largely cosmetic in addressing real, significant water quality issues. This situation has arisen from a lack of understanding/application of existing knowledge of water quality issues by those responsible for BMP development, deployment, and evaluation. Current conventional urban BMPs are based largely on hydraulic considerations with little or no regard to true water quality issues. These issues are not new; they have been well-known in the water quality management field since the late 1960s/early 1970s. As discussed by Jones- Lee and Lee (1998b), current conventional urban BMPs can best be characterized as "snake oil" BMPs with respect to managing constituents in urban area and highway stormwater runoff that have the potential to cause significant adverse impacts to the beneficial uses of the receiving waters for the runoff.

The current US EPA (2002d,e) BMP ratcheting-down process that is in place in California and is spreading nationally, where finding a water quality standard violation in the NPDES-permitted stormwater runoff requires that the permit holder work with the regulatory agency in applying ever-more-effective BMPs to eliminate the water quality standard violation, will result in massive public expenditures on the order of one to three dollars per person per day in the permitted communities contributing to stormwater runoff, for the retrofit installation and operation of conventional BMPs. The current US EPA regulatory approach, involving the BMP ratcheting-down process, is obviously fundamentally flawed, in which large amounts of public funds could be spent developing and operating conventional BMPs that will, when full compliance with water quality standards is required, have to be replaced by advanced water and wastewater treatment processes. The projected national cost of full compliance with water quality standards at the point of discharge for urban stormwater runoff is on the order of several hundred billion dollars. This translates to about five to ten dollars per person per day for the acquisition of property and construction and operation of the advanced treatment works needed to comply with existing water quality standards.

The Water Environment Federation and the American Society of Civil Engineers have published WEF Manual of Practice No. 23, "Urban Runoff Quality Management" (WEF/ASCE

1998). This manual provides information on the design and characteristics of a number of BMPs that are used to manage chemical constituents and pathogen-indicator organisms in urban stormwater runoff. The BMPs included are retention ponds; extended detention basins; wetland basins; wetland channels; sand filters; oil, grease and sand traps; infiltration and percolation facilities. The discussion presented of many of these BMPs has applicability for managing many of the same types of constituents in agricultural stormwater runoff. Unfortunately, as discussed by Jones-Lee and Lee (1998b), some of the information provided in this manual on water quality issues is inadequate. For example, while information is provided on the design of infiltration systems and their expected performance, the information that was readily available in the literature at the time of the development of the manual, on the potential problems of infiltrating urban stormwater into groundwater systems, is not discussed.

The state of California Stormwater Quality Task Force is developing an updated BMP manual. This is being done under the leadership of Mr. Scott Taylor who chairs a Task Force work group devoted to this effort. The Task Force maintains a website (www. stormwatertaskforce.org) where Task Force activities, including information on the BMP manual, are posted. This manual will, when developed, provide updated information on the performance of urban stormwater runoff water quality BMPs.

The Water Resources Council of the American Society of Civil Engineers (ASCE, 2000, 2002), under contract with the US EPA (see US EPA, 2002f), has compiled a "National Stormwater Best Management Practices (BMP) Database." This database contains approximately 160 BMPs that are used to control constituents in urban stormwater runoff. It is available online from www.bmpdatabase.org. This database is designed to present, in standardized format, information on BMP performance. The development of this database includes, *"(1) collecting and evaluating existing BMP design and performance data, (2) designing and creating the national BMP database, (3) developing BMP performance evaluation protocols, and (4) evaluating the data collected and reporting initial findings."*

The BMPs included within this database are detention basins, media filters, grass filters/swales, hydrodynamic devices, infiltration basins, nonstructural BMPs (e.g., street cleaning, maintenance), percolation trenches/dry wells, porous pavements, retention ponds, wetland basins, wetland channels and others (inlet filters/traps). The focus of the ASCE BMP compilation is on across-the-BMP-unit removal of a variety of potential pollutants (such as heavy metals, suspended solids, oil and grease and organics) and includes information on nutrients. US EPA (2002f) has published guidance for monitoring of urban stormwater BMPs to develop the data for inclusion of a BMP evaluation in the ASCE database. As discussed by Jones-Lee and Lee (1998b), it is important not to assume that the across-the-BMP-unit removal is an adequate basis for selecting a BMP, since the BMP must be selected based on controlling constituents in runoff waters to a certain degree to reduce/eliminate the water quality impacts in the receiving waters for the runoff.

While the ASCE database is directed primarily toward developing information on BMPs that are used in urban stormwater runoff water quality management, the information provided in this database on the various BMPs is applicable to the same type of BMP performance for agricultural/rural stormwater runoff water quality management. In making this application, it is important to consider some of the differences between the water quality characteristics of urban stormwater runoff and agricultural stormwater runoff. Some of these include that urban stormwater runoff generally has higher flows per unit rainfall intensity/duration than agricultural runoff. This arises from the significantly less infiltration that occurs in urban areas associated with the paving of the area. Also, urban stormwater runoff tends to have greater concentrations of heavy metals (such as copper, lead, zinc and cadmium) than agricultural stormwater runoff. The latter may not be true in those areas where heavy metals such as copper and zinc are used on agricultural lands as pesticides and/or soil amendments.

Another difference is that urban stormwater runoff tends to have higher oil and grease content and certain types of organic potential pollutants (such as PAHs and dioxins) than agricultural runoff. Both agricultural and urban runoff can have aquatic life toxicity due to pesticides. Agricultural runoff would tend to have higher suspended solids (associated with erosion) and total dissolved solids. In some areas of the San Joaquin River watershed, agricultural drainage/stormwater runoff can have elevated concentrations of boron and selenium. When considering the suitability of a potential BMP, it is important to examine the hydrological, physical, chemical and biological characteristics of the potential pollutant and the BMP, in order to evaluate whether a particular BMP would be expected to be effective in removing a constituent from a particular source runoff/discharge to a certain degree. If this consideration is given, then much of the urban stormwater runoff BMP experience is applicable to agricultural runoff BMP development.

Those responsible for developing water quality BMPs for agricultural runoff should become familiar with the various groups and publications on urban stormwater runoff BMPs. Those working in the urban area have been addressing a number of the same water quality management issues over the past 10 years or so as are now beginning to be faced by agricultural interests.

BMP Evaluation

Once the BMP/management goal has been established – such as no exceedance of a water quality standard (objective) by any amount more than once in three years, or some other target value – then there is need to review the arena of potential water quality BMPs to treat/manage the runoff/discharges from the area(s) of concern. In addition to considering how a prospective BMP (such as a detention basin, grassy swale or strip) has been shown to be able to remove constituents of concern, at this time and potentially in the future, it is especially important to consider the situation that will exist under high flow/runoff conditions. While many BMPs can remove nitrogen, phosphorus, pesticides, etc., under certain climatic and flow regimes (especially low flow conditions), few of them are effective in controlling nitrogen and/or phosphorus, as well as many other constituents, under elevated flows. Unless the US EPA changes how water quality standards are implemented, ultimately BMPs will be needed to control nutrient and, for that matter, other constituent (such as pesticides) releases under the high flow conditions that will cause violation of the water quality standards at the point of discharge.

There are several aspects of high flow runoff situations that should be considered in regulating nutrient runoff/discharges. The most important is that in the Central Valley, the high flows from agricultural lands occur during the winter when there are few, if any, nutrient-related water quality problems in the San Joaquin and Sacramento River watersheds and the Delta. An issue of potential concern is whether the high winter/spring flows and their associated elevated total phosphorus loads are used to fill water supply reservoirs in the San Francisco Bay area and in Southern California. Woodard (2000) has summarized the nutrient load data to the Delta. There are strong seasonal components to these loads, with the highest loads occurring during the winter/spring. It will be important to understand the relative significance of high flow winter stormwater runoff from agricultural lands in impacting receiving-water water quality.

In selecting the initial set of BMPs, or even the follow-on BMPs, it is important to consider not only the initial cost, but the long-term cost and the BMPs' efficacy in achieving the near-term and long-term goals. It is possible that there will be situations where spending a little more money on the initial BMPs could, in the long run, save considerable overall funds in the bigger-picture BMPs that are going to be needed. Even in urban areas, the days of simply installing some BMP from a master list being adequate to satisfy the regulations, are over, in many parts of the US. The efficacy of BMPs to achieve the desired goal needs to be adequately and reliably evaluated, paying particular attention to the high flow and other conditions, such as season of the year, which tend to cause the conventional BMPs to be unable to achieve the degree of treatment/management needed.

Science of BMP Development

A critical review of the literature on the TMDLs that are advocated for control of potential pollutants in irrigated agriculture stormwater runoff and tailwater releases shows that, often, limited incorporation of the science that is applicable to BMP development has occurred. There is considerable information in the non-agriculture literature that could serve as a guide to the development of appropriate BMPs for certain types of potential pollutants present in irrigated agricultural runoff/discharges. All treatment-type BMPs are based on certain basic physics and chemistry/biochemistry governing the ability of a particular removal process to reduce the concentrations of a constituent to a certain degree for a certain chemical type/form in the runoff/discharge waters. There is substantial literature in the aquatic chemistry field and in the water and wastewater treatment field that has applicability to developing appropriate agricultural runoff water quality BMPs. Little of this information has been incorporated into the agricultural runoff water quality BMP literature.

Any potential BMP for removal of a certain type of constituent should be evaluated over the range of hydrological (rainfall runoff) conditions that can occur in the area of potential application of the BMP. As discussed herein, of particular importance for the conventional agricultural water quality BMPs is the ability of the BMP unit to work effectively under high flow conditions. It is not enough to evaluate BMPs based on low or moderate flows under the conditions where the BMP must also be able to function under high flow to remove constituents effectively to meet regulatory requirements. Vegetative areas, ponds, and other conventional agricultural so-called BMPs are often not effective in removing many of the potentially significant pollutants in agricultural runoff during elevated flow conditions, due to the short hydraulic residence time of the water passing through the unit.

Not only must an understanding be gained of how the potential BMP responds to various hydrological conditions, but also there is need to understand the hydraulics of the BMP treatment unit - i.e., how the water and its associated dissolved constituents are conveyed through the treatment unit. Of concern is whether there is short-circuiting of the inflow water to the outlet which reduces the actual residence time of the water and associated dissolved constituents compared to the theoretical detention time (unit volume divided by inflow rate). Further, for particulate potential pollutants, the hydraulics of the movement of various types and sizes of particles should be understood in developing appropriate BMPs. There is substantial theoretical and applied literature on these issues in the water and wastewater treatment field. Application of this literature to BMPs based on vegetative areas and detention/retention ponds should be made.

The physical and chemical characteristics of potential pollutants should also be understood in developing BMPs for their removal from agricultural runoff/discharges. Potential pollutants, such as pesticides and nutrients that are associated with particles in the runoff waters, will be removed by various types of BMPs differently depending on whether the particles are colloidal, finely divided particulates, or associated with larger, denser particles. It is not enough just to know that the potential pollutant is particulate. The size of the particles and their densities will play a major role in their removal in sedimentation basins/ponds.

Further, since sorption is an important process upon which removal in many conventional BMPs is based, the characteristics of the chemical species of the potential pollutant need to be understood in order to develop an appropriate BMP for its removal from agricultural runoff/discharges. The removal of a constituent by sorption will be significantly different if the constituent is in the dissolved aquo species, or complexed with organics or inorganics. The aqueous environmental chemistry of a potential pollutant controls its transport/fate in agricultural runoff and in the receiving waters for this runoff and within BMP treatment units. There are eight types of chemical reactions that govern the aqueous environmental chemistry of a potential pollutant. These include oxidation-reduction, acid-base, precipitation, complexation, sorption, volatilization, biochemical transformation and gas exchange. Each of these reaction types proceeds in the runoff water and the BMP treatment units according to its characteristic kinetics (rates) and thermodynamics (positions of equilibrium). These aquatic-chemistry issues need to be considered in selecting and evaluating an appropriate BMP for a particular situation.

An example of these issues is the work on pesticides as reported in Cheng (1990). Cheng edited a Soil Science of America publication entitled Pesticides in the Soil Environment: Processes, Impacts, and Modeling. This publication provides substantial information on the variety of physical, chemical, and biological factors that need to be incorporated into BMP development. Similar discussions apply to most other potential pollutants in agricultural runoff/discharges, such as the aquatic plant nutrients (nitrogen and phosphorus compounds).

The Rice Herbicide Management Program, developed by the California Department of Pesticide Regulation and the rice growers to meet CVRWQCB requirements for reducing the concentrations of herbicides discharged from rice fields that cause aquatic life toxicity and tastes and odors in domestic water supplies, is based on a water management program, where the herbicide-treated water is held on the fields for a sufficient time to allow degradation of the herbicide. This is an example of how understanding the aquatic chemistry of a potential pollutant can lead to a BMP for its management. Information on the rice pesticide control program is available at www.cdpr.ca.gov/docs/sw/2001prev.pdf and www.cdpr.ca.gov/docs/enfcmpli/penfltrs/penf2002/2002012.htm.

There is an urgent need for those developing/evaluating agricultural runoff/tailwater discharge water quality BMPs to better incorporate the basic scientific principles governing the behavior of potential pollutants in runoff/discharge waters and BMP treatment units.

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.

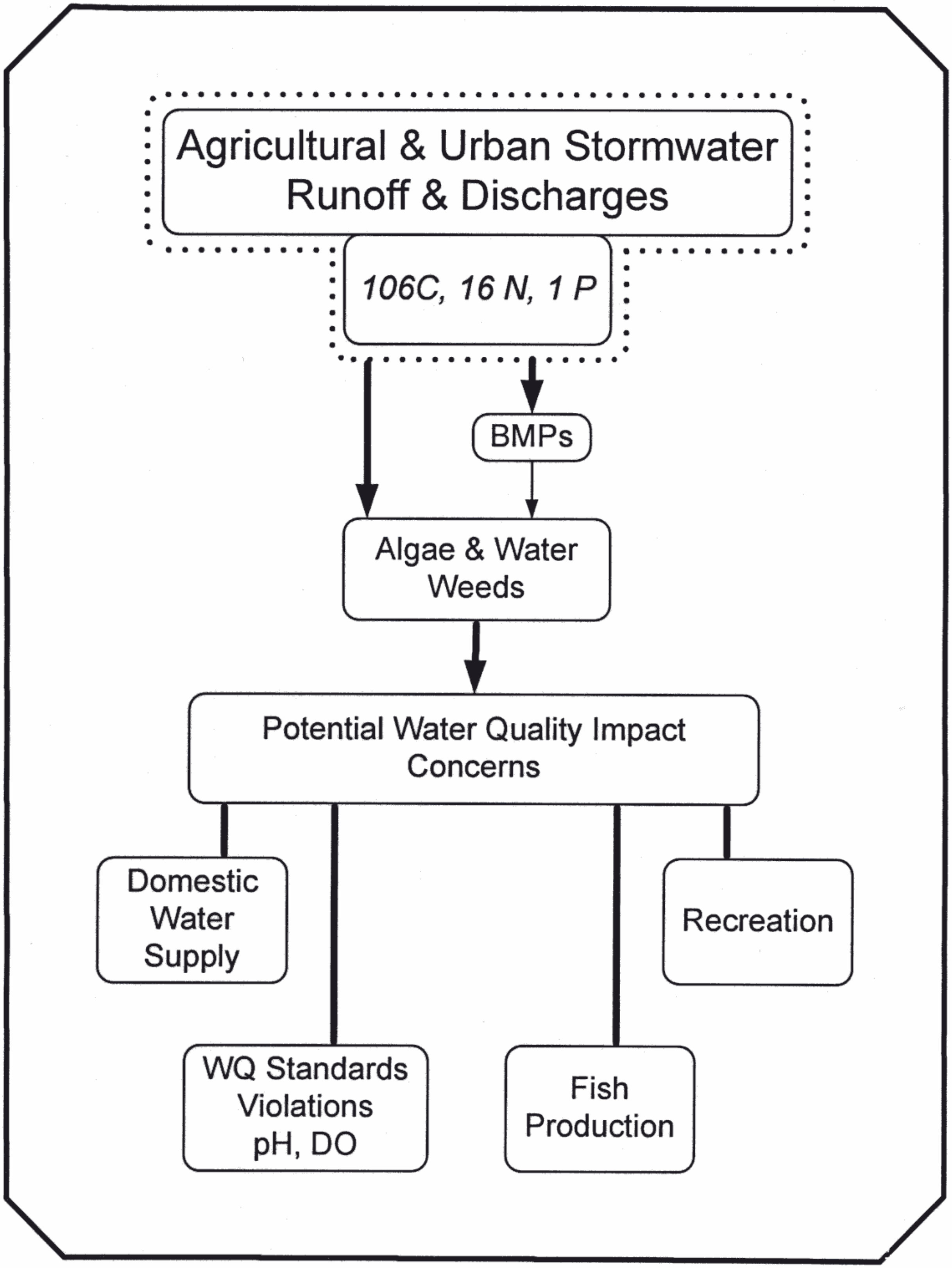
Another complicating factor in developing nutrient management programs is that the impacts of excessive fertilization are often subjective with respect to impairing the recreational use of waterbodies, where they are dependent on the public's response to the aquatic plant biomass in the waterbodies of 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

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



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 discussed by Lee (1971). A brief summary of water quality problems caused by excessive fertilization, which can lead to a 303(d) listing of a waterbody as "impaired," is presented below.

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

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

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.

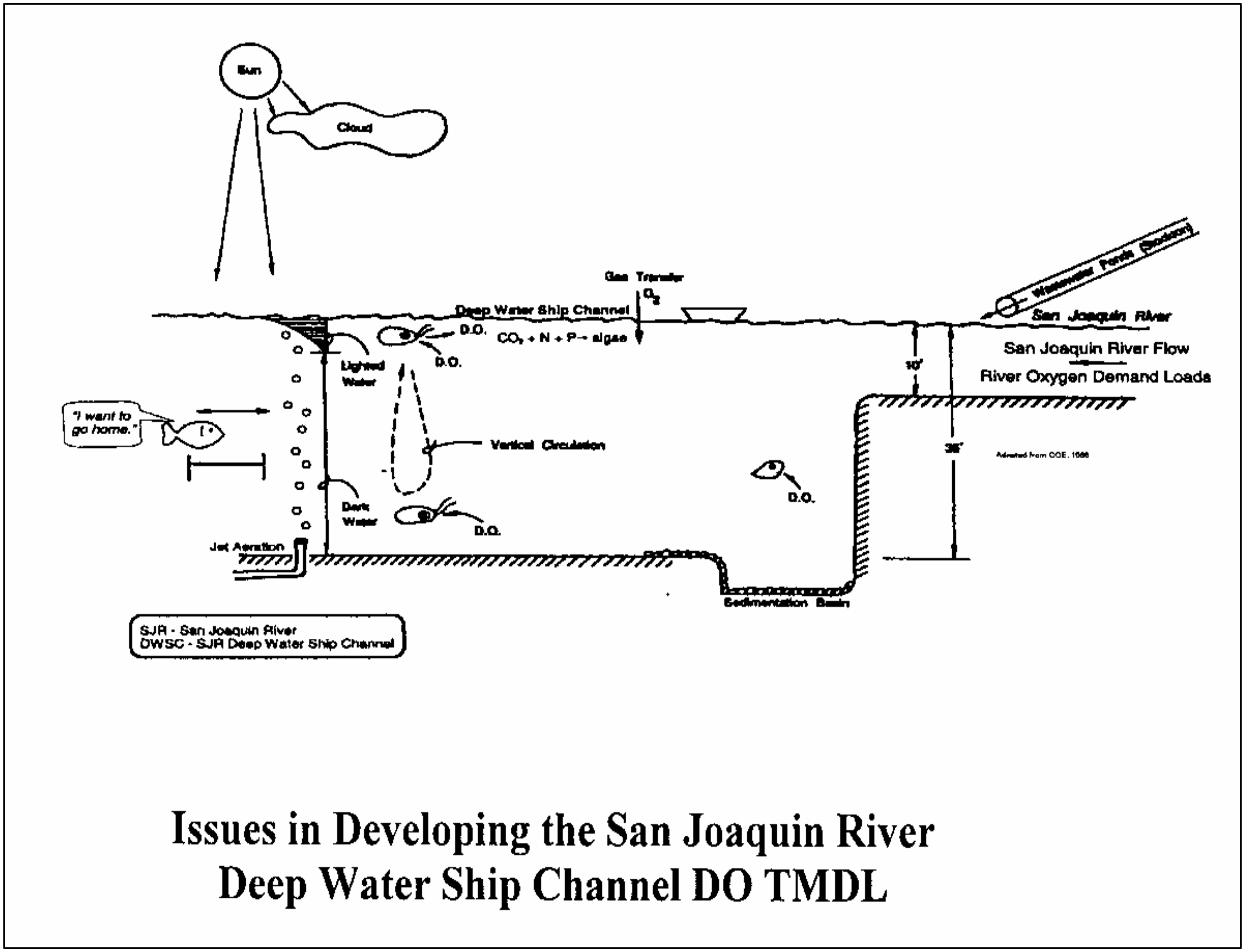
Impaired Recreation. Excessive growth of algae, both planktonic and attached, can affect the use of waterbodies for swimming, boating and fishing, through interference with water contact. They can also lead to severe odor problems due to decaying algae, algal scums, etc.

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.)

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.

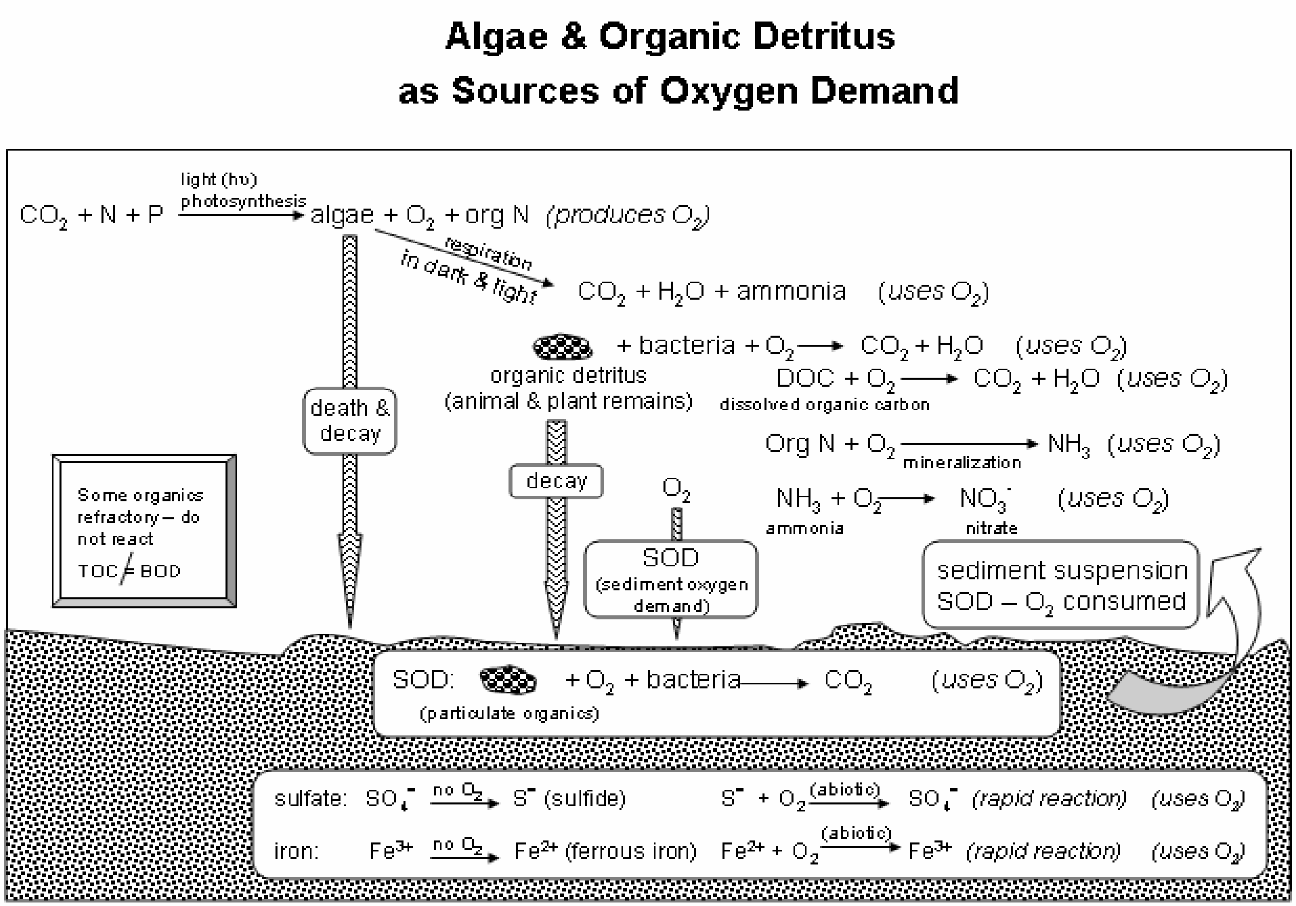
Overall Impacts of Excessive Fertilization. Excessive fertilization is one of the most important causes of water quality impairment of waterbodies. The US EPA (2000a), in its last National Water Quality Inventory, has listed nutrients as the leading cause of water quality impaired lakes

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



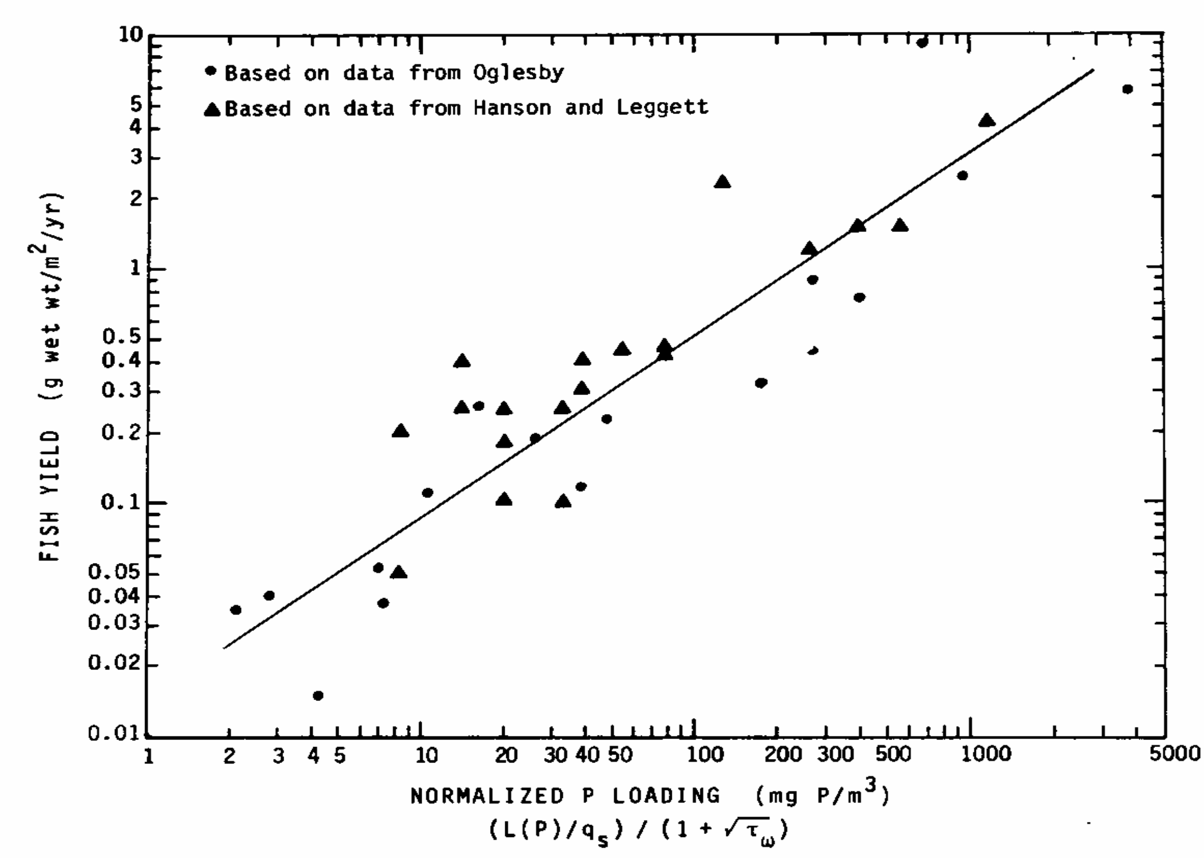
From Lee and Jones-Lee (2000).

Figure 4. DO Depletion Reactions in the SJR DWSC



From Lee and Jones-Lee (2000).

Figure 5. Effect of Phosphorus Loads on Fish Production



(The terminology used in the abscissa of Figure 5 is explained in the subsequent section of this paper.)

Source: Lee and Jones (1991b)

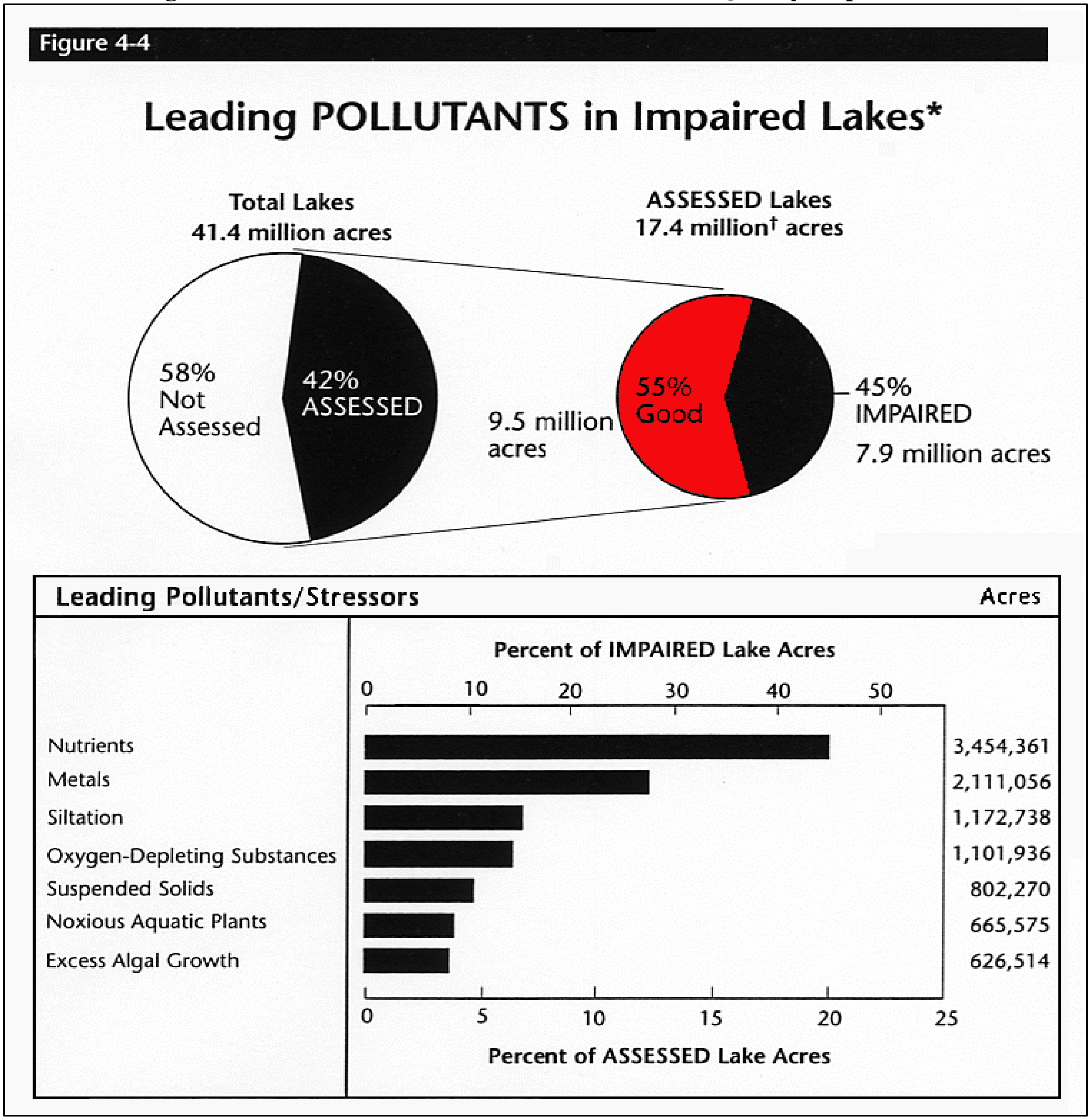
and reservoirs (Figure 6). Further, as shown in Figure 7, the Agency lists agriculture as the primary source of constituents (nutrients and sediments) that impair lakes.

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.

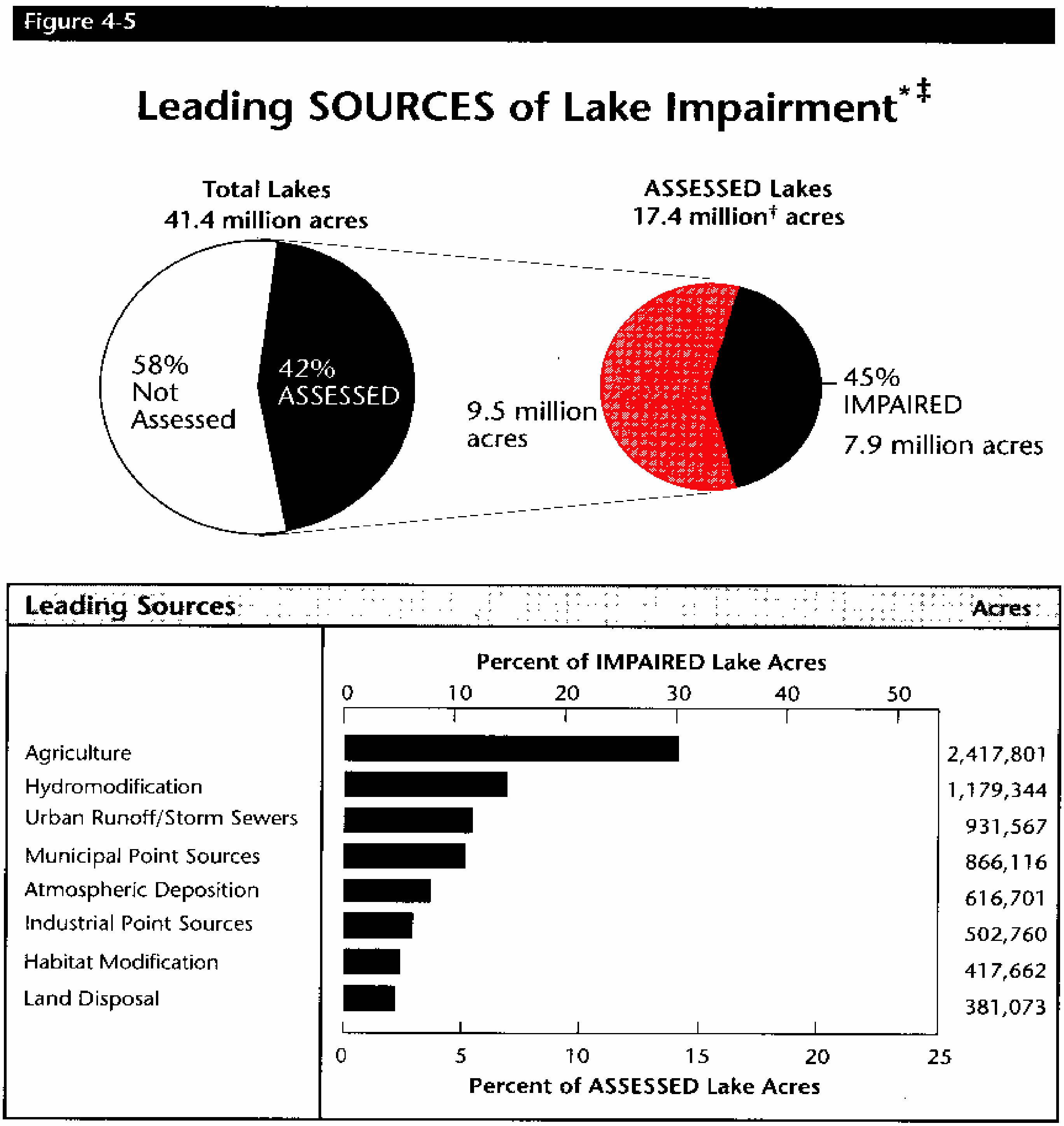
With respect to phosphorus, it is the soluble orthophosphate that is available to support algal growth. There are many forms of phosphorus that do not support algal growth, particularly the particulate forms, as well as some organophosphorus compounds and oxygen-phosphorus polymer chain and ring compounds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

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)

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).

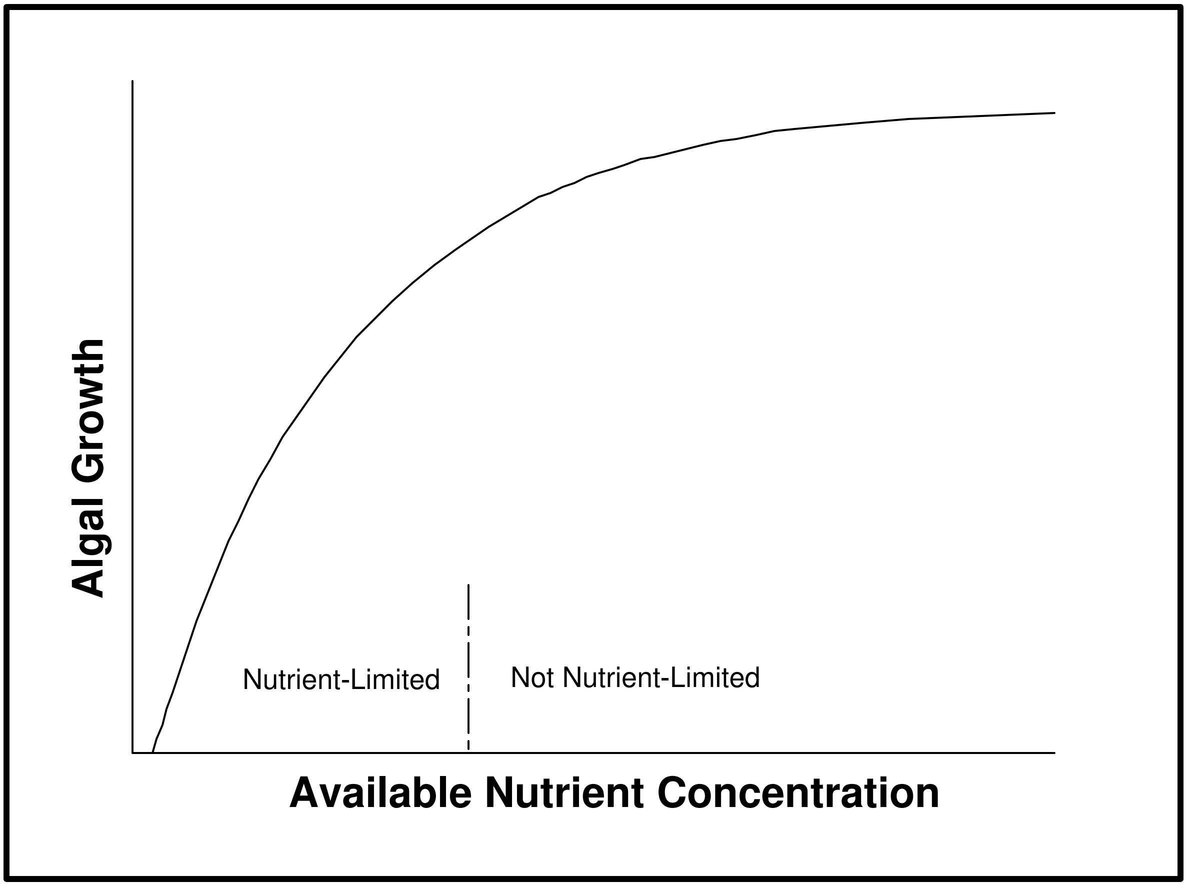
The approach that should be used to determine whether nitrogen or phosphorus is limiting algal growth is to examine the concentrations of available forms of nutrients at peak biomass, and then, if the concentrations present are below growth-rate-limiting concentrations, there is reasonable certainty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

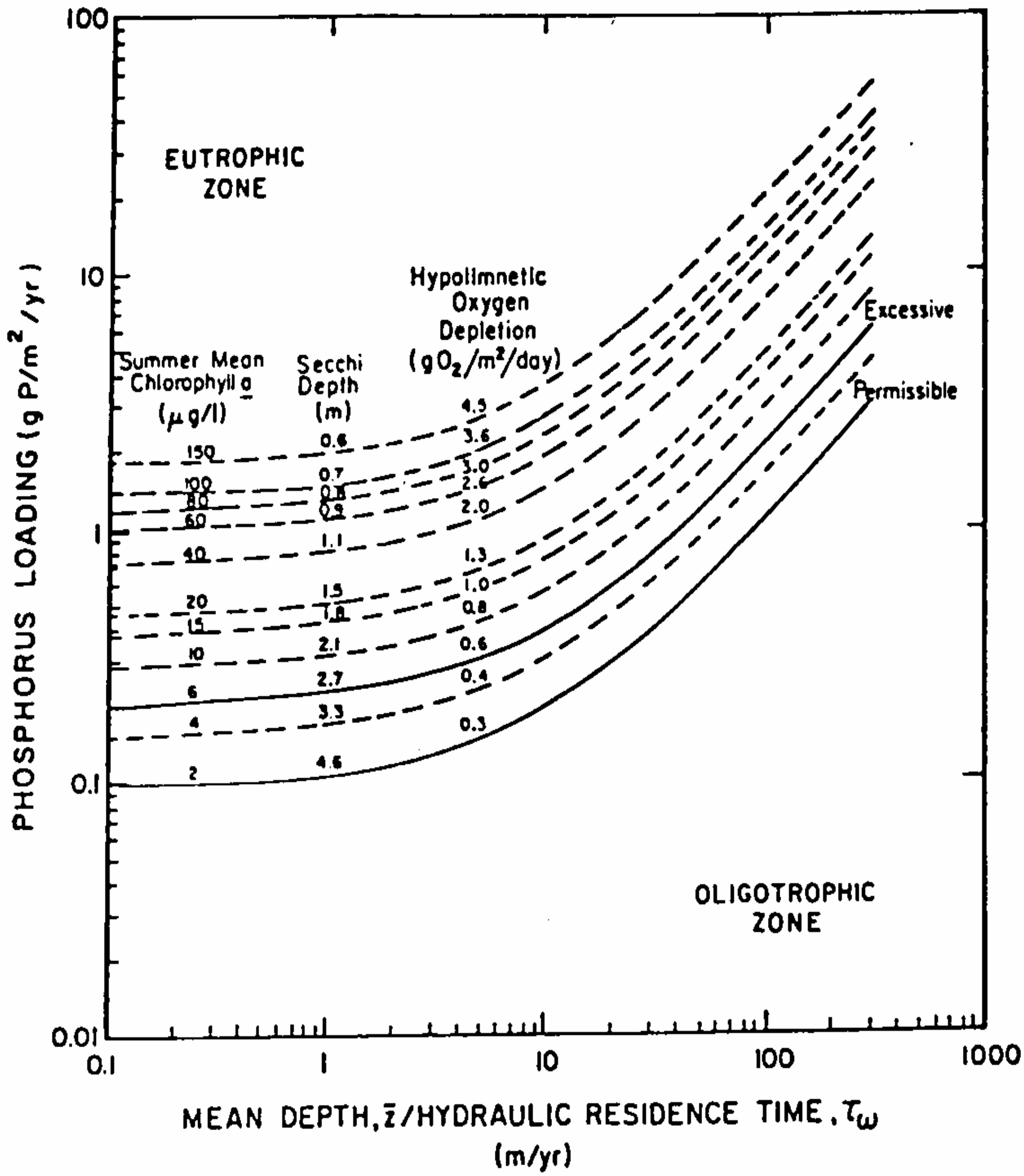
The deterministic modeling approach, while able to be tuned to relate nutrient loads to eutrophication response, may have limited predictive capability. Because of the number of equations used, there is no unique solution to the model, and therefore, tuning the model may not properly represent the conditions 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.

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)

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.

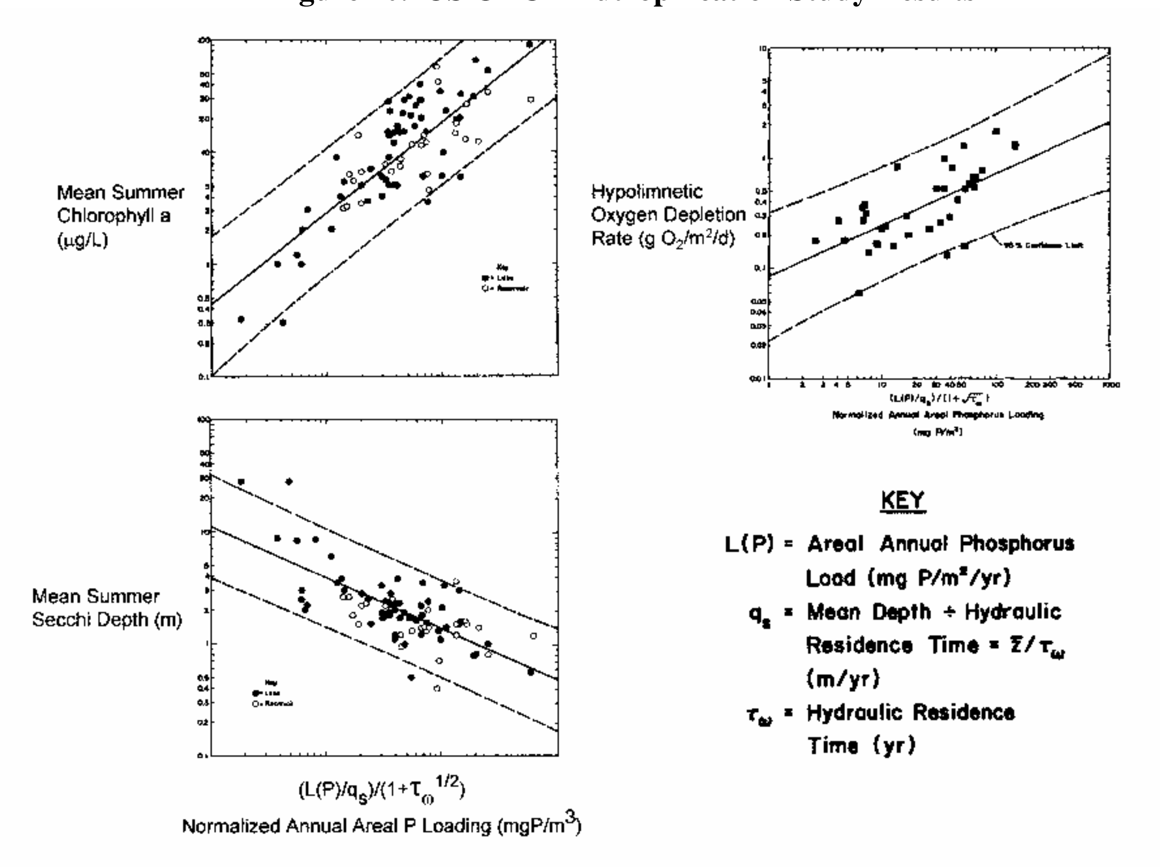
For lakes/impoundments that do not follow the phosphorus load-eutrophication response relationship that was developed in the OECD Eutrophication studies, as well as rivers and streams, it is necessary to conduct site-specific studies to determine the eutrophication-related water quality of interest to 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.

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).

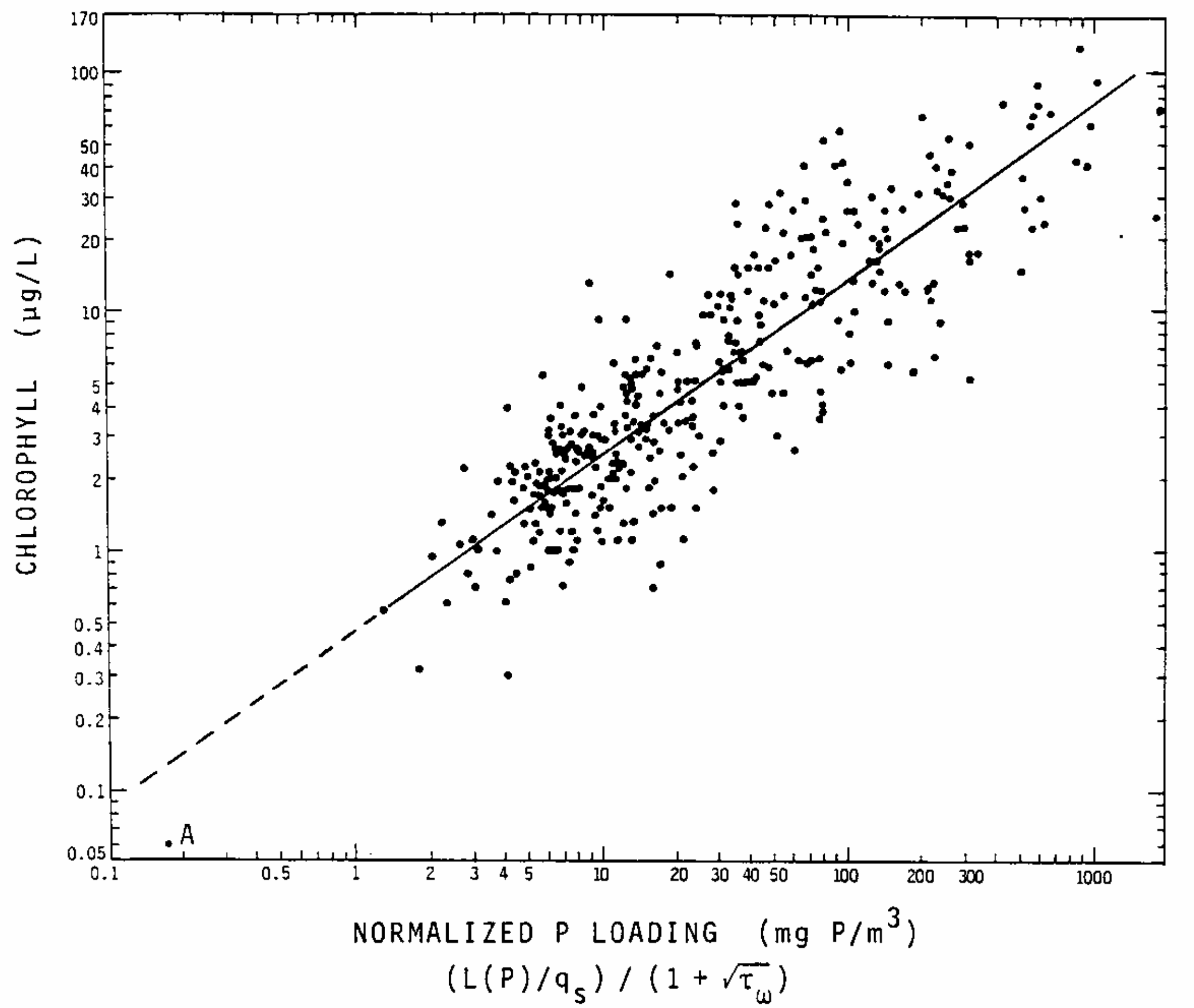
Figure 10. US OECD Eutrophication Study Results



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

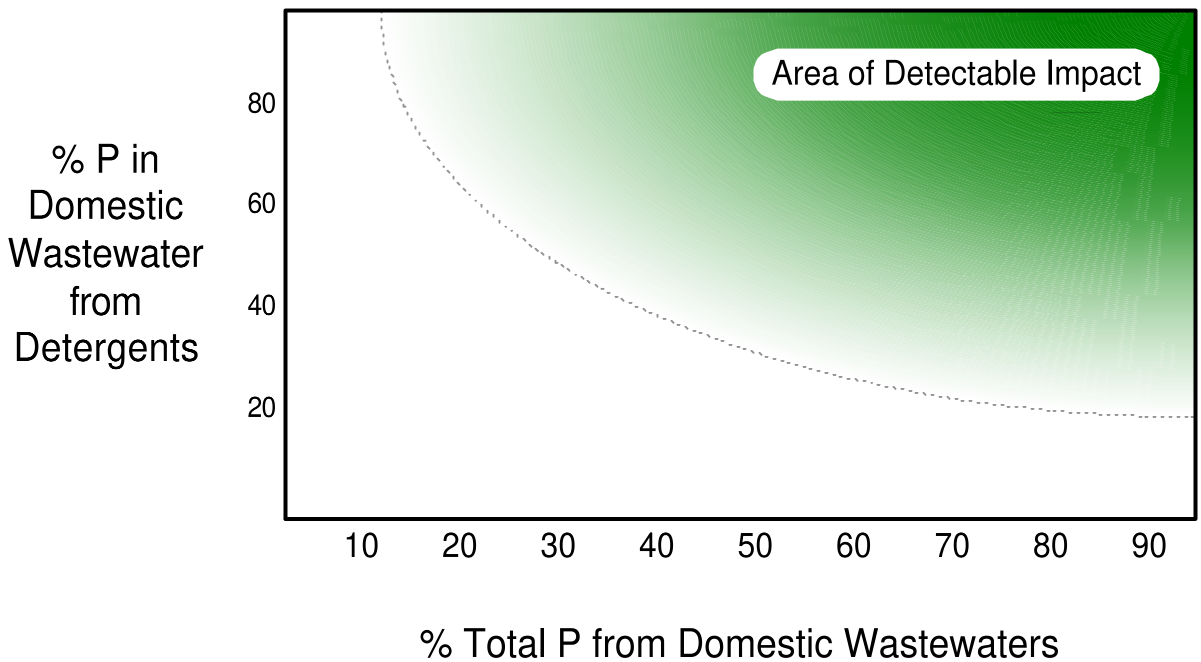


From Jones and Lee (1986).

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

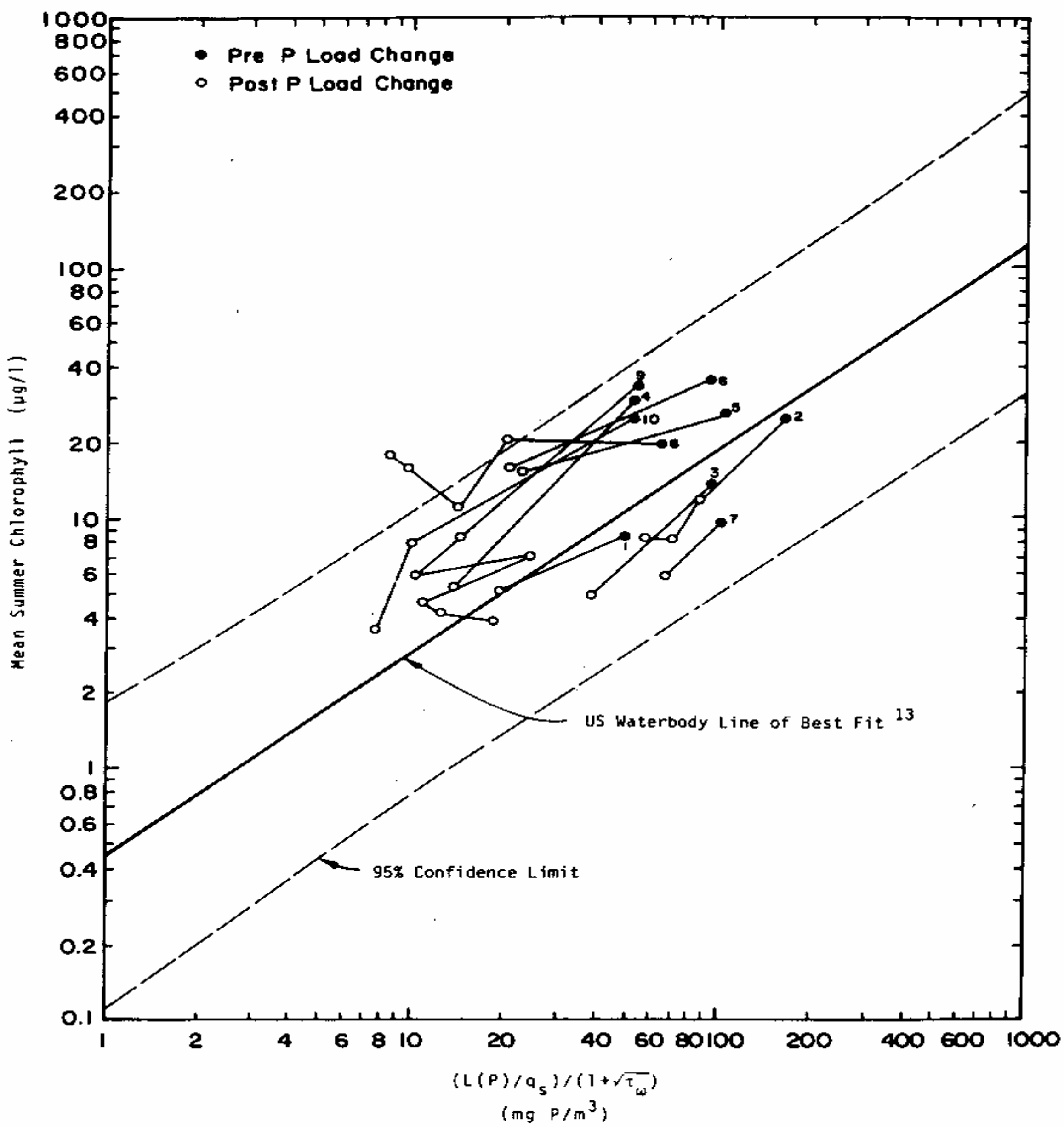


From Lee and Jones (1986).

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.

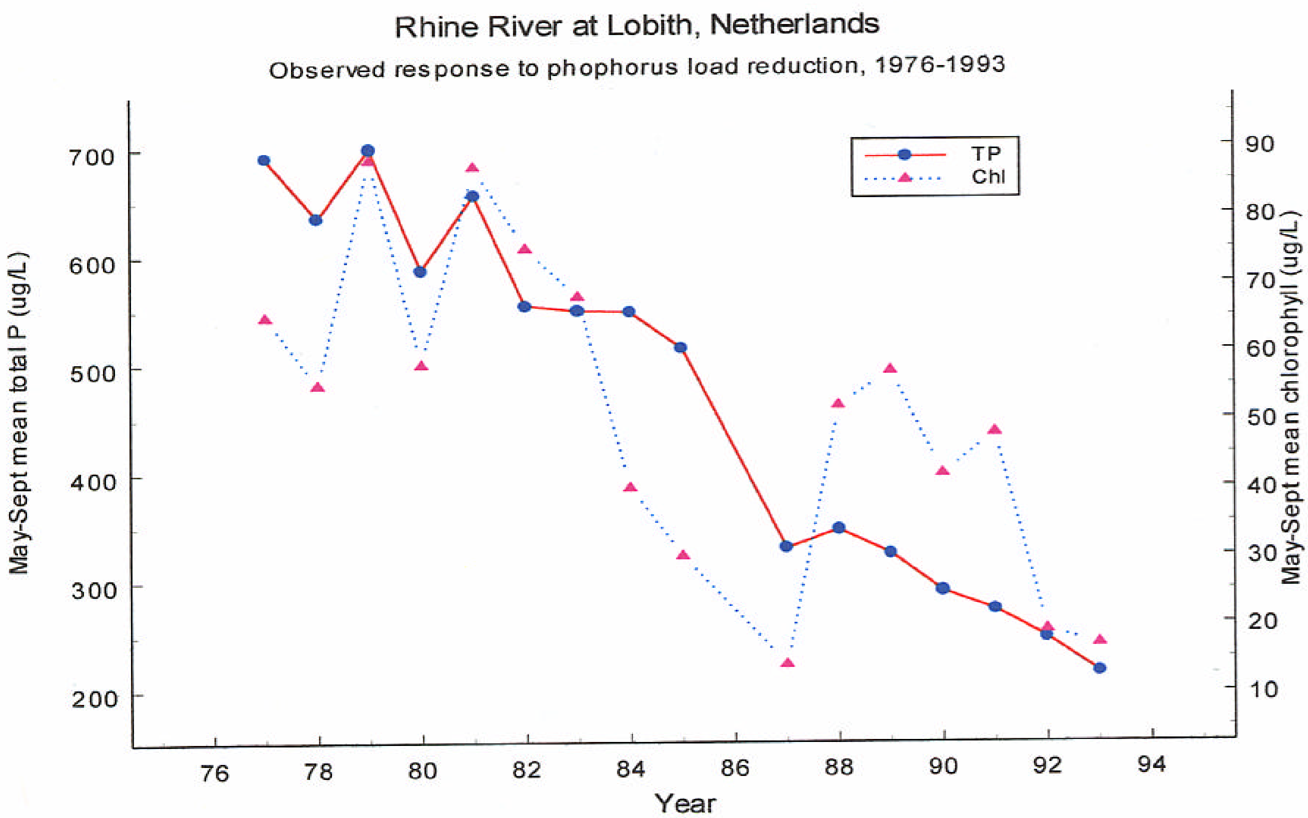
Figure 13. Effect of Phosphorus Loads to Waterbodies on Planktonic Chlorophyll



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

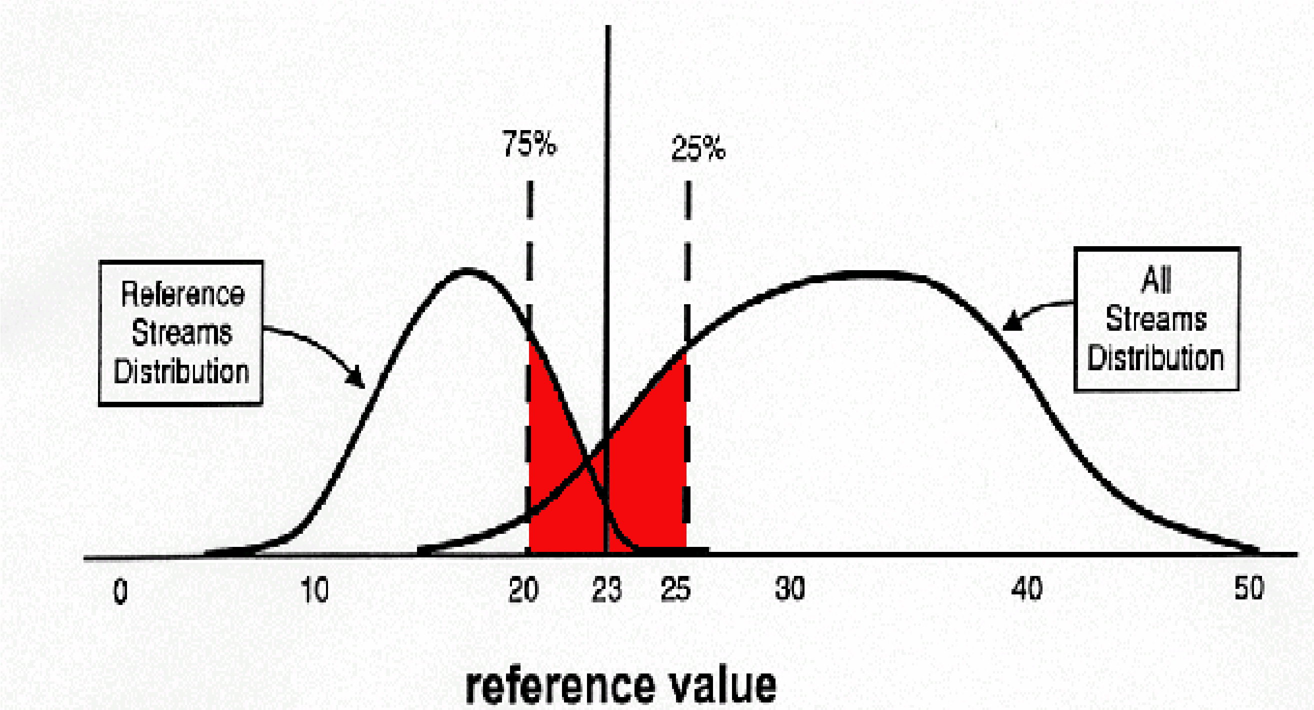


Figure 8. Selecting reference values for total phosphorus concentration (μg/L) using percentiles from reference streams and total stream populations.

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

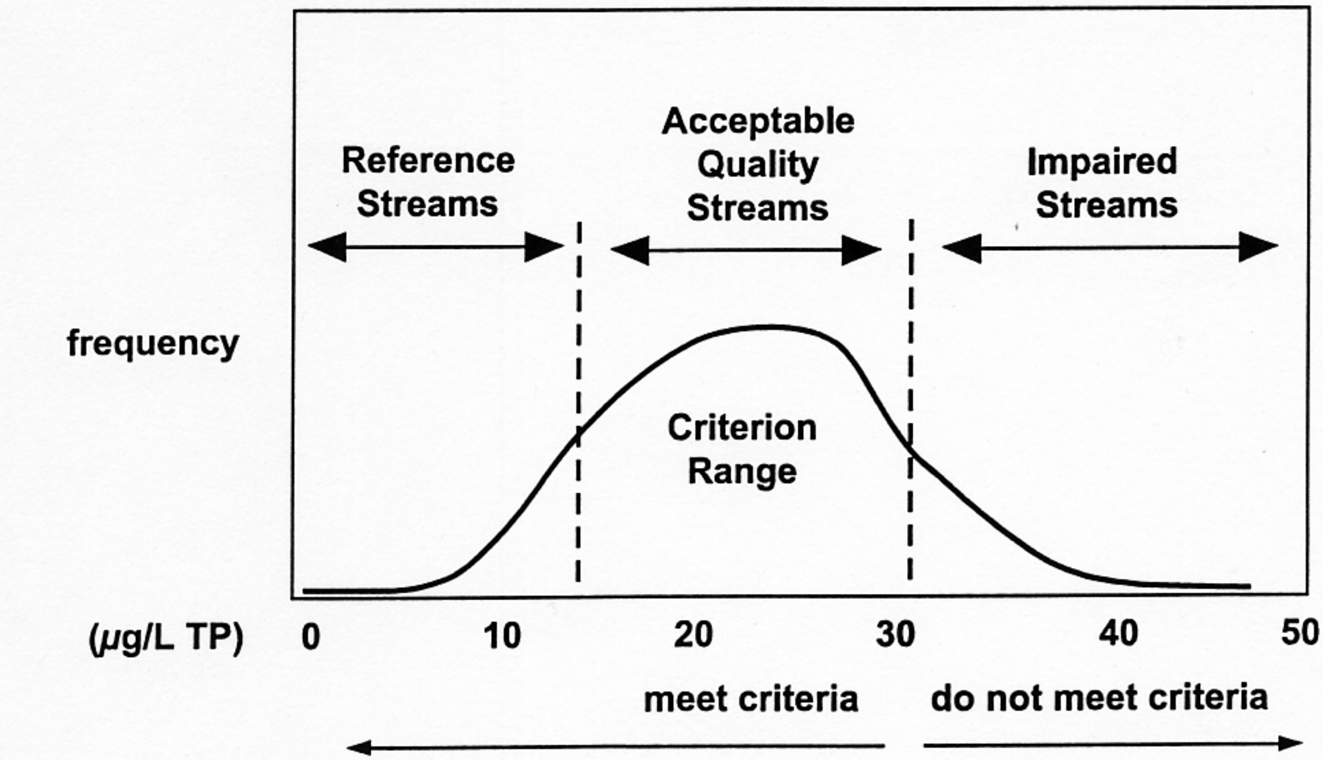


Figure 9. Frequency distribution divided into three segments that represent (from left to right) high-quality reference streams, acceptable quality streams, and impaired streams.

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.

SJR Mainstem. 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.

SJR Upstream of Reservoirs. 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.

SJR Deep Water Ship Channel. 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.

SJR Mainstem Tributaries. 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.

Developing/Selecting a Stormwater Runoff BMP

All too often, a “water quality” BMP for either urban or agricultural runoff situations is selected based on the fact that it is on the list of BMPs that has been developed by some agency or professional group. A stormwater runoff water quality BMP should, by definition, represent a “best management practice” for the control of one or more constituents that are adversely impacting the designated beneficial uses of the receiving waters or downstream waters from the runoff of concern. The term “BMP,” when applied to nutrient control from agricultural sources, might be better replaced with the term “management approach” since in many instances the management programs will require an integrated use of several approaches to controlling nutrients in agricultural field runoff/discharges.

Meeting Regulatory Requirements

The most important step in selecting the appropriate BMP(s) is to define the objective of the control program. If the program has as its required objective the attainment of water quality standards in the discharge waters and/or the receiving waters, then the so-called "BMP" should be able to control the constituent concentration in the runoff so that it does not cause or contribute to violations of a water quality standard in the receiving waters. This situation could become important as the US EPA nutrient criteria are adopted into state water quality standards that represent enforceable limits at the edge of the field. Since, often, stormwater runoff is not allowed a mixing zone between the runoff waters and the receiving waters, this means that the concentrations of the constituents in the runoff waters cannot exceed the applicable water quality standard by any amount more than once in three years.

In the urban stormwater runoff water quality management field, the US EPA (1990) defined the objective of stormwater runoff water quality management as the control of **pollution** to the maximum extent practicable, using best management practices. Pollution is defined in the Clean Water Act as an impairment of the beneficial uses of a water. It has been further determined, through interpretation of these regulations by the US EPA and the courts, that, ultimately, NPDES-permitted urban stormwater runoff, like all other NPDES-permitted discharges, must not cause or contribute to violations of water quality standards in the receiving waters for the runoff. This has led to a BMP ratcheting-down process, where the dischargers and the regulatory agencies must come to an agreement that, if the stormwater runoff contains constituents that can cause or contribute to violations of water quality standards at the point of discharge (i.e., no mixing zones are allowed), then increasingly more effective best management practices will need to be implemented. While, for a number of years, little progress was made in the BMP ratcheting-down process for urban stormwater runoff, that situation is now beginning to change. The February 2002 decision by the Environmental Appeals Board of the United States Environmental Protection Agency, Washington, D.C. (US EPA, 2002d), determined that, while urban stormwater runoff water quality management agencies do not at this time have to control constituents in the runoff waters to meet water quality standards, they must show progress toward achieving these standards through the BMP ratcheting-down process.

While in the urban stormwater runoff water quality management field the BMP ratcheting-down process is in effect today, this approach is not necessarily in effect for agricultural runoff, in order to satisfy TMDL targets, although there is some discussion by Central Valley Regional Water Quality Control Board staff about the Board potentially adopting a BMP ratcheting-down process as part of making progress toward controlling diazinon in stormwater runoff from dormant-sprayed orchards. If that process is adopted for agricultural runoff, then there will be the same need as exists now for urban runoff, to convincingly demonstrate that the BMPs selected have a reasonable potential to control the constituent of concern to the degree needed. It also should be understood that, within a few years, as part of evaluating compliance with the TMDL target, it may be necessary to install ever-more-effective BMPs.

The situation with respect to managing urban stormwater runoff so that it does not cause or contribute to water quality standard violations may be important in helping to establish the selection and implementation of BMPs for agricultural stormwater runoff/discharges. With respect to agricultural runoff/discharges, there is no corresponding federal legislation for nonpoint-source discharges. Further, there is no requirement that such discharges be issued an NPDES permit. However, in California, Porter-Cologne (SWRCB, 1989) allows the imposition of discharge requirements to nonpoint sources of pollution. The Porter-Cologne regulations state, with respect to waste discharge requirements:

"§13263

(a) The regional board, after any necessary hearing, shall prescribe requirements as to the nature of any proposed discharge, existing discharge, or material change therein, except discharges into a community sewer system, with relation to the conditions existing from time to time in the disposal area or receiving waters upon or into which the discharge is made or proposed. The requirements shall implement relevant water quality control plans, if any have been adopted, and shall take into consideration the beneficial uses to be protected, the water quality objectives reasonably required for that purpose, other waste discharges, the need to prevent nuisance, and the provisions of Section 13241.

(b) A regional board, in prescribing requirements, need not authorize the utilization of the full waste assimilation capacities of the receiving waters.

(c) The requirements may contain a time schedule, subject to revision in the discretion of the board.

(d) The board may prescribe requirements although no discharge report has been filed.

(e) Upon application by any affected person or on its own motion, the regional board may review and revise requirements. All requirements shall be reviewed periodically.

(f) The regional board shall notify in writing the person making or proposing the discharge or the change therein of the discharge requirements to be met. After receipt of such notice, the person so notified shall provide adequate means to meet such requirements.

(g) No discharge of waste into the waters of the state, whether or not such discharge is made pursuant to waste discharge requirements, shall create a vested right to continue such discharge. All discharges of waste into waters of the state are privileges, not rights."

§13241

Each regional board shall establish such water quality objectives in water quality control plans as in its judgment will ensure the reasonable protection of beneficial uses and the prevention of nuisance; however, it is recognized that it may be possible for the quality of water to be changed to some degree without unreasonably affecting beneficial uses. Factors to be considered by a regional board in establishing water quality objectives shall include, but not necessarily be limited to, all of the following:

(a) Past, present, and probable future beneficial uses of water.

(b) Environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto.

(c) Water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area.

(d) Economic considerations.

(e) The need for developing housing within the region. (Amended by Stats. 1979, Ch. 947.)"

It is under these provisions that waste discharge requirements can be issued to any agricultural stormwater runoff or discharge of tailwater/drain water which causes or contributes to violations of water quality standards in the State's waters or impairs the beneficial uses of a waterbody.

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.

Integrated Approach for Managing Agriculturally-Derived Water Quality Impacts

It is recommended that the water quality stakeholders (agricultural interests, regulatory agencies, environmental groups and the public) in each of the major tributaries of the San Joaquin River and Sacramento River watersheds, as well as the mainstem of each river, organize an integrated water quality monitoring program to define the potential water quality problems in each watershed and downstream thereof that are caused by constituents derived from the watershed. This monitoring program should follow the approach recommended by Lee and Jones-Lee (2002e) for conducting a comprehensive watershed-based NPS water quality evaluation. Also, the stakeholders in various parts of the Delta (south, mid, northeast) should conduct comprehensive water quality monitoring programs in their part of the Delta. The focus of these monitoring programs should be on determining whether regulated potential pollutants exist in the State's waters within the watershed at concentrations that exceed CVRWQCB water quality objectives. An Evaluation Monitoring (Jones-Lee and Lee 1998a) approach should be used which focuses on determining the impacts of chemical constituents and pathogen indicator organisms on the beneficial uses of waters within the watershed.

It is important that this monitoring program consider the full range of constituents of potential concern. The constituents listed in Table 1 represent an initial starting point for this evaluation. While the focal point of a particular monitoring program might be pesticides, at the same time as monitoring for pesticides in the runoff waters, monitoring should be conducted for the other potential pollutants such as nutrients, TDS, TOC and other parameters of potential concern.

The results of these monitoring programs should be used to define the constituents that cause significant water quality use impairment in the watershed or parts thereof. Based on this information the stakeholders in the watershed should organize an integrated management practice (BMP) evaluation program to determine the degree of control of the constituents of concern that can be achieved at various costs. While evaluating the ability of a management practice to remove a particular constituent, monitoring should also be done for the removal of other constituents of concern in this watershed or other watersheds. This approach will help build the management practice efficacy information base. It will be important to obtain cost information of all management practice evaluations. This information should then be used by the stakeholders to formulate a technically valid, cost-effective NPS and point source management program to protect the designated beneficial uses of the waterbodies in the watershed as well as downstream.

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Appendix A
AN INTEGRATED APPROACH FOR TMDL DEVELOPMENT FOR AGRICULTURAL STORMWATER RUNOFF, TAILWATER RELEASES AND SUBSURFACE DRAIN WATER[1]

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ABSTRACT

Irrigated agriculture in the San Joaquin River watershed is subject to compliance with TMDLs for selenium, total dissolved salts, organophosphate pesticides (diazinon and chlorpyrifos), boron and oxygen demand (nutrients/algae). The proposed Central Valley Regional Water Quality Control Board irrigated agriculture waiver water quality monitoring program will likely show that irrigated agricultural stormwater runoff and tail water/subsurface drain water discharges cause violations of existing and soon to be developed water quality objectives (standards). As a result, agricultural interests in this watershed also potentially face compliance with TMDLs for nutrients (nitrogen and phosphorus), total organic carbon, unknown-caused toxicity, sediment toxicity, organochlorine (legacy) pesticides (such as DDT, chlordane, toxaphene etc.) and pathogen-indicator organisms. There is need for agricultural interests and the regulatory agencies to approach the development of the TMDLs in an integrated, coordinated effort. This effort should include a comprehensive monitoring/water quality impact evaluation program that addresses the stormwater runoff, tailwater and subsurface drain water discharges for all constituents that are potentially subject to Clean Water Act 303(d) listing. The development of BMPs for the control of agricultural releases/discharges should evaluate the control of all constituents that are potentially subject to future TMDL regulation.

INTRODUCTION

Irrigated agriculture in the San Joaquin River watershed of the Central Valley of California faces significant challenges in staying economically viable and meeting the variety of regulatory constraints that are being implemented to control excessive concentrations of a variety of chemical constituents that are present in irrigated agricultural lands' stormwater runoff and irrigation return waters (tailwater)/ subsurface drain waters. Tailwater refers to irrigation water that is in surface water runoff from the irrigated fields, while subsurface drain water is water that is derived from a subsurface collection system designed to lower the water table. Irrigated agriculture in the San Joaquin River watershed faces multiple total maximum daily loads (TMDLs) designed to control chemical constituents so that their concentrations in waters receiving agricultural runoff/discharges do not exceed water quality standards/objectives. This discussion of potential TMDLs in the San Joaquin River watershed is based on the authors experience/expertise. This discussion does not necessarily reflect the Central Valley Regional Water Quality Board views on these issues.

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1 Lee and Jones-Lee (2002b)

CURRENT, PENDING AND POTENTIAL FUTURE TMDLs

Table 1 presents a listing of current, pending and potential TMDLs faced by agricultural interests in the San Joaquin River watershed.

Table 1. San Joaquin River Watershed TMDLs

Current TMDLs
- Selenium
- Salinity, Total Dissolved Solids
- Boron
- OP Pesticides (Diazinon, Chlorpyrifos)
- Oxygen Demanding Substances, (BOD, Ammonia, Organic N)

Pending
- Organochlorine Pesticides, (DDT, Chlordane, Dieldrin, Toxaphene, etc.)
- PCBs
- Mercury
- Unknown-Caused Toxicity
- Toxicity to Algae (Herbicides)

Potential Future
- Nutrients, Excessive Fertilization (Nitrogen and Phosphorus Compounds)
- High pH, Low DO caused by Excessive Fertilization (Photosynthesis)
- Alternative Pesticides to OP Pesticides
- Total Organic Carbon, Trihalomethanes in Domestic Water Supplies
- Excessive Sediment, Erosion, Turbidity
- Pathogen-Indicator Organisms, *E. coli*
- Sediment Toxicity, Pesticides, Nutrients/Algae/Sediment Ammonia
- Temperature (?)
- Dioxins/Furans, Combustion Residues (?)

Current SJR Watershed TMDLs

Agriculture in some parts of the San Joaquin River watershed is already facing TMDLs designed to control discharges of selenium, total salts, organophosphate pesticides (diazinon and chlorpyrifos) and boron. The Central Valley Regional Water Quality Control Board (CVRWQCB) has proposed TMDLs to control salinity and boron in the San Joaquin River watershed. Further, there are TMDLs pending that are based on controlling organophosphate pesticides (diazinon and chlorpyrifos) and organochlorine (legacy) pesticides, such as DDT, chlordane, dieldrin, toxaphene, etc., in the San Joaquin River watershed.

Low dissolved oxygen concentrations below the water quality objective in the San Joaquin River (SJR) Deep Water Ship Channel(DWSC) near Stockton have caused the CVRWQCB to develop a TMDL to control discharges of the oxygen-demanding materials and/or conditions that contribute to the DWSC low-DO problem. Lee and Jones-Lee (2000, 2001 and 2002a) have provided a review of this matter. As they report, a major cause of the DWSC low-DO problem is the discharge of nutrients from agricultural lands that develop into algae in the SJR tributaries and the mainstem that are transported into the DWSC, where they die and decompose, leading to low DO. The Mud and Salt Slough watersheds and the SJR upstream of Lander Avenue (Highway 165) are the primary sources of the algae that cause this problem.

Pending TMDLs

In a few years, (likely by 2006) in accord with US EPA's (2001) announced program, it is highly likely that TMDLs will need to be developed to control the concentrations of nitrogen and phosphorus compounds in agricultural stormwater runoff, irrigation tailwater and subsurface drain water to control excessive fertilization of the San Joaquin River and its tributary and downstream waters in the Delta and in water supply reservoirs that use Delta water as a water supply source. Lee and Jones-Lee (2002b) have recently reviewed the issues pertinent to managing phosphorus runoff from agricultural lands. They discuss that there are a variety of factors that need to be investigated in order to develop technically-valid, cost effective phosphorus runoff management programs.

The San Joaquin River and some of its tributaries have been found to be toxic to aquatic life standard test organisms used in US EPA toxicity testing procedures. Studies on this toxicity have thus far failed to identify the cause of the toxicity. This has led the CVRWQCB to develop a TMDL to control this toxicity as "unknown-caused toxicity." Possibly a substantial part of the unknown caused toxicity could be derived from releases from agricultural lands.

The organochlorine pesticides such as DDT, dieldrin, toxaphene, chlordane, etc., are "legacy" pesticides that were banned from use many years ago because of their persistence and their potential to cause cancer in people. However, because of their widespread use by agriculture and persistence in soil they are still present in agricultural soils and in waterbodies that have received runoff from irrigated agriculture in many areas of the Central Valley of California. Past and current runoff/discharges from irrigated lands in the San Joaquin River watershed have resulted in excessive concentrations of several of the legacy pesticides in edible fish tissue taken from waterbodies influenced by agricultural runoff in the Central Valley. This bioaccumulation is of concern since these pesticides are a threat to cause cancer in those who use the fish as food. This has caused the CVRWQCB and the State Water Resources Control Board (SWRCB, 1998) to list about a dozen waterbodies in the Central Valley as 303(d) "impaired" waterbodies, which requires that a TMDL be developed to control the excessive bioaccumulation of the organochlorine pesticides.

Potential TMDLs

Increasing attention is being given to aquatic sediment water quality impacts. This is causing the US EPA and the California State Water Resources Control Board to develop sediment quality guidelines. These guidelines will focus on determining excessive concentrations of chemical constituents in sediments that affect water quality. These guidelines will likely include sediment toxicity. Pesticides, heavy metals and nutrients that develop into algae are common causes of sediment toxicity. The algae cause sediment toxicity through their death and decay in the sediments, which results in the release of ammonia which is highly toxic to aquatic life.

Another potential TMDL that the San Joaquin River watershed irrigated agriculture faces could be the need to reduce the concentrations of total organic carbon (TOC) that are discharged by the

San Joaquin River to the Sacramento-San Joaquin River Delta, which in turn cause water utilities that utilize Delta water as a raw water source to have to develop more expensive water treatment processes to control trihalomethane formation. Delta water contains excessive total organic carbon compared to the regulatory limits that the US EPA is imposing on water utilities to minimize trihalomethane formation as part of disinfection of the water supply. The San Joaquin River and the Delta could potentially be listed as 303(d) impaired due to excessive TOC. This listing will require that a TMDL be developed to control TOC discharges from irrigated agriculture and other sources. Of particular concern are drainage from wetlands areas.

Some agricultural lands, especially on the west side of the San Joaquin River are experiencing significant erosion. This leads to westside tributaries and the SJR being highly turbid. This erosion also leads to excessive siltation within the Delta. It is possible that a TMDL could be developed to control the excessive turbidity/sediment in the San Joaquin River and Delta.

The US EPA (2002) is requiring that states adopt and enforce more appropriate contact recreation sanitary-indicator organism water quality standards than the fecal coliform standard that is being used today. The SWRCB and the CVRWQCB are in the process of adopting US EPA recommended contact recreation (swimming, wading, etc.) water quality standards to protect the health of those who contact recreate in the State's waters. The US EPA recommends that the fecal coliform standard be abandoned as a contact recreation standard and that an *E coli* standard be adopted. It is possible that irrigated agricultural lands, especially those receiving animal manure and/or biosolids (sewage sludge) will have elevated *E coli* in the stormwater runoff and tailwater discharges. This will lead to a 303(d) listing and a TMDL to control the excessive *E coli* in irrigated agricultural runoff/discharges.

There are several other potential TMDLs listed in Table 1, such as mercury, PCBs, dioxins/furans, temperature, etc., which could affect some agricultural interests. There is insufficient information at this time to evaluate whether there would be excessive concentrations of any of these constituents in irrigated agricultural stormwater runoff and tail water/subsurface drain water discharges compared to water quality standards/ objectives.

This paper suggests approaches that irrigated agriculture and regulatory agencies may wish to consider to integrate water quality management in stormwater runoff, irrigation tailwater and subsurface drain water discharges. This paper recommends an integrated approach for monitoring and development of BMPs to control the concentrations of potential pollutants.

ORIGIN OF THE TMDL PROCESS

As part of revising the federal water pollution control act in 1972, which through subsequent revisions has become known as the Clean Water Act (CWA), the US Congress established a regulatory approach that, by the early 1980s, was supposed to bring under control all discharges of wastewaters that cause or contribute to violations of water quality standards in receiving waters for the discharges. At that same time, the US Congress required that the US EPA develop water quality criteria that will protect the designated beneficial uses of the nation's waters. This water quality-based approach is the foundation for the current TMDL program. In 1987, as part of revision of the Clean Water Act, the TMDL requirements were set in place, where all waterbodies that were found to contain concentrations of constituents in excess of the water quality standard/objective were to be placed on the 303(d) list and classified as "impaired" waterbodies. This classification then must lead to the development of a total maximum daily load (TMDL) of constituents causing the violations of the water quality standards, where a control program is to be developed to limit the amount of constituents entering the waterbodies that have violations of water quality standards for the constituents of concern.

While the TMDL regulations have been in place for many years, they have not been enforced by either the US EPA or the state pollution control agencies. Finally, by the mid-1990s, environmental groups began to take the US EPA to court to require that TMDLs be developed for all constituents that are causing a waterbody to be listed on the 303(d) list of impaired waterbodies. The US EPA Region 9 (and elsewhere) reached settlement agreements with environmental groups, which mandated that a technical TMDL be developed for all constituents and waterbodies that were on the 303(d) list of impaired waterbodies.

The authors are involved in and/or are closely following a number of TMDLs that are being developed at this time. In each of these, there is inadequate time to properly develop a technically valid, cost-effective TMDL that will cause the waterbody to come into compliance with appropriate water quality standards. Further, regulatory agencies and, in many instances, dischargers, especially in the agricultural community, do not have the necessary technical or financial resources to properly develop a technical TMDL to control the concentrations of constituents that are leading to excessive concentrations compared to water quality standards.

Ag Waiver Issues

A significant factor in bringing the need for additional TMDLs to the forefront in the Central Valley of California is the ag waiver monitoring program that is being developed by the CVRWQCB. For many years irrigated agriculture in the Central Valley has been exempt from waste discharge requirements (WDRs) based on the premise that stormwater runoff and tailwater discharges do not cause excessive sediment discharges compared to CVRWQCB Basin Plan water quality objectives and do not cause aquatic life toxicity. In the summer of 2001, in response to a petition filed by the DeltaKeeper, the CVRWQCB issued a Resolution which required that the agricultural community and/or the CVRWQCB develop a comprehensive monitoring program of constructed agricultural drains and agricultural-dominated waterbodies within the Central Valley. This Resolution requires that a monitoring program be developed which will assess whether agricultural tailwater, subsurface drain water and/or stormwater runoff contains constituents that impair the beneficial uses of receiving waters, including causing these waters to violate water quality objectives. Particular attention is to be given to aquatic life toxicity and sediment discharges that violate the Basin Plan turbidity water quality objective. The implementation of this requirement is underway.

Based on what is known about the characteristics of agricultural stormwater runoff and agricultural subsurface drain/tailwater, it is likely that the soon-to-be-implemented monitoring program will demonstrate that there are a variety of constituents (see Table 1) that are being discharged from irrigated agriculture that violate water quality standards (objectives). Lee and Jones-Lee (2002c) have recently developed a report pertinent to developing the Phase II of the ag waiver monitoring program.

An important aspect of the ag waiver water quality monitoring program is that the CVRWQCB specified that the monitoring include irrigated agricultural "field" runoff. While the initial monitoring is focusing on the large constructed agricultural drains, eventually this will have to be expanded to include edge-of-the-field monitoring, in accord with having to meet the CVRWQCB's Resolution. According to Wanger (2002), constructed agricultural drains have been determined to be "waters of the State." However, according to Jennings (xxx) agriculture drains do not have to meet the same water quality objectives as the State's rivers and streams. Within 5 to 10 years, under the current Clean Water Act requirements, there likely could be a large increase in the number of agricultural-related TMDLs that will be developed to bring the waters of the State, including agricultural drain waters, into compliance with water quality objectives.

SUGGESTED APPROACH

Agriculture in the Central Valley faces several significant economic hurdles that arise from overproduction and foreign competition, leading to low prices for some agricultural crops. Managing water pollution is another of these economic hurdles that will have to be faced. It is not going to go away. It is suggested that it is in the best interests of agriculture to take a proactive approach toward defining existing water quality problems/violations of water quality objectives that are being caused by various agricultural practices. This will require acquisition of funding to characterize the concentrations, loads, beneficial use impacts, and technically-valid, cost effective BMPs for agricultural runoff/discharge waters.

While there may be some in the agricultural community who hold the position that conducting such a comprehensive monitoring/evaluation program would develop data that would show that there are water quality problems associated with agricultural runoff/discharges, and therefore, such a water quality monitoring program should not be initiated by the agricultural community, this "ostrich" approach can readily prove to be significantly detrimental to agricultural interests and can lead to over-regulation of agricultural runoff/discharge-associated constituents. It is in the best interest of agriculture to initiate a comprehensive monitoring/management program that defines the water quality problems that exist in irrigated agricultural stormwater runoff and tailwater/subsurface drain water discharges.

Addressing Exceedances of Water Quality Objectives

Of particular importance is ascertaining whether there are exceedances of the existing or soon-to-be-implemented water quality criteria/objectives in irrigated agricultural runoff/discharge-impacted waters. If exceedances are found, then the next step is to determine if the exceedances are "administrative" exceedances related to the overly protective nature of federal and state water quality criteria/standards/objectives, or represent real, significant impairment of the beneficial uses of the receiving waters for the agricultural discharges/runoff. This evaluation will require site-specific studies at a variety of locations throughout the Central Valley to define, for potentially toxic substances such as pesticides, whether the numbers, types and characteristics of aquatic life in the agricultural-dominated waterbodies or those influenced by such waterbodies are significantly impacted by the agricultural runoff/discharges.

If it is found that the violations of the water quality objectives are administrative, then work needs to be done to adjust the objectives so that they will protect the designated beneficial uses of the receiving waters without unnecessary expenditures for control of potential pollutant in runoff/discharges. If it is found that certain agricultural practices are leading to an impairment of the beneficial uses of the receiving waters, then management programs to control the agricultural practices to prevent runoff of pollutants – i.e., those constituents that impair the beneficial uses of the receiving waters – need to be developed and implemented. This program could require support of the public through the legislature to help some farming interests fund the water pollution evaluation and control programs.

The evaluation of the water quality impacts of stormwater runoff/tailwater discharges and subsurface drain water is a key component in developing a technically valid, cost-effective water quality management program. Those who understand how the US EPA water quality criteria and state standards/objectives are developed, understand that these are mandated by Congress to be based on a worst-case-based evaluation that does not necessarily consider site-specific factors that cause a potential pollutant to be a non-pollutant. The US EPA recognized this situation in adopting the water quality criteria development approach, which was mandated by Congress as part of developing the Clean Water Act.

The Agency (US EPA, 1994) developed the second edition of its "Handbook of Water Quality," which provides guidance on how to make site-specific adjustments of worst-case-based water quality criteria to consider the variety of factors that can cause constituents that are pollutants at some locations to be non-pollutants at others. Lee and Jones-Lee (1996) have provided background information on this issue, where they recommend that the first step in addressing an exceedance of a water quality standard is to evaluate whether the standard is appropriate for a particular discharge to a particular waterbody. Further, the previous and current administrations of the US EPA have been working to improve the ability to make site-specific adjustments of worst-case-based water quality criteria. These efforts are reducing the cost of the site-specific adjustments.

Need for Water Quality Impact Evaluation

A prime example of the need to conduct site-specific studies of water quality impacts is associated with the use of diazinon as a dormant spray in orchards in the Central Valley. Diazinon is an organophosphate pesticide that is applied to orchards during the winter to control certain pests that damage crops the following summer. It has been found that diazinon is highly toxic to certain types of zooplankton (small animals) that are part of small fish food. A review of the types of organisms impacted by diazinon shows that only certain types of zooplankton are affected. While under the current regulatory regime, unless demonstrated otherwise, any aquatic life toxicity must be controlled at the source, it is possible that the pulses of diazinon that are occurring today in stormwater runoff from dormant-sprayed orchards are not causing significant adverse impacts to the numbers, types and characteristics of desirable forms of aquatic life in the receiving waters for the dormant-sprayed field runoff. There can be other forms of zooplankton that can serve as larval fish food which are not affected by diazinon toxicity. It is also possible, however, that diazinon toxicity causes the death of key forms of aquatic life that are essential for some important fish population development.

While this situation has been known for many years, it has not been adequately addressed. There is need to better understand the impacts of diazinon-caused toxicity on the beneficial uses of waterbodies. Thus far, the agricultural community, pesticide manufacturers, and the regulated community have been unwilling to support the studies needed to determine whether the toxic pulses of diazinon associated with its use as a dormant spray in orchards are causing significant adverse impacts on the beneficial uses of waterbodies.

As it stands now under the current regulatory arena, it is likely that diazinon's use as a dormant spray will have to be phased out, and some other pesticide or group of pesticides, such as the pyrethroids, will be used in its place, which may, in fact, cause even greater environmental harm than diazinon. This situation arises out of the fact that the current US EPA Office of Pesticide Programs and California Department of Pesticide Regulation's pesticide evaluation program does not include evaluation of whether stormwater runoff or irrigation water releases from areas where the pesticide has been applied can cause aquatic life toxicity in the receiving waters for these runoff/releases.

Lee and Jones-Lee (2002c) are developing guidance on the monitoring program that should be conducted to determine if stormwater runoff or irrigation tailwater discharges/subsurface drain water releases are causing potential water quality impacts in the receiving waters. They emphasize the importance of developing a comprehensive monitoring program to monitor for all the parameters of concern, as opposed to the current, somewhat piecemeal approach of only addressing some of the parameters that are likely present in agricultural stormwater runoff/releases.

As Lee and Jones-Lee stressed, it is important to develop the monitoring program based on how various chemicals are used on agricultural properties and the hydrology of runoff/discharges from the areas of use. The routine one-sample-per-month (or some other periodic sampling) typically does not provide the information needed to properly evaluate exceedances of water quality objectives. A properly conducted monitoring program focuses on event-based sampling, which is tied to use and understanding of the transport/fate of the constituents to the areas applied and in the runoff/discharge waters.

Far too often, water quality management programs focus on chemical constituent control rather than on chemical impact control. As discussed by Lee and Jones-Lee (1999), there is often a poor correlation between the concentrations of constituents and their impacts on aquatic life and other beneficial uses of waterbodies. In order to address this situation Lee and Jones-Lee (1998) have developed what they call the Evaluation Monitoring approach, which specifically focuses on determining the impacts of chemical constituents, rather than their concentrations. This is the approach that should be adopted in managing violations of water quality objectives from irrigated agricultural runoff/discharges.

Need for Financial Support

It is important in conducting the monitoring/evaluation programs to involve all stakeholders in helping to design, implement and interpret the results of the monitoring/evaluation program. It is in everyone's interests to develop a program that is acceptable to all of those concerned about the potential impacts of irrigated agricultural runoff/discharges. It will be necessary in getting stakeholders' buy-in to these programs, to help financially support certain groups of stakeholders, such as environmental groups, some agricultural groups and, in some areas, regulatory agencies. Without this support/buy-in the current confrontational approach will continue. This approach is contrary to the interests of irrigated agriculture, environmental groups, regulatory agencies and the public, since it frequently leads to court-ordered decisions. Courts, under the current legal system, are generally not well equipped to properly address complex technical issues of water quality management.

CONCLUSIONS

Irrigated agriculture in the Central Valley of California, as well as elsewhere in the State and the US, faces a multitude of TMDLs that arise out of existing or potential exceedances of water quality standards/objectives that are in place now or that will be developed over the next few years. It will be important for irrigated agriculture, regulatory agencies, environmental groups and members of the public to work together to evaluate the various types of irrigated agricultural stormwater runoff/discharges, the existing and potential exceedances of water quality standards/objectives, and the water quality significance of these exceedances in terms of impact on the designated beneficial uses of the receiving waters for the runoff/discharges. If the exceedances are found to be administrative, related to the overly protective nature of worst-case-based water quality criteria, then work needs to be done to adjust the standards to protect the beneficial uses without unnecessary expenditures for constituent control in agricultural runoff/discharges.

If it is found that there are significant adverse impacts due to runoff/discharge-associated constituents, then appropriately evaluated and implemented management programs need to be developed to ensure that the alternative agricultural practices are cost-effective and reliable in improving the beneficial uses of the receiving waters for the runoff/discharges. A highly coordinated, integrated, stakeholder-based approach needs to be developed and implemented, where all interested parties can work together to help support viable irrigated agriculture in the Central Valley.

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Appendix B
Qualifications to Undertake this Review

G. Fred Lee is President of G. Fred Lee & Associates, a specialty water quality consulting firm located in El Macero, California. After obtaining his PhD from Harvard University in 1960, in environmental engineering and environmental sciences, he taught graduate level environmental engineering/environmental science courses and conducted graduate level research at several major US universities for 30 years. During this time, he conducted over $5 million in research, and published over 500 papers and reports.

Anne Jones-Lee is Vice-President of G Fred Lee & Associates. She obtained a bachelors degree in biology from Southern Methodist University and a PhD degree in environmental sciences from the University of Texas, Dallas in 1978. She taught graduate level environmental science courses at several major US universities for 11 years. She and Dr G. F. Lee have worked together as a team since the mid 1970s.

Dr. Lee's work on urban stormwater quality impact evaluation and management began in the late 1960s while he was a professor at the University of Wisconsin, Madison. He and his graduate students did some of the first work done on this topic. He has been active in evaluating and developing management approaches for urban area street and highway stormwater runoff water quality for over 30 years. He and Dr. Jones-Lee have published over 100 papers and reports on the approaches that should be used to develop technically valid, cost-effective best management practices (BMPs) for urban area street and highway stormwater runoff. Many of their recent publications on this topic are available from their website, http://www.gfredlee.com. During the 1990s, Drs. G. F. and A. J. Lee became involved in developing BMPs for managing highway stormwater runoff for the Eastern Transportation Corridor, a new toll road in Orange County, California. They developed Evaluation Monitoring as an approach that focuses on finding real water quality use impairment in receiving waters for stormwater runoff and then developing technically valid, cost-effective BMPs to control the water quality impacts to the maximum extent practicable.

Drs. G. F. and A. J. Lee periodically publish the Stormwater Runoff Water Quality Science/Engineering Newsletter. This is an email-based newsletter distributed at no cost to over 7,500 individuals interested in developing and implementing technically valid and cost-effective approaches for managing the significant water quality impacts of constituents in urban and rural stormwater runoff. The newsletter is now in its fifth year. Past issues are available from their website.

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 120 papers and reports on these issues. Some of their more recent writings on these issues are available from their website.

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 13 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.