Interpretation of Nutrient Water Quality Data[1]
Associated with Irrigated Agricultural Ag Waiver Monitoring

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Background

Excessive growth of aquatic plants causes significant water quality/beneficial-use problems in a number of Central Valley waterbodies. A major problem of concern is the reduction of dissolved oxygen concentrations due to algal respiration and bacterial decomposition of dead algae. The growth of aquatic plants to excessive levels is driven by nitrogen and phosphorus compounds from a variety of sources, including agriculture stormwater runoff, tail water and subsurface drain water discharges. Because of the significance of those sources of nutrients for Central Valley waterbodies, the California Central Valley Regional Water Quality Control Board (CVRWQCB) has required that the Irrigated Agricultural Waiver water quality monitoring program be expanded in the spring 2006 to include the suite of nitrogen and phosphorus compounds that serve as aquatic plant nutrients.

The CVRWQCB regulates aquatic plant nutrients as "biostimulatory substances" in accord with the Basin Plan (CVRWQCB, 1998):

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

However, because the Basin Plan provides no guidance on how to evaluate "excessive" biostimulatory substances, there is uncertainty regarding the interpretation of aquatic plant nutrient concentration data in terms of water quality problems. The nutrients, themselves, are not problematic; they are only of concern as they become manifested in excessive amounts of aquatic plant material, some of which is essential for maintaining a healthy system.

The senior author, G. Fred Lee, has been involved in the investigation and evaluation of aquatic plant nutrients, and the interpretation of concentration data relative to impacts on the stimulation of excessive growth of aquatic plants that adversely affect water quality for over 45 years at various locations in the US and several parts of the world. The authors have published extensively on this issue; their more recent publications are available on their web site, www.gredlee.com in the "Excessive Fertilization" section
http://www.gfredlee.com/pexfert2.htm.

In 2002, the CVRWQCB staff requested that the authors develop a review of the issues that need to be considered in appropriately regulating excessive growths of aquatic plants (Lee and Jones-Lee, 2002a). That review provided guidance to regulatory agencies, agricultural and other

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nutrient dischargers such as urban areas domestic wastewater and stormwater runoff, and the public on the types of nutrient and other data that are needed to evaluate the presence of excessive biostimulatory substances (nutrients) in a waterbody. The Lee and Jones-Lee (2002a) review does not represent official CVRWQCB policy or requirements. It does, however, provide fundamental findings gleaned from the results of many millions of dollars' worth of studies on nutrient loads and concentrations and their impacts on many types of waterbodies in various parts of the US and many other countries. That insight and guidance has applicability to the interpretation of the CVRWQCB (2005a) Irrigated Agriculture Ag Waiver nutrient concentration data as well.

As Lee and Jones-Lee (2002a,b, 2005a) discussed, a variety of issues needs to be considered in evaluating the water quality significance of nutrient concentration data of the type that would be generated in the CVRWQCB (2005a,b) proposed Ag Waiver water quality monitoring program for runoff/discharges from irrigated agriculture in the Central Valley of California. Unlike the situation for many chemical pollutants, there are no numeric, chemical-specific water quality criteria that can serve as reliable water quality standards for aquatic plant nutrients. Numerous and extensive studies over the past 45 years have demonstrated that it is not possible to evaluate the aquatic-plant-related water quality significance of nitrogen and phosphorus concentrations at a monitoring location, such as an Ag Waiver water quality monitoring point, on their own without substantial additional, particular, site-specific information. The type of additional information needed in the interpretation of nutrient data is described below.

Nature of Water Quality/Beneficial-Use Impairment

One of the most important aspects of evaluating nitrogen and phosphorus concentration data is the identification of the water quality-beneficial use impairment that occurs at and downstream of the monitoring point caused by excessive growths of aquatic plants. Planktonic algae, attached algae, floating macrophytes (water hyacinth, and duckweed, etc.), and emergent macrophytes (those rooted in the sediments, e.g., cattails, egeria) each has can have an important on water quality and aquatic resources. Aquatic plants serve as the base of the food web and are thus a critical component of aquatic ecosystems. Higher nutrient loads support higher planktonic algal growth and greater fish production. Some aquatic vegetation provides important nursery grounds for fish and substrate for other organisms.

Conversely, the presence of excessive amounts of any of these types of growth can cause adverse impacts on beneficial uses/water quality depending on the characteristics of the water and desired use. For example, it can cause:

- impairment of domestic and agricultural water supplies – Excessive amounts of algae in a water supply can cause tastes and odors, as well as contribute to excessive trihalomethanes in the treated water.
- violations of water quality objectives (WQO) for DO and pH – Depending on the characteristics of the area, photosynthesis/respiration by algae and some other aquatic plants can be sufficient to cause substantial diel (night/day) pH and dissolved oxygen changes which lead to violations of water quality standards for those constituents.
- adverse impacts on fisheries – Respiration by algae and bacterial decomposition of aquatic plants can depress dissolved oxygen concentrations to the point at which it

adversely affects or precludes the existence of certain fish and other aquatic life. Excessive planktonic algae can also result in stunted fish populations or selection against more desirable types of fish.

- impairment of recreation (boating, swimming, wading, waterskiing) – The decay of the accumulation of algae on a water surface or on a beach area can lead to highly obnoxious odors and be aesthetically unpleasing. Excessive amounts of emergent aquatic plants can impair access to or enjoyment of recreational waters.
- impairment of aesthetic enjoyment of beach and nearby areas – The decomposition of excessive algae can lead to the production of scum and odors.
- toxicity to aquatic life, wildlife and humans – In sufficient amounts, bluegreen algae can, at times, excrete/release chemicals that are toxic to animals that drink the water.

These types of water quality problems are well-known and have been reviewed by Lee (1973), Lee et al. (1978), Lee and Jones-Lee (2002b, 2005a), Jones-Lee and Lee (2005). In developing a nutrient management program there is need to achieve a balance between beneficial effects of aquatic plants and adverse impacts on the beneficial uses of a waterbody. Such judgments are often colored by the experience and perspective of the affected public. Further, without an understanding of the site-specific problem and conditions supporting the aquatic plant growth, nutrient reductions may not address the problem, or may simply shift the type of problem manifested rather than eliminate water quality problems.

Availability of Nutrients

Nutrient load reduction may not result in improvement in water quality if it is focused on unavailable nutrient forms, on non-limiting nutrients, or is of insufficient magnitude to effect a perceptible change in aquatic plant growth. Nitrogen and phosphorus exist in aquatic systems, sediments, soils, and runoff and other discharges in a variety of chemical forms; only some of those forms are available to support the growth of aquatic plants. Some available forms can be converted to unavailable forms, and under the right conditions some unavailable forms can become available. Lee et al. (1980) presented a review of the numerous studies conducted in the 1960s and 1970s on the forms of nutrients that are available to support algal growth.

To be effective, nutrient management programs must consider the availability of nutrients, especially phosphorus in controllable sources. Of particular concern in this regard are the particulate forms of phosphorus in agricultural and urban stormwater runoff. Much of the particulate P in urban and land runoff is not available to support algal growth and does not convert to an algal available form. As discussed by Lee and Jones-Lee (2002a), the algal-available P in runoff can be estimated as the sum of the soluble ortho P plus about 0.2 of the particulate P. The US EPA's current nutrient criteria development effort is based on the measurement of total phosphorus, irrespective of the availability of the P to support algal growth. This approach ignores what is known about the bioavailability and aquatic chemistry of phosphorus in aquatic systems and can lead to gross overregulation of nutrients in runoff from some sources.

Coupling between Nutrient Load and Impact

Attempts have been made to develop chemical-specific numeric criteria to regulate nutrients, such as the US EPA's current efforts to develop generic nutrient criteria for waterbodies in an ecoregion. Such approaches often lead to unreliable assessments of the impacts of nutrients on water quality, and hence unreliable control programs, because it does not adequately address the key factors that control how nutrient input becomes manifested as aquatic plant biomass. Making reliable assessments require understanding of and accounting for the hydrology and hydrodynamics of the system as well as the nature and pattern of nutrient input, including, as noted above, the availability of the nutrients. The authors have reviewed the development, verification, and application of reliable methods for determining the nature and amount of nutrient control that will produce predictable changes in eutrophication-related water quality, as well as specific issues that need to be address in making such an assessment in a technically valid, cost-effective manner (Lee et al., 1978; Lee and Jones, 1991; Jones-Lee and Lee, 2005).

There are situations, however, for which the coupling between measured nutrient loads/concentrations and the development of excessive growths of aquatic plants is poorly understood and difficult to quantify. This is especially true for riverine systems. Because of this, monitoring and evaluation programs need to have sufficient flexibility to define the coupling on a site-specific basis. For example, in riverine systems, nutrients discharged from a source in the watershed can contribute to excessive fertilization water quality problems hundreds of miles downstream. Depending on the situation, such a source may be of greater significance to water quality and than a source nearer the excessive fertilization problem. This is the case for the Central Valley where nutrients discharged from a source in the upper Sacramento or San Joaquin River watershed can contribute to excessive fertilization water quality problems hundreds of miles downstream, such as in the Delta or in a Southern California water supply reservoir that lead to taste and odors in a domestic water supply.

Water Quality Concerns in the Sacramento & San Joaquin Rivers and Their Delta

The Sacramento River and the San Joaquin River (SJR), two of California's largest rivers, are both located in the Central Valley. USGS Circulars 1159 and 1215 provide basic background information on these rivers and their watersheds (Domagalski et al., 2000; Dubrovsky et al., 1998). Their primary source of water is rainfall and snowmelt from the Sierra-Nevada mountains. At their source, the water in these rivers is of high quality with low levels of aquatic plant nutrients (nitrogen and phosphorus). Both rivers flow through highly productive irrigated agricultural lands, to the Sacramento-San Joaquin Delta, and ultimately to San Francisco Bay and the Pacific Ocean. Both rivers and their major tributaries are dammed for the purpose of providing domestic and agricultural water supply. Approximately 23 million people in California rely on water from the Delta as a domestic water supply.

Generally, the Sacramento River is considered to be of good quality as it enters the Delta. The planktonic algae level in the Sacramento River as it enters the Delta is low, with mid-summer planktonic algal chlorophyll concentrations typically of a few micrograms per liter (Dahlgren, 2004, pers communication). The major water quality problems at that point are the mercury, organochlorine "legacy" pesticides (e.g., DDT, chlordane, toxaphene), and PCBs that bioaccumulate in fish tissue to sufficient levels to be a health threat to those who eat the fish. This excessive bioaccumulation problem is also found in the Delta where the pollutants are derived from upstream and local Delta sources. Areas formerly mined in the Sierra Nevada mountains and coast range are the primary sources of mercury to the Sacramento and San Joaquin Rivers and Delta. The organochlorine legacy pesticides are derived from agricultural and urban areas where they were once used.

As it enters the upper San Joaquin Valley near Fresno, the San Joaquin River water is low in planktonic algae and is of generally high water quality. However, except during spring flood flows, all of the high-quality water in the river is diverted at Friant Dam by US Bureau of Reclamation (USBR) irrigation water supply projects. This has resulted in the SJR's being dry, during most years, from Friant Dam to near the confluence of the river with Mud and Salt Sloughs near Lander Avenue/Highway 165 – distance of about 60 miles. Judge Karlton's (2004) ruling now requires that the USBR release sufficient amounts of water from Friant Dam to the SJR to restore the SJR fisheries that were destroyed by the USBR's diversion of SJR water at Friant Dam to agriculture. Lee and Jones-Lee (2005b) updated their discussion of the SJR water quality problems to include the potential water quality impacts of Friant Dam releases to the upper SJR.

The generally poor water quality of the SJR downstream of Lander Avenue is largely the result of contaminants in irrigation tail water and subsurface drain waters that are discharged into Mud and Salt Sloughs which are, in turn, discharged to the SJR. Major water quality problems and concerns include excessive bioaccumulations of mercury, organochlorine legacy pesticides (e.g., DDT) and PCBs in fish; aquatic life toxicity due to pesticides discharged from agricultural use; excessive salt in the SJR and some tributaries; and excessive aquatic plant growth. Lee and Jones-Lee (2002c; 2004a,b; 2005b) have discussed the water quality problems of the SJR and the Delta in greater detail and specificity.

The nutrient-related water quality concerns for the Sacramento and San Joaquin River and Delta are twofold. First, the nutrients have contributed to excessive growth of planktonic algae that adversely affects the quality of the water for domestic water supply. Second, the growth of planktonic algae to excessive levels, and their subsequent decomposition, in various parts of the system have been a primary cause of low dissolved oxygen problems in the Deep Water Ship Channel (DWSC).

Evaluation of Nutrient Loads to the Delta

Presented below is a suggested approach for evaluating aquatic plant nutrient loads to, and impacts on water quality in, the Delta and its mainstem tributaries. For this discussion, the system is divided into nutrient load/impact areas based on the hydrology, land-use in the area watershed, nutrient concentrations, and aquatic plant-related water quality characteristics. Each of these areas should be evaluated as separate nutrient loads/water quality impact areas.

San Joaquin River Watershed. The San Joaquin River watershed, defined as the watershed upstream of Vernalis, can be divided into two subunits. One is the area of the east side reservoirs and the land upstream of those reservoirs. These reservoirs and their tributaries typically have low aquatic plant nutrient levels and high aquatic-plant-related water quality. There are several exceptions to this situation, however, when aquatic plants in upstream, smaller reservoirs cause water quality problems that require treatment to control excessive aquatic plants. The other subunit of the SJR watershed major nutrient load/impact area is the rivers, streams and sloughs downstream of the reservoirs on the east side, and all west side streams, rivers and sloughs. Several of those areas tend to have high nutrient levels and excessive growth of aquatic plants. The nutrients from those watershed areas contribute to water quality problems in the mainstem SJR (SJR below the reservoirs) and in the mainstem tributaries

SJR Mainstem. Even though there are high nutrient concentrations and high planktonic algal chlorophyll levels in the SJR mainstem, people who utilize these areas for recreation or other purposes may not consider those particular waters to be "impaired." This is because the appearance of excessive algal growth is masked by the high background inorganic turbidity derived from upstream erosion. Therefore, at this time, the primary nutrient-related water quality concern for the mainstem of the SJR is the contribution of the nutrients in that reach to the algae and other aquatic plants that develop downstream of Vernalis.

SJR Mainstem Tributaries. In order to reduce the nutrient level and planktonic algal growth in the SJR mainstem to improve downstream water quality, it would be necessary to evaluate and reduce the loads of nutrients from direct discharges and discharges/runoff to its tributaries. The main sources of nutrients to the SJR mainstem are stormwater runoff from agricultural land and some wastewater/stormwater runoff/discharges from urban and agricultural activities such as dairies. Controlling nutrient in runoff waters is difficult and costly.

As discussed by Lee and Jones-Lee (2003) during the summer of 2000, more than 50% of the oxygen demanding materials in the SJR at Vernalis, was derived from algae discharged to the SJR by Mud and Salt Sloughs, and the SJR above Lander Avenue that continue to multiply in the SJR as they are carried downstream to the Delta.. The discharges of nutrients to Mud and Salt Sloughs will likely change in conjunction with the reduction in selenium and salt discharges to these waters being implemented by irrigated agricultural operations. These control programs will likely change the nature and amounts of tail water and subsurface drain water discharged, which, in turn, will reduce nutrient discharges to the head waters of these waterbodies. This could reduce nutrient concentrations in the SJR and, more significantly, the planktonic algal loads carried in the SJR at Vernalis.

Another factor that could influence the nutrient and algal load in the SJR mainstem is the court-ordered release of water from Friant Dam to the SJR channel. These releases would be expected to add low-nutrient water to the upper river which would dilute the elevated nutrients, algae and turbidity in the river, and increase the flow of the SJR in the Deep Water Ship Channel.

Once the control programs for selenium and salt have been implemented, there will be need to investigate the potential impacts of selective nutrient control in the major SJR tributaries on the potential to reduce the algae-related oxygen demand that is contributed to the mainstem of the SJR which at times represents a significant contribution of oxygen demand to the DWSC. These investigations could lead to the development of nutrient control within the SJR tributaries designed to limit algal growth within these tributaries in order to reduce algal related oxygen demand contributed to the DWSC.

Much of the SJR Vernalis water is drawn from the main channel to the export pumps at the Head of Old River, before it reaches the DWSC. An exception to this situation occurs during VAMP when the export pumping of South Delta water is curtailed to support the migration of salmon smolts through San Francisco Bay to the ocean. During VAMP, the Head of Old River Barrier is closed and several thousand cfs of east side reservoir water is released to the SJR.

Lake McCloud and Port of Stockton Turning Basin. The city of Stockton has special nutrient-related water quality problems in Lake McCloud and in the channel that connects that lake to the Port of Stockton Turning Basin, a dead-end channel. At times during the summer/fall, the Turning Basin experiences excessive growths of blue-green algae that develop a floating scum and cause airborne odors. There is also, at that location, a persistent thermal stratification which serves to trap the decomposing algae in the bottom waters. This leads to low dissolved oxygen concentrations in the near-bottom waters during substantial periods of time. The nutrient-related impacts in the Port of Stockton Turning Basin are sufficiently different in nature from what is experienced in other areas of the river and Delta to merit this area's being considered as a separate nutrient/impact unit, apart from the Deep Water Ship Channel.

Deep Water Ship Channel. The SJR Deep Water Ship Channel extends from the Port of Stockton to where it joins with the Sacramento River. Because of its unusual morphological and hydrological characteristics and nutrient-related water quality problems, the San Joaquin River Deep Water Ship Channel between the Port of Stockton and Disappointment Slough/Columbia Cut should be considered as a distinct nutrient impact unit. The primary nutrient-related concern in the DWSC is the low dissolved oxygen and associated water quality objective violations. The low dissolved oxygen conditions develop from the exertion of the oxygen demand created by the death of algae that develop upstream of the DWSC. The sluggish flow in the DWSC allows the exertion of oxygen demand there and the concomitant reduction in dissolved oxygen concentration. Lee and Jones-Lee (2003, 2004b) have reviewed the impact of the upstream sources of nutrients on the low DO problem in the SJR DWSC.

The portion of the San Joaquin River Deep Water Ship Channel downstream of Disappointment Slough/Columbia Cut should be considered to be part of the North/Central Delta area since, for much of the year, the water in that area is typically low-nutrient Sacramento River water that is drawn to the state and federal South Delta export projects pumps.

Delta. The Delta should be evaluated as two areas: the North/Central Delta and the South Delta. The South Delta is separated from the North/Central Delta by the temporary barriers on the South Delta channels; the permanent operable barriers will be installed there in 2009. The water in the eastern part of the South Delta is dominated by SJR Vernalis water that is sucked to the South Delta export pumps at Tracy and Banks. That water has high nutrient concentrations and experiences excessive growth of planktonic and attached algae and other aquatic plant (water hyacinths and egeria).

The North/Central Delta area also experiences excessive growths of water hyacinths, egeria, and some planktonic and attached algae including Microcystis. These growths are not the scum-forming growths found in Lake McCloud but rather are of concern because they may be a source of bluegreen algae-caused toxicity.

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 of whether or not the nutrients/algae that are developed within the SJR watershed that enter the Delta, either through the Head of Old River or through the Deep Water Ship Channel via Turner Cut, cause significant adverse impacts on the beneficial uses of Delta waters. The Delta has several nutrient-related water quality problems, including sufficient growths of water hyacinth and egeria to require herbicide application for their control. There are low DO problems within the South Delta channels related to the algae-derived oxygen demand that develops in the SJR upstream of Vernalis and is discharged to Delta waters either via Old River or through the DWSC. 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 where the situation is influenced by the export pumping of Central Delta water to Central and Southern California via the export projects.

Downstream of Delta Water Users. Some of the water exported from the Delta is stored in downstream reservoirs for domestic water supply purposes. However, there is sufficient algal growth in those reservoirs to cause taste and odor and other treatment problems. A portion of the nutrients that contribute to this excessive algal growth is from the San Joaquin River watershed. Trying to reduce algal growth in those reservoirs by controlling the nutrient sources – largely runoff from agricultural lands in the SJR watershed – could be judged to be not cost-effective. The agricultural interests in the SJR watershed have limited financial ability to support anything other than modest nutrient control efforts that may not effect significant algal reduction in the reservoirs. It may be more cost-effective for those water utilities that experience these problems to provide the additional water treatment needed to remedy the adverse effects than to try to initiate nutrient control in the SJR watershed.

POTW Effluent Dependent and Agricultural Drains. Waterbodies that are fed largely by domestic wastewater effluent, and agricultural drains comprise a special category of waterbodies in the valley floor of the Sacramento River and SJR watersheds. Many of those waterbodies experience excessive growths of algae and other aquatic plants that can lead to violations of CVRWQCB Basin Plan water quality objectives for pH and DO. Because the impairment of the beneficial uses of these waters by nutrients is manifested in a significantly different manner than the impairment in the mainstem of the Sacramento River and San Joaquin River and their major tributaries, those waterbodies should be considered as a separate nutrient/impact area.

Sacramento River Watershed. The Sacramento River watershed should be divided into three nutrient load/impact areas. One area should include the Sacramento River below Shasta Dam and all other reservoirs in the watershed. The second should include the Sacramento River upstream of the reservoir and those tributaries that do not have reservoirs on them. The third should include rivers and tributaries to Lake Shasta.

The Sacramento River water is low in nutrients and normally does not experience excessive algal growth.

Deficiencies in Current and Proposed Nutrient Water Quality Monitoring Program

The current CVRWQCB (2005a) Agricultural Waiver water quality monitoring program requires agricultural interests in the Central Valley of California to start monitoring for aquatic plant nutrients in the spring 2006. The renewal of the Agricultural Waiver water quality monitoring program proposed by the CVRWQCB (2005b) retains that requirement.

The original Agricultural Waiver monitoring program set forth in July 2003 had several technical deficiencies with regard to nutrient assessment. One significant deficiency was that it did not require monitoring of all the chemicals that are or could become nutrients that stimulate aquatic plant growth. That deficiency was corrected by the specific inclusion of total Kjeldahl nitrogen, nitrate, nitrite, ammonia, total P, and soluble orthophosphate (CVRWQCB, 2005a). In addition, measurement of water temperature, pH and dissolved oxygen at the time of sampling also became required. However, the amended program still did not require the monitoring of pH and DO in the surface waters (upper 2 ft) in the early morning and late afternoon when there is the greatest likelihood of violation of WQOs for pH and DO caused by photosynthetic activity. Also there were no requirements for monitoring pH, DO and temperature with depth in the water column to determine if the water column is stratified which could lead to DO WQO violations in near-bottom waters.

Without proper monitoring for response parameters it is not possible to reliably determine if nutrient discharges from agricultural activities are causing water quality objective violations at an ag waiver monitoring point. Nominally, diel measurements (at a minimum in the early morning by about 8:00 am and near 4:00 pm) of pH, DO and temperature should be made through the monitoring location water column, at 1-ft depth intervals, from the surface to the bottom. Samples should also be collected at about 0.5-m depth for measurement of planktonic algal chlorophyll; the presence of attached algae and floating macrophytes should be noted. Secchi depth should also be measured to access the impact of planktonic algae on water clarity. This information is needed to assess the nutrient-related water quality characteristics at the monitoring location. Lee and Jones-Lee (2002d) have provided additional detailed guidance on the issues that need to be considered and incorporated into a credible water quality monitoring program for non-point-source pollutants.

Impact of Nutrients on Fisheries Resources.

One of the paradoxes of the nutrient situation in 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 (see Lee and Jones 1991) that significantly limiting the amount of available nutrients entering a waterbody will reduce fish biomass. Controlling the input of available nutrient to the Delta could be adverse to fisheries production within the Delta. The federal and state export pumping of South Delta water is a major reason for the low nutrient levels in the North and Central Delta; the water pumped for export is primarily low-nutrient Sacramento River water. During the summer and fall on the order of 12,000 cfs of South Delta water is pumped by the two export projects; all but about 1,000 to 1,500 cfs is derived from the Sacramento River. This brings large amounts of low-nutrient water into the Central Delta and thereby reduces the primary production in the northern and Central Delta.

Another reason for the low planktonic algal chlorophyll in the North and Central Delta is likely to be the presence of *Corbicula,* a freshwater clam that harvests phytoplankton. In some areas of the Delta channels, the sediments are covered with this clam. There is need to better understand the relationships among phytoplankton biomass, fish production, and the factors limiting algal biomass in the Delta. This information is essential to developing an appropriate balance between nutrient-related water quality and aquatic ecosystem productivity in the Delta.

Recommended Nutrient Criteria Development Approach

For each of the nutrient load/impact areas, the stakeholders should work through the Regional Water Board to organize a stakeholder process. Through this process public input could be made on the nutrient-related water quality problems that occur within each region and downstream of the area, that are influenced by nutrient loads from the areas delineated. The Regional Board should then, through normal Board procedures, formally adopt those nutrient-related water quality characteristics that, through the public process, are determined to be appropriate for the area.

Summary

Overall, the primary water quality problems caused by excessive nutrients contributed to the San Joaquin River from its watershed are,

- excessive growth of algae that contribute to the low-DO problem in the DWSC,
- excessive growths of water hyacinth and egeria that adversely affect water use, and
- taste, odor and other water quality problems in domestic water supplies that use the Delta as a raw water source.

The low-DO problems can be solved through a combination of oxygen-demand control, aeration, management of flows through the DWSC, and nutrient control. After the low-DO problem in the DWSC is managed, the focus of nutrient control in the SJR watershed should shift to the use problems caused by excessive growths of water hyacinth and egeria, and to the taste, odor and other water quality problems that develop in domestic water supplies that use the Delta as a raw water source.

To create a nutrient control program in the SJR watershed to control excessive water hyacinth/egeria and algae in water supply reservoirs it is necessary to determine the key sources of available forms of nutrient inputs, and then the nature and level of nutrient control needed, from the SJR watershed and from in-Delta sources (irrigated agriculture tailwater). 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 stormwater runoff and agricultural runoff/discharges, as well as atmospheric and other sources, and their respective impacts on controlling the problems.

Lee and Jones-Lee (2002b) provided more detailed discussion of an advisable approach to establish an appropriate nutrient control program. Key steps in that approach include:

- developing a statement of the water quality/beneficial-use problem caused by excessive fertilization in the situation of concern;
- identify the desired eutrophication-related water quality characteristics – i.e., the goal for nutrient control;
- determine the sources of nutrients, focusing on available forms;
- identify and quantify the linkage between nutrient loads and eutrophication-related water quality response (modeling);

- quantify the required degree of control of which nutrients in order to attain the desired water quality characteristics;
- initiate a Phase I nutrient control implementation plan to control the nutrients to the level needed to achieve the desired water quality;
- monitor the waterbody for three to five years (at least three times the P residence time) after nutrient control is implemented to determine whether the anticipated/desired water quality is being achieved;
- if desired water quality is not achieved in three to five years, initiate a Phase II to improve the load-response model using site-specific monitoring results. Then, reassess the nutrient loads and load reductions that should lead to the desired water quality.

Establishing Nutrient Load-Eutrophication Response Relationships. Following the general approach outlined above, it is recommended that for each of the Central Valley nutrient load/impact areas defined above, site-specific investigations be conducted to identify the relationship between nutrient load and eutrophication-related water quality and sources of available nutrients. Then a determination should be made of the reduction in available nutrient input needed to achieve the nutrient-related water quality desired by the public for that waterbody and downstream waterbodies impacted by that waterbody. Generally this will require the development of an available-nutrient-load—eutrophication response relationship (model) for the waterbody. Jones-Lee and Lee (2001) have provided an updated review of the OECD nutrient load-eutrophication response relationships that have been developed and evaluated by Jones and Lee (1986); their work shows how they can be used to estimate the nutrient load needed to achieve the desired eutrophication-related water quality. If properly applied, that approach can work well for certain types of waterbodies, especially lakes and reservoirs where the nutrient impacts are manifested in the excessive growths of planktonic algae. For other waterbodies, however, such as streams, rivers, near-shore marine waters, site-specific investigations will need to be conducted to determine the appropriate available-nutrient load to achieve the desired eutrophication-related water quality. Because of the variety of types of eutrophication "models" available, and the limitations on their applicability and reliability, it is important that those conducting these studies are familiar with, and fully understand the subtleties of the eutrophication management literature. Without such a level of understanding, experience has taught that the nutrient management program developed could be unreliable and wasteful of resources.

In general, the development of appropriate nutrient criteria for a waterbody hinges on the development of reliable and quantified relationships between the loads of available nutrients and eutrophication-related water quality characteristics in the waterbody. Based on such relationships, the nature and extent of nutrient control needed from various sources to achieve the desired eutrophication-related water quality can be determined and established as the nutrient criteria. As discussed by Jones-Lee and Lee (2001) and Lee and Jones-Lee (2004a), it is extremely important that it be the *available* phosphorous load that is considered, rather than the US EPA's recommended approach of using *total* phosphorous load. This is especially important in the consideration of nutrient loads from ag and urban stormwater runoff. Failure to follow this approach can significantly overestimate the amount of phosphorous available in the waterbody to support algae and other aquatic growth. It will also overestimate the expected improvement in eutrophication-related water quality characteristics that can be achieved from controlling nutrients from those sources.

With respect to developing nutrient criteria for the Delta, its tributaries and downstream water users, site-specific available nutrient loads developed can 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, however, will be that the control goal is not a water quality standard, but rather a publicly developed desired degree of fertility (i.e., eutrophication-related water quality characteristics) that is appropriate for each nutrient management unit. This approach can lead to scientifically defensible nutrient criteria for a waterbody.

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