Assessing the Water Quality Significance of N & P Compound Concentrations in Agricultural Runoff[1]

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Abstract
Excessive growth of aquatic plants causes significant water quality/beneficial-use problems, including low dissolved oxygen, impairment of domestic water supplies' water quality, impairment of recreation, etc. The growth of aquatic plants to excessive levels is driven by nitrogen and phosphorus compounds from a variety of sources, including agricultural stormwater runoff, tail water and subsurface drain water discharges. Because of the significance of those sources, many water quality monitoring programs include the suite of nitrogen and phosphorus compounds that serve as aquatic plant nutrients. To this end, statements such as, "Water shall not contain biostimulatory substances which promote aquatic growths in concentrations that cause nuisance or adversely affect beneficial uses" are in some regulations. However, guidance is not provided on how to evaluate "excessive" biostimulatory substances. 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 ecosystem. This paper discusses the issues that need to be considered in determining excessive concentrations of nutrients in agricultural runoff.

Background

Excessive growth of aquatic plants causes significant water quality/beneficial-use problems in a number of California 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 in the San Joaquin River Deep Water Ship Channel (DWSC) near the Port of Stockton, as well as in some of the South Delta channels. The growth of aquatic plants to excessive levels is driven by nitrogen and phosphorus compounds from a variety of sources, including agricultural 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 2005, 2006) 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.*

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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 ecosystem.

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 website, 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 nutrient dischargers (such as urban area 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 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 (2005) Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Ag Waiver) nutrient concentration data as well.

As Lee and Jones-Lee (2002a,b; 2005, 2006) discussed, a variety of issues need to be considered in evaluating the water quality significance of nutrient concentration data of the type that would be generated in the CVRWQCB (2005) 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 can have an important effect 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. Overall, the excessive growth of aquatic plants is recognized as one of the most important causes of water quality deterioration. 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 (WQOs) 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 where they adversely affect or preclude 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, 2005), 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.

Nutrients and Their Availability

The chemicals of concern as aquatic plant nutrients are phosphorus compounds (soluble orthophosphate), nitrate, nitrite, ammonia and, to some extent, organic nitrogen. While potassium is an important nutrient for terrestrial plants, it is not a nutrient that can limit aquatic plant growth, since sufficient potassium is available to meet aquatic plant needs. In soil systems, potassium can limit terrestrial plant growth, since only part of it is available. In aquatic systems, only part of the total phosphorus and organic nitrogen are available to support algal growth.

The typical algal stoichiometry (chemical composition) is 106 carbons and 16 nitrogens to one phosphorus. Typically, in freshwater systems, the amount of algae that develops is limited by the available phosphorus, although in waterbodies containing large amounts of nitrogen and phosphorus, the amount of light that penetrates into the water column can limit the total algal biomass that develops in the water.

A key issue in managing excessive fertilization is the reduction of nutrient loads to the waterbody, to limit the amount of algal biomass that develops in it. 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, 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 they do not adequately address the key factors that control how nutrient input becomes manifested as aquatic plant biomass. Making reliable assessments requires 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 addressed 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 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.

Recommended Nutrient Criteria Development Approach

Typically, in accordance with the federal Clean Water Act, the regulation of chemicals that adversely impact water quality is based on chemical-specific numeric water quality criteria. These criteria are developed in accordance with US EPA guidelines. The criteria are to be used by states to develop state water quality standards. Exceedance of a standard is a violation of the Clean Water Act, which requires that control programs be implemented to reduce the input of the chemical causing the exceedance. This regulatory program is implemented through the total maximum daily load (TMDL) approach, which is relatively simple to administer, since all that needs to be done is to measure the concentration of a chemical of potential concern and compare it to the water quality standard, to determine if there is a violation of the Clean Water Act.

Over the years, there have been a number of attempts to develop numeric nutrient water quality criteria/standards that could be implemented in a similar way to heavy metals, organics, and other substances regulated through the numeric criteria/standard approach. Beginning in the 1990s, the US EPA initiated an effort to develop chemical-specific numeric water quality criteria for nitrogen and phosphorus compounds. Part of this effort focused on developing national default criteria. It has been found that this approach is not technically valid and can readily lead to inappropriate regulation of nutrient discharges. These issues are discussed in Lee and Jones-Lee (2002a,b; 2004). As they discuss, **it is not possible to reliably regulate nutrient discharges based on generic numeric, chemical-specific concentration limits for nitrogen and phosphorus compounds.**

The interpretation of nutrient water quality data should be based on existing or potential water quality problems at the monitoring point and downstream of it. For each nutrient load/impact area (lake, reservoir, stream, river, etc.), the stakeholders should work through the regulatory agency 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, which are influenced by nutrient loads from the areas delineated. The regulatory agency should then, through normal regulatory procedures, formally establish those nutrient-related water quality characteristics that, through the public process, are determined to be appropriate for each waterbody of concern. This approach makes the interpretation of nutrient concentration data at a monitoring point a complex process, in which one or more site-specific evaluations need to be made over a several-year period, to determine the relationship between nutrient concentrations at a monitoring point on a source (such as a river or stream) and the desired nutrient-related water quality at that location and downstream of it.

The downstream waterbodies can be located at considerable distances from the monitoring point. For example, nutrients present in the headwaters of the Mississippi, Missouri and Ohio Rivers are impacting water quality in the Gulf of Mexico, through the stimulation of algae that die, decompose and cause low dissolved oxygen (anoxia) in some Gulf waters. In October 2005 the US EPA held a Mississippi River Basin Nutrients Science Workshop, which provides background information on the Mississippi River Basin and Gulf of Mexico hypoxia. The proceedings from this workshop are available at
http://www.epa.gov/msbasin/taskforce/reassess2005.htm#mtg.
Similarly, as discussed by Lee and Jones-Lee (2006), nutrients present in the San Joaquin River upstream of Vernalis in the Central Valley of California can stimulate algal growth in water supply reservoirs in Southern California that use Sacramento-San Joaquin River Delta water as a raw water source.

Lee and Jones-Lee (2002b) provide a discussion of an approach to establish an appropriate nutrient control program. Key steps in this approach include:

- develop a statement of the water quality/beneficial-use problem caused by excessive fertilization in each 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 – total phosphorus mass in the waterbody divided by annual P load) after nutrient control is implemented to determine whether the anticipated/desired water quality is being achieved;
- if the 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.

Additional information on these issues is provided in Lee and Jones-Lee (2002a, 2004).

In conducting the site-specific evaluation, consideration should be given to the types of aquatic plants that are of concern in each waterbody of concern. Nutrient control programs focusing on excessive planktonic algae will not likely be appropriate for problems with excessive growths of water hyacinth, egeria or cattails. It is important to consider the local public's perception of water quality problems in making this assessment, since it is the public of an area (the waterbody users) who are impacted by excessive aquatic plant growth. An appropriate nutrient control program to achieve a desired level of planktonic algae in a lake in Wisconsin where the public has the opportunity to experience a variety of waterbodies with different degrees of fertility, would not likely be considered appropriate/necessary by the public in a southern US reservoir where waterbodies are typically highly fertile. Further, the members of the public who are interested in fishing will likely desire waterbodies with an elevated degree of fertility and its associated higher fish production than those members of the public who are interested in boating, swimming, waterskiing, etc., who typically would desire low-productivity (clear, low-algae) water.

In addition, the appropriate nutrient loads to achieve a desired eutrophication-related water quality will be significantly different for different types of waterbodies, such as a lake or reservoir, stream, river, estuary or near-shore marine waters. Further, within a particular waterbody type, the morphological and hydrological characteristics of the waterbody (lakes and reservoirs) – such as the depth, surface area, hydraulic residence time, and, for streams and rivers, velocity – will affect the relationship between nutrient loads and aquatic-plant-related water quality.

Overall, interpretation of the water quality significance of measured nutrient concentrations requires a detailed site-specific evaluation of a variety of factors. There is no simple approach for interpretation of nutrient concentration data relative to excessive biostimulation of aquatic plants.

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