A Proposal for Assessing Algal-Available Phosphorus Loads in Runoff from Irrigated Agriculture in the Central Valley of California*

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President & Vice President, G. Fred Lee & Associates
Project Collaborator: **Jeffrey L. Miller, Ph.D., DABT**
AQUA-Science President and Chief Technical Officer
Summary resumes are appended to this proposal

Funding Request Amount: $50,000 per year for three years is requested. *This amount is limited by restrictions on funding level imposed by potential funding agency. A larger scale project could readily be conducted if additional funds were available.*

Executive Summary

Problem: The San Joaquin River (SJR) and the south and southwestern Sacramento-San Joaquin River Delta experience excessive growths of planktonic algae that lead to significant water quality impairment in terms of low dissolved oxygen; excessive growth of water weeds; and tastes, odors and other problems in domestic water supplies. These issues are discussed in a summary report by Lee and Jones-Lee (2004a). One of the approaches that is being considered to control excessive fertilization of the SJR and the Delta is limiting the amounts of aquatic plant nutrients (N and P) discharged to the SJR and its tributaries from irrigated agriculture. Based on the information available, the focus of the nutrient control programs will need to be on phosphorus control, since the available phosphorus concentrations in the SJR and Delta are more closely associated with growth-rate-limiting concentrations than nitrogen. At this time the US EPA and the California State Water Resources Control Board (SWRCB), as part of their developing water quality criteria for nutrients, are ignoring the well established fact that a substantial part of the particulate phosphorus in agricultural stormwater runoff is in a non-algal-available form. As discussed by Lee and Jones-Lee (2002), in order to develop technically valid, cost-effective phosphorus management approaches, it will be necessary to assess, for Central Valley irrigated agricultural runoff, whether phosphorus associated with particulates is, like particulate phosphorus in other parts of the world, largely unavailable for algal growth.

Project Objectives, Approach and Evaluation: The objective of this project is to determine, on samples of stormwater runoff and tailwater discharges from irrigated agricultural areas in the Central Valley, the total and algal-available phosphorus concentrations. This will be done using

* Adapted from research proposal submitted by G. Fred Lee & Associates to the California Department of Food and Agriculture Fertilizer Research and Education Program, 2006.

algal assay techniques involving incubation of runoff/discharge samples of water, under controlled laboratory conditions, to determine the amount of algal growth that occurs in the runoff/discharge samples relative to the total phosphorus concentrations in the sample, and the growth of the test algae under 100% algal available phosphorus in the test solution. The techniques used were developed in the 1960s in Dr. Lee's laboratories at the University of Wisconsin, Madison, and are now well established in the literature (see US EPA 2002). The laboratory studies will be conducted under the supervision of Dr. Jeff Miller in the facilities of AQUA-*Science*, located in Davis, California. Drs. Lee and Miller have worked together as a team on a number of projects. AQUA-*Science* has the equipment, facilities and algal assay experience necessary to conduct algal assays of available P. Evaluation of project success will be based on providing sufficient information so that the federal and state water quality management agencies focus excessive fertilization control programs on algal-available P, rather than total P, thereby potentially saving agricultural interests in the SJR watershed and elsewhere in California large amounts of funds in not having to develop control programs for particulate P that is in non-algal-available forms.

Audience: The results of this study will be used by agricultural interests and regulatory agencies to determine whether there is need to control particulate phosphorus in runoff/discharges from irrigated agriculture in the Central Valley. A significantly different phosphorus runoff management strategy can potentially be developed, if it focuses on soluble phosphorus rather than total phosphorus. This could save agricultural interests considerable funds in implementing management practices for phosphorus in runoff/discharges, by not having to develop large settling basins/filters to remove the particulate phosphorus during periods of high winter stormwater runoff from their lands.

Justification for Project

Problem: The San Joaquin River (SJR) and the south and southwestern Sacramento-San Joaquin River Delta experience excessive growths of planktonic algae that lead to significant water quality impairment. For example, the San Joaquin River Deep Water Ship Channel (DWSC) near the Port of Stockton experiences dissolved oxygen (DO) depletions below the water quality objective each summer and fall. A major cause of the DO depletions is the growth of planktonic algae in the SJR which, upon reaching the DWSC, die, decompose and become the primary source of oxygen demand. These issues are presented in Lee and Jones-Lee (2003, 2004b).

In addition, there are low-DO problems in some of the channels in the South Delta associated with excessive growths of algae that die, decompose and exert an oxygen demand. Further, domestic water utilities that utilize Delta water as a water source in Southern California and the San Francisco Bay Area experience excessive growths of algae in their water supply reservoirs that lead to severe taste and odor and other treatment problems. These issues are discussed in a summary report by Lee and Jones-Lee (2004a), "Overview of Sacramento-San Joaquin River Delta Water Quality Issues," and Lee and Jones-Lee (2006), "San Joaquin River Water Quality Issues," which are available on their website. As Lee and Jones-Lee have discussed, one of the approaches that is being considered to control excessive fertilization of the SJR and the Delta is limiting the amounts of aquatic plant nutrients (N and P) discharged to the SJR and its tributaries

from irrigated agriculture. Based on the information available, the focus of the nutrient control programs will need to be on phosphorus control, since the available phosphorus concentrations in the SJR and Delta are more closely associated with growth-rate-limiting concentrations than nitrogen, and since controlling phosphorus in runoff waters is more likely economically achievable than controlling nitrogen (nitrate).

In the 1960s, while Dr. G. F. Lee was a professor at the University of Wisconsin, Madison, he undertook extensive research on the forms of phosphorus in agricultural and urban stormwater runoff that are available to support algal growth. A summary of this work was published in an International Joint Commission for the Great Lakes symposium as "Availability of Phosphorus to Phytoplankton and Its Implication for Phosphorus Management Strategies" (Lee et al. 1980).

At this time the US EPA, as part of developing water quality criteria for nutrients, is ignoring the well established fact that a substantial part of the particulate phosphorus in agricultural stormwater runoff is in a non-algal-available form. It is also found that the water quality regulatory agencies (Regional Water Quality Control Boards) in California, as well as the California State Water Resources Control Board, are not familiar with the concept of the unavailability of particulate phosphorus as a factor in influencing algal growth. As a result, they are largely following the US EPA's current policy of focusing on total phosphorus, rather than algal-available phosphorus, in their nutrient control programs. As discussed by Lee and Jones-Lee (2002), in their ""Review of Management Practices for Controlling the Water Quality Impacts of Potential Pollutants in Irrigated Agriculture Stormwater Runoff and Tailwater Discharges," in order to develop technically valid, cost-effective phosphorus management approaches, it will be necessary to assess, for Central Valley irrigated agricultural runoff, whether phosphorus associated with particulates is, like particulate phosphorus derived from erosion from agricultural lands in other parts of the world, largely unavailable for algal growth.

CVRWQCB Agricultural Waiver Program. As part of Dr. Lee's efforts to improve the state of knowledge on managing excessive fertilization of waterbodies in the Central Valley, and his long-term interest in and work on impacts of agricultural land runoff/discharges, he has been active in the Central Valley Regional Water Quality Control Board's (CVRWQCB's) Agricultural Waiver program (Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands, CVRWQCB 2006).

California water pollution control regulations (the Porter-Cologne Act, SWRCB 2006) enable the State and Regional Water Quality Control Boards to require that all discharges/runoff to the State's waters not cause violations of water quality standards (objectives). Typically these regulations are implemented through issuance of Waste Discharge Requirements (WDRs) to sources of pollutants. For many years the State and Regional Water Boards chose to waive these requirements for compliance with water quality objectives for discharges from irrigated lands. However, several years ago, the state legislature terminated the ability of the State and Regional Water Quality Control Boards to somewhat automatically issue an irrigated agricultural waiver from the Porter-Cologne requirements of not causing water quality standards violations in the State's waters. This has led to the Central Valley Regional Water Quality Control Board's (as well as other Regional Water Quality Control Boards in the State) issuing a Conditional Waiver of WDRs, which requires that agricultural interests conduct water quality monitoring programs

to determine if their discharges cause violations of water quality standards (objectives). Upon finding such violations, agricultural interests are required to implement management practices to eliminate them.

Beginning in the spring of 2006, the list of monitored water quality parameters has been expanded to include nitrogen and phosphorus compounds. Coincidentally, the State Water Resources Control Board is following the US EPA mandate of developing water quality criteria for nitrogen and phosphorus compounds which can protect waterbodies from impairment of use by excessive growths of aquatic plants. Ultimately, the Agricultural Waiver water quality monitoring program and the development of nutrient-based water quality objectives will, for many waterbodies, especially in parts of the San Joaquin River watershed and within the SJR as well as in the South and Central Delta, lead to the need to develop management practices that will control nutrient runoff from agricultural lands which exceeds the water quality criteria/objectives that are being developed.

An area of particular concern in the SJR watershed is the situation that develops in the winter-spring associated with large rainfall runoff events, which leads to the transport of elevated concentrations of particulate phosphorus in the runoff waters. If the water quality criteria/objectives that are applied to agricultural runoff during winter-spring runoff periods are based on total phosphorus, then agricultural interests will be faced with developing management practices to control large volumes of runoff and associated particulate phosphorus that occur in winter-spring storms. However, based on studies conducted in other areas, the particulate phosphorus present in soils eroded from agricultural lands is largely unavailable to support algal growth in the receiving waters for the runoff. Further, it does not convert to available forms in downstream waterbodies. A significantly different phosphorus management strategy can be developed if the focus is on algal-available forms of phosphorus (primarily soluble orthophosphate and some forms of particulate organic phosphate), which would be present primarily in tailwater discharges from irrigated lands, compared to inorganic particulate phosphorus, which is associated with erosion of agricultural lands during winter-spring runoff periods. These issues have been discussed in a report that was developed for the Central Valley Regional Water Quality Control Board by Lee and Jones-Lee (2002).

Ultimately, the approaches that will be used in the application of fertilizers in crop production in the Central Valley will be significantly influenced by the need to control losses of nutrients from agricultural lands. Information on the need to control particulate phosphorus discharged from agricultural lands during winter-spring stormwater runoff periods could become a major factor in determining crop fertilization practices.

Impact: The results of this research could have a significant impact on economic concerns of Central Valley agricultural interests. The profitability of much of Central Valley agriculture is marginal. Increased costs associated with water pollution control through implementation of management practices arising from the Agricultural Waiver requirements could be sufficient to make some Central Valley agriculture uneconomical. Water quality management programs for agricultural runoff should be based on a technically valid assessment of the need to control various potential pollutants to a certain degree in the runoff waters. The large amounts of funds that would be needed to try to collect and treat particulate phosphorus in winter-spring

stormwater runoff from agricultural lands could be shown to be unnecessary through the results of this project.

Related Research: Beginning in the early 1960s, while Director of the Water Chemistry Program at the University of Wisconsin, Madison, Dr. G. F. Lee focused much of his graduate students' research efforts on determining the sources, amounts and impacts on water quality of nitrogen and phosphorus compounds. His research in these areas represented a pioneering effort to develop information that could be used by regulatory agencies and agricultural interests in more cost-effectively managing the excessive fertilization of waterbodies by aquatic plant nutrients. As summarized in his Summary Resume (which is appended), Dr. Lee, working with his graduate students and others, was instrumental in developing nutrient export coefficients from various types of land use. These nutrient export rates were developed from his participation in the US part of the international OECD Eutrophication Studies, where, through examining information on the amounts of aquatic plant nutrients present in runoff from about 100 watersheds across the US, he was able to develop general guidelines on the amounts of N and P exported from agricultural and urban areas per unit area per year. These results were published in "Nutrient Loading Estimates for Lakes" (Rast and Lee 1983/1984).

One of the issues of particular concern in the 1960s in regulating phosphorus impacts on the Great Lakes and other inland waterbodies was the potential for the phosphorus in lake sediments to be available to support algal growth in the water column. Dr. Lee had a number of graduate students conduct their theses and dissertations on this issue. A paper which summarizes the results of these studies, "Significance of Oxic versus Anoxic Conditions for Lake Mendota Sediment Phosphorus Release" (Lee, Sonzogni and Spear 1977) demonstrated that the inorganically bound phosphorus in lake sediments was not available to support algal growth. The release of P from lake sediments, as typically observed in the limnological literature, is due to the mineralization of planktonic algae that have died and settled to the sediments.

Dr. Lee was responsible for conducting one of the most comprehensive studies ever undertaken on algal-available phosphorus loads to a waterbody. This study was a US EPA-sponsored investigation of the phosphorus loads to Lake Ontario, which was conducted as part of the International Field Year for the Great Lakes. Three reports resulted from this study:

- "Algal Nutrient Availability and Limitation in Lake Ontario during IFYGL – Part I. Available Phosphorus in Urban Runoff and Lake Ontario Tributary Waters" (Cowen and Lee 1976),
- "Algal Nutrient Availability and Limitation in Lake Ontario during IFYGL – Part II. Nitrogen Available in Lake Ontario Tributary Water Samples and Urban Runoff from Madison, Wisconsin" (Cowen et al. 1977), and
- "Algal Nutrient Availability and Limitation in Lake Ontario during IFYGL – Part III. Algal Nutrient Limitation in Lake Ontario during IFYGL" (Sridharan and Lee 1977).

Additional discussion of these reports is presented in a subsequent section, under Methodology.

During the 1960s and 1970s there was considerable interest in developing phosphorus management strategies for Lake Erie. Lake Erie was experiencing excessive growths of algae that led to impaired water quality and low dissolved oxygen in the lake. The predecessor organization to the US EPA, and its Canadian counterpart, proposed a phosphorus management

strategy involving treatment of the domestic wastewaters discharged to the lake as a means of reducing phosphorus loads. At that time there was opposition to this approach by some who claimed that treating domestic wastewaters for phosphorus control would not reduce the phosphorus in the lake waters because of the large reservoir of phosphorus in the lake sediments. This led to interest in algal-available phosphorus that is present in Lake Erie sediments and Lake Erie shoreline bluff erosion as a source of phosphorus for the lake. As part of this interest, the International Joint Commission for the Great Lakes organized a conference devoted to phosphorus management strategies for lakes in which Dr. Lee was invited to present a summary of the work that he and his graduate students had been doing on algal-available forms of phosphorus. This led to the publication of "Availability of Phosphorus to Phytoplankton and its Implications for Phosphorus Management Strategies" (Lee et al. 1980).

This paper presented an integrated summary of the previous work that Dr. Lee and his graduate students had done on this issue in the 1960s and 1970s, as well as the subsequent work of others. The key finding from this work was that the algal available phosphorus in a water sample was equal to the soluble orthophosphate plus about 20 percent of the particulate phosphorus. These results were based on algal assay studies, in which water samples were incubated under conditions where the only source of phosphorus for algal growth was that originally present in the sample at the time of collection.

In the 1970s and 1980s, Dr. Lee was involved in a number of studies of waterbodies in other countries, including Spain and Argentina, in which he was able to examine nutrient load-eutrophication response relationships for waterbodies in which a large part of the phosphorus load to the waterbody was in inorganic particulate forms associated with erosion in the waterbody's watershed. It was found that these waterbodies did not fit the normalized phosphorus load planktonic algal chlorophyll response relationships that had been developed for waterbodies throughout most of the world, where the phosphorus load was primarily soluble orthophosphate. The waterbodies with high particulate phosphorus loads, such as Salto Grande Reservoir in Argentina and Uruguay, which receives runoff from Brazil, produced far less planktonic algal chlorophyll than would be expected. However, when the total phosphorus loads to this waterbody were adjusted for the expected algal-available forms, the normalized phosphorus load produced the planktonic algae in the reservoir that would be expected. Similar results were found for waterbodies in Spain, South Africa and the US. The Salto Grande studies resulted in a paper, "Aplicacion Preliminar de un Modelo de Eutrofication al Embalse de Salto Grande" (Beron and Lee 1984).

More recently, in October 2005, the US EPA held a Mississippi River Basin Nutrients Science Workshop in St. Louis, MO, at which the issue of available phosphorus was discussed by Machesky of the Illinois State Water Survey, in a presentation entitled, "The Impact of Sediments on the Potential Bioavailability of Phosphorus in Illinois Streams" (Machesky et al. 2005). He found that a large part of the particulate phosphorus present during periods of high runoff was unavailable to support algal growth.

It is likely that studies on the algal availability of particulate phosphorus present in stormwater runoff from agricultural lands in the San Joaquin River watershed will show, as has been shown for other areas, that the erosion-derived particulate phosphorus in agricultural land runoff is

largely unavailable to support algal growth. This finding could have a significant impact on phosphorus management strategy and the application of nutrients (phosphorus) to agricultural lands in this watershed.

Relationship Between Algal Blooms and Phosphorus Concentrations. The role of phosphorus in stimulating the growth of algae in waterbodies is an issue that Dr. G. F. Lee has been involved in since 1960. This involvement has included personally conducting several million dollars in research on this issue in a variety of waterbodies located throughout the US and in many other countries. Further, Dr. Lee has been involved in advisory panels and committees that have investigated this situation in waterbodies located throughout most of the world. The total research effort of Dr. Lee, either directly or through participation in advisory panels over the past 47 years, on the role of phosphorus in contributing to excessive fertilization of waterbodies, exceeds $75 million. These studies have included recently assessing the role of phosphorus in stimulating excessive growths of algae in the San Joaquin River, some of its tributaries and the Delta. He and his associates, especially Dr. Anne Jones-Lee, have published extensively on this research. Their publications of the last 15 years or so, as well as several important papers developed prior to that time, are available on their website, www.gfredlee.com, in the Excessive Fertilization section (http://www.gfredlee.com/pexfert2.htm).

During the 1970s, through the Organization for Economic Cooperation and Development (OECD), 22 countries in western Europe, North America, Japan and Australia conducted five-year studies on about 200 waterbodies, in which they examined the relationship between phosphorus loads to the waterbody and the planktonic algal chlorophyll that develops in it. This effort is estimated to represent a 50-million-dollar study that included freshwater lakes, reservoirs and several estuarine marine systems. Dr. G. F. Lee was selected by the US EPA to develop a synthesis report for the US part of these studies, "Summary Analysis of the North American (US Portion) OECD Eutrophication Project: Nutrient Loading-Lake Response Relationships and Trophic State Indices" (Rast and Lee 1978). Further, he served on the international steering committee for the overall studies. These studies demonstrated that the original approach developed by R. Vollenweider, relating the normalized phosphorus loads to the waterbody to the planktonic algal chlorophyll that develops in the waterbody, is typically a reliable approach for relating phosphorus loads to planktonic algal concentrations.

The approach for relating phosphorus loads to waterbodies/in-lake phosphorus concentrations to planktonic algal chlorophyll utilizes the normalized annual areal phosphorus load to the waterbody based on its mean depth and hydraulic residence time (filling time) to predict, based on an internationally developed over-750-waterbody database, the amount of planktonic algae, as measured by chlorophyll, that will develop in a waterbody. These issues have been reviewed by Jones and Lee (1986). While the focal point of the original studies was freshwater lakes and reservoirs, the database has been expanded to riverine systems and near-shore marine waters.

The key information that is needed to relate algal blooms to phosphorus concentrations is the concentrations/loads of algal available phosphorus. As discussed in this proposal, total phosphorus is not a reliable predictor of chlorophyll concentrations for situations where a large amount of the phosphorus is present in inorganic, particulate forms (such as derived from erosion of agricultural lands), which have been shown by numerous investigators in other parts of the

world to be unavailable to support algal growth. It is not possible to reliably predict planktonic algal growth based on total phosphorus loads when an appreciable part of the phosphorus load is in an inorganic, particulate form.

Grower Use: Since SJR watershed growers will eventually face the need to control nutrient runoff from their lands as a result of Agricultural Waiver monitoring and agricultural nutrient criteria/objective development, growers would have a strong economic incentive to adopt the results of this project if it shows, as expected, that little improvement in the eutrophication-related water quality of the lower San Joaquin River and the Delta would arise from the potentially large expenditure of funds needed to control particulate phosphorus in winter-spring stormwater runoff from their lands.

Objectives

The objective of this project is to determine, on samples of stormwater runoff and tailwater discharges from irrigated agricultural areas in the San Joaquin River watershed, the total and algal available phosphorus concentrations. These results will lead to the development of a report that will provide guidance on the approach that can be followed to manage phosphorus in stormwater runoff from agricultural lands in a technically valid, cost-effective manner.

Workplans and Methods

Workplan: The first year of the proposed project will be devoted to, first, examining the results of the Central Valley Regional Water Quality Control Board's Agricultural Waiver monitoring program and other databases for information on the concentrations of phosphorus in various SJR watershed waterbodies that are potentially impacted by stormwater runoff from irrigated agricultural lands. Based on a review of the existing database, locations for sample collection within the SJR watershed will be selected. It is anticipated that the initial sampling will be conducted at about four sites in late fall, before any major winter rainfall runoff events occur. At the time of major rainfall runoff events, additional sampling of these selected locations will occur, with the purpose of obtaining samples of runoff when the greatest concentrations of particulate phosphorus will be present in the samples. There will be need to do some sampling with time on selected waterbodies to determine if the particulate algal-available phosphorus significantly changes during a single runoff event. In addition, specifically targeted sampling will be done at previously selected sites during the winter-spring period, during lower flow conditions, to examine how the total and algal available P changes as a function of flow.

The same first-year sampling locations will be sampled during the irrigation season, such as in June and August, to examine how total P and algal available P changes during the period when the waterbody primarily receives tailwater discharges from agricultural lands.

The results of the first year's studies will be critically examined to provide guidance on how the sampling program should be modified and what new sampling locations should be included. The results of the past year's Agricultural Waiver monitoring of phosphorus from various locations in the watershed will be used to guide the second year's studies.

A similar approach will be used to develop the third (final) year's project study approach, where the results of the first two years will be used to guide the sampling locations and times. It is anticipated that the three years of study will be needed to adequately cover the range of climatic, runoff and other conditions that can influence total and algal available P concentrations/loads in a waterbody.

The final report from the three-year study will present and discuss the data collected during the study, and how these results should be used to develop a phosphorus management strategy for runoff from agricultural lands in the San Joaquin River watershed.

Methods: The project will be conducted using algal assay techniques involving incubation of runoff/discharge samples of water, under controlled laboratory conditions, to determine the amount of algal growth that occurs in the runoff/discharge samples relative to the total phosphorus concentrations in the sample. The techniques used were developed in the 1960s in Dr. Lee's laboratories (see Cowen and Lee 1976) and are now well established in the literature (see APHA, et al. (1998) Standard Methods for Examination of Water and Wastewaters, section 8110 Algae).

Grab samples will be collected by G. Fred Lee & Associates in 2.5 gal cubitainers™, placed on wet ice in ice chests, and delivered to AQUA-*Science* (A-S) for processing and testing. Measurements of dissolved oxygen (DO) and temperature will be taken in the field. Initial measurements of pH, alkalinity, hardness, and conductivity will be made at A-S upon sample receipt. An aliquot of the test sample will be filtered (0.45 µm) to remove particulate P. Aliquots of unfiltered and filtered test samples will be sent to CalTest Laboratory (Napa, CA) for determination of total phosphorus and soluble orthophosphate. Within 24 hrs of receipt, algal assays will be initiated on the unfiltered sample. Specifically, the US EPA (2002) algal toxicity test methodology will be used, with the modification that the water samples will be tested using standard algal assay media; however, no phosphorus will be added to the media, in order that algal growth that occurs must use the algal available P in the test sample at the time of collection.

In addition to the test samples, three algal growth curves will be generated with each test event using the US EPA algal growth media containing the standard amount of P along with two additional concentrations of P to bracket the expected P concentrations (18.6-186 µg/L) in the study area based on previous studies. Samples will be tested in an environmental chamber under continuous lighting with continuous shaking. The amount of algal growth in the sample will be measured on days 0, 4, 8, 12 and 16 by cell counts and/or light scattering using spectrophotometric means to determine algal growth curves in accordance with standard procedures set forth in the US EPA (2002) and APHA, et al. (1998) Standard Methods procedures.

The laboratory studies will be conducted under the supervision of Dr. Jeff Miller in the facilities of AQUA-*Science*, located in Davis, California. A-S has been a leader in aquatic toxicity testing, environmental research and consulting for over 20 years. Currently, A-S is ELAP-certified to conduct 23 aquatic toxicity tests with a wide variety of freshwater, estuarine and marine test organisms including algae, invertebrates, and fish. A-S operates a 3,000 sq. ft. state-of-the-art bioassay laboratory in Davis, CA. Dilution waters include reverse-osmosis and

granular carbon treated well water and Bodega Bay seawater that consistently support growth and reproduction of sensitive test species. The facility has two temperature control rooms and four environmental chambers capable of running up to six independent temperature/photoperiod regimes simultaneously. The lab is equipped with the latest available instrumentation to measure water quality parameters and has separate facilities for test organism culture and testing, dose preparation, data reduction and clerical functions. A-S has extensive algae testing experience including ambient waters for the Agricultural Waiver and State Board ambient monitoring programs, domestic wastewater effluent for numerous NPDES clients as well as algae Phase I and II Toxicity Identification Evaluations (TIEs) to identify the cause(s) of algal toxicity detected in these programs. In addition, A-S has published novel and innovative TIE tools and procedures for several species, including algae. The algae toxicity test endpoint can be determined using electronic cell counting (Coulter™ counters), spectrophotometry (A750) or manual cell counting. At present, A-S has the capability to conduct 120 algae toxicity test replicates. Additional algae testing capability can be added as required.

Experimental Site: The studies will be conducted on samples taken from several sites in the San Joaquin River watershed, with the sites to be determined after existing data review.

Project Management, Evaluation and Outreach

Management: The overall project management will be conducted by Drs. G. Fred Lee and Jeff Miller. They will work as a team in planning and in sample collection and processing, where Dr. Lee will be primarily responsible for sample collecting, and Dr. Miller will be primarily responsible for sample processing and developing of a data report. Drs. Lee and Miller will be jointly responsible for developing interim and final reports, and the professional papers that may result from this study. The overall fiscal responsibility for the project will lie with Dr. Lee of G. Fred Lee & Associates.

Dr. Anne Jones-Lee, Vice President of G. Fred Lee & Associates, will work with Dr. G. F. Lee in conducting these studies. She will be primarily responsible for administrative activities associated with project administration, as well as assisting with data presentation and report preparation. She and Dr. Lee were co-PIs for the $2-million CALFED-supported low-DO project on the San Joaquin River Deep Water Ship Channel. In addition to contributing to the technical aspects of the project she was primarily responsible for project administration and is well experienced in this type of activity.

Evaluation: The success of the project will be evaluated based on the results of the studies, ultimately leading to a technically valid, cost-effective approach for managing phosphorus in agricultural runoff that leads to excessive fertilization of waterbodies influenced by nutrients discharged from agricultural lands in the San Joaquin River watershed.

Outreach: The results of these studies, as they become sufficiently completed to be presented to the regulatory community and agricultural interests, will be made available through presentations to the Central Valley Regional Water Quality Control Board's Agricultural Waiver Technical Issues Committee and to the Regional Board staff and Board members. These meetings are attended by representatives of the various Agricultural Waiver coalitions and by regulatory

agency staff. Dr. Lee has an over-15-year cooperative relationship with the Central Valley Regional Water Quality Control Board.

In addition, presentations to other agricultural interest groups will be made as the opportunities to make such presentations become available. Further, professional papers and trade journal publications, including publication in *California Agriculture*, will be developed to make the results of these investigations widely available.

Budget Itemization

Budget

Project Title: Assessing Algal-Available Phosphorus Loads in Runoff from Irrigated Agriculture in the Central Valley of California

Principal Investigator: G. Fred Lee, PhD, PE, DEE

Fiscal Year (January 1 – December 31): Assuming project can be initiated on January 1, 2007

Table 1

Expenses	Request	Other Funding/ Discussion	Total Budget
A. Operating Expenses			
G. Fred Lee, PhD, DEE, Project PI	$10,000.00	See Note 1	$10,000.00
Jeff Miller, PhD, DABT, Co-Investigator	1,500.00	See Note 2	1,500.00
Anne Jones-Lee, PhD, Co-Investigator	5,000.00	See Note 3	5,000.00
Secretarial (30 hr @ $28/hr)	840.00	See Note 4	840.00
Hourly help (50 hr @ $15/hr)	750.00	See Note 5	750.00
Subtotal A	18,090.00		18,090.00
B. Operating Expenses			
Travel			
Sample Collection:			
4 trips for 4 locations (150 mi/trip @ $0.445/mi)	400.50		400.50
Equipment	None		0.00
Subtotal B	400.50		400.50
C. Professional/Consultant Services			
Subcontract to AQUA-*Science*		See Note 6	
Algal assays (16 samples @ $1,000/sample),	16,000.00		16,000.00
3 Algal growth curves per test event (12 samples@ $650)	7,800.00		7,800.00
Sample filtration (16 samples @ $40/sample)	640.00		640.00
Chemical Analysis – total phosphate (16 samples @ $47/sample),	752.00		752.00
Chemical Analysis – soluble orthophosphate (16 samples @ $31/sample)	496.00		496.00
Additional testing yet to be defined depending on results of standard testing	5,000.00		5,000.00
D. Other Expenses			
Supplies (ice)	100.00		100.00
Office supplies	200.00		200.00
Photocopies, telephone, reports	500.00		500.00
Total Budget (A+B+C+D)	49,978.50	See Note 7	49,978.50

Note 1: As principal investigator for the project, Dr. G. Fred Lee will be responsible for planning, implementation and reporting of results. He will be assisted by Dr. Jeff Miller and Dr. Anne Jones-Lee.

Note 2: The funds for Dr. Jeff Miller's time will cover, in part, the time that he will devote to helping to plan the studies and develop reports on them.

Note 3: Dr. Anne Jones-Lee will work closely with Dr. G. Fred Lee in project planning, implementation and reporting.

Note 4: The secretarial support is for preparation of reports and correspondence.

Note 5: The hourly help is to assist Dr. Lee in sample collection.

Note 6: A subcontract will be issued by G. Fred Lee & Associates to AQUA-*Science* for sample chemical analyses and algal assays of available P. In addition to determining the amount of algal growth that occurs in the samples based on the available P in the sample, standard algal growth curves, with amounts of phosphorus similar to those present in the samples, will be conducted to demonstrate the amount of growth that should occur if all of the phosphorus in the sample is available for algal growth.

It is anticipated that it will be possible to collect four sets of samples from four locations in the San Joaquin River watershed at four different times during each year of the project budget period. It may be possible to increase the number of samples to be processed within the funds made available if no unexpected problems occur. However, since some water samples collected from the San Joaquin River watershed have been shown by Dr. Miller to contain herbicides which are toxic to algae, there may be need to modify the number of samples processed, to remove the toxicity prior to the algal assays of available P.

Note 7: The total amount of funds requested is based on the potential sponsor's limitation of $50,000.00 per year. It is expected, based on the amount of time that Drs. Lee, Jones-Lee and Miller will devote to this project, that the project is equivalent to a traditionally funded university project with a total budget well over $100,000.00 per year.

Discussion of Budget. Table 1 presents the proposed budget for Year 1 of this project. Years 2 and 3 of the project are anticipated to have approximately the same total budget and budget breakdown as Year 1. Some changes in the second and third year budget could be made with respect to the number of samples processed and locations sampled, depending on the results of the previous year.

The principal investigators on this project are not salaried personnel where it would be possible to delineate the percent of their time and a corresponding dollar amount for this time. Drs. G. Fred Lee, Jeff Miller and Anne Jones-Lee will undertake this project in lump sum amounts for their time. In the case of Dr. G. F. Lee, he typically charges $250/hr for his time as a consultant to governmental agencies and industry. Dr. A. Jones-Lee charges $125/hr for her time. Dr. J. Miller also charges $125/hr for consulting. These rates include overhead and fees. For Dr. G. F. Lee, $10,000 for the total requested payment from the project funds represents 40 hours of his time at his normal billing rate. Similarly, $5,000 total requested payment for Dr. A. Jones-Lee represents 40 hours of her time at her normal billing rate. Both Drs. Lee and Jones-Lee expect to invest far more time into properly conducting this project than the 40 hours that would be involved if they charged for their time at their standard consulting rate. Dr. Lee expects to devote more than 40 hours to sample collection alone. As owners of G. Fred Lee & Associates, they are in the position to make a commitment to devote the time necessary to successfully conduct a high-quality project, regardless of the amount of time they will have to spend.

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Supplemental References

During the past several years, Dr. Lee has received requests to present reviews at conferences, as well as develop papers and reports, on the role of phosphorus in stimulating excessive growths of algae as related to excessive fertilization of waterbodies. A listing of some of these publications is presented below:

Lee, G. F. and Jones-Lee, A., "Developing Nutrient Criteria/TMDLs to Manage Excessive Fertilization of Waterbodies," Proceedings Water Environment Federation TMDL 2002 Conference, Phoenix, AZ, November (2002).
http://www.gfredlee.com/WEFN.Criteria.pdf

Lee, G. F., and Jones-Lee, A., "Additional Information on Impact of Waterbody Fertilization on Fish Production," Report of G. Fred Lee & Associates, El Macero, CA, Published as "Water body fertilisation: Impact on fish production," SCOPE Newsletter 56: 6-7, June (2004).
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Summary Resume of G. Fred Lee, PhD, PE, DEE
Academic Background and Professional Experience Pertinent to this Project

Dr. G. Fred Lee is President of G. Fred Lee & Associates, which consists of Drs. G. Fred Lee and Anne Jones-Lee as the principals in the firm. They specialize in addressing advanced technical aspects of water supply water quality, water and wastewater treatment, water pollution control, and solid and hazardous waste impact evaluation and management. Dr. Lee holds a B.A. degree from San Jose State College. After obtaining his Master of Science in Public Health degree from the University of North Carolina in 1957, focusing on water quality, and a PhD degree from Harvard University in 1960 in Environmental Engineering with an emphasis on aquatic chemistry, Dr. Lee taught university graduate-level environmental engineering and environmental science courses for 30 years at several US universities. During this time, he conducted over $5 million of research and published over 475 papers and reports. Dr. G. F. Lee has been a full-time consultant since 1989. Since then he has developed another 600 papers and reports. One of his areas of specialization is the development of technically valid water quality investigations and cost-effective pollutant control programs to protect the designated beneficial uses of waterbodies without significant unnecessary expenditures for constituent control. Drs. G. Fred Lee and Anne Jones-Lee have established a website, www.gfredlee.com, where they make available their recent papers and reports. Additional information on Dr. G. F. Lee's professional activities is available upon request.

Of particular relevance to this proposal is the over 45 years of research and consulting that Dr. Lee has done on excessive fertilization (eutrophication) of waterbodies. Beginning in 1960, when he held the position of Director of the Water Chemistry Program at the University of Wisconsin, Madison, Dr. Lee was involved in evaluating aquatic plant nutrient sources (nitrogen (N) and phosphorus (P) compounds) that lead to excessive fertilization of waterbodies, as manifested by planktonic (suspended) algae and/or water weeds, and developing approaches for the control of nutrients. His university-based studies included pioneering work on the amounts and factors influencing the concentrations/loads of N and P compounds in stormwater runoff from agricultural and urban areas. In the 1970s, Dr. Lee was selected by the US EPA to develop a synthesis report for the US part of the international Organization for Economic Cooperation and Development (OECD) Eutrophication Studies. These studies focused on evaluating the impact of nutrient loads to waterbodies on their eutrophication-related water quality, focusing on planktonic algal growth. The international OECD Eutrophication Studies involved 22 countries in North America, Europe, Japan and Australia, investigating 200 waterbodies over five years. As part of the US OECD eutrophication studies, Dr. Lee and his graduate students developed nutrient export coefficients from various types of land use. These coefficients can be used to estimate the amounts of N and P compounds derived from agricultural and urban areas per unit time and area. It became evident from the OECD Eutrophication Studies that, for some waterbodies, the total normalized phosphorus load to the waterbody was not a reliable predictor of planktonic algal growth within the waterbody. This was particularly true for waterbodies where a large part of the phosphorus load was in a particulate form, associated with erosional transport of phosphorus from agricultural lands. Following the completion of the international OECD Eutrophication Studies, Drs. Lee and Jones-Lee have continued their work on nutrient load-eutrophication response relationships for waterbodies, where they now have included over 750 waterbodies located in various parts of the world in their database of normalized phosphorus

load-planktonic algal chlorophyll relationships. This has been published by Jones and Lee (1986[†]).

Part of Dr. Lee's studies conducted at the University of Wisconsin, Madison, were devoted to assessing algal available phosphorus in stormwater runoff from various types of land use. This work ultimately led to Dr. Lee's being invited by the International Joint Commission (IJC) for the Great Lakes to develop a synthesis paper (Lee et al. 1980) on what was known then about algal available phosphorus, for presentation at an IJC international conference on phosphorus management strategies for lakes. It was evident from Dr. Lee's pioneering work as well as the subsequent work of others, that substantial parts of the particulate phosphorus derived from agricultural lands was not available to support algal growth. This finding has particular significance to developing agricultural runoff phosphorus control programs, since if the high phosphorus loads derived during large runoff events are not available to support algae, then trying to capture and control particulate phosphorus during large runoff events becomes unnecessary, thereby saving agricultural interests large amounts of funds developing best management practices (BMPs) to control particulate phosphorus in runoff from their lands.

In 1989, when Dr. Lee retired from university graduate-level teaching and research and expanded his part-time consulting to a full-time activity, one of the first positions that he held was as a consultant to Delta Wetlands on estimating the potential water quality in Sacramento-San Joaquin River Delta island water supply reservoirs. He continued to be active through the 1990s on Delta water quality issues, where in 1999 he became an advisor to the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) low dissolved oxygen (DO) TMDL Steering Committee. In 2000 he was selected by this Committee and CALFED to be the coordinating principal investigator for a $2-million CALFED project devoted to developing information pertinent to understanding and then managing the low-DO problem that occurs in the SJR DWSC near the Port of Stockton. Drs. G. F. Lee and A. Jones-Lee have developed a series of reports on these studies, including a synthesis report (Lee and Jones-Lee 2003, 2004b). These studies demonstrated that the low-DO problem was due to the growth of algae in the SJR watershed, which, upon entering the DWSC, die and decompose, exerting an oxygen demand. They also demonstrated that the nitrogen and phosphorus that lead to excessive growths of algae in the SJR are primarily derived from agricultural runoff and subsurface drain water.

Lee and Jones-Lee's work on the San Joaquin River and Delta watershed water quality issues has resulted in the development of two water quality reports, "Overview of Sacramento-San Joaquin River Delta Water Quality Issues," (Lee and Jones-Lee 2004a) and "San Joaquin River Water Quality Issues"(Lee and Jones-Lee 2006). These reports discuss the fact that, in addition to the low-DO problem in the DWSC near the Port of Stockton, there are excessive algal growth problems in the South Delta and in domestic water utility water supply reservoirs that utilize Delta water as a water source. These nutrient-related water quality problems are causing the US EPA and the California State Water Resources Control Board to develop nutrient water quality criteria (objectives) which could be used to limit the amounts of N and P discharged from agricultural and other lands in the Delta watershed. There is need for information on how much of the total phosphorus discharged from agricultural lands in the Delta watershed is available to support algal growth. Support of this project will provide this information.

[†] References cited in this section are included in the proposal's list of references.

Summary Resume of
Jeffrey L. Miller, Ph.D., DABT
AQUA-*Science* President and Chief Technical Officer

Dr. Miller is the founder of AQUA-*Science* (A-S), an environmental toxicology consulting and testing firm located in Davis, CA. For the past 25 years, Dr. Miller has designed and conducted numerous water-related environmental studies to determine the effects of municipal effluents, surface waters and storm water on a wide variety of freshwater, estuarine and marine organisms. Dr. Miller is a nationally recognized expert on the application of Phase I, II and III TIE procedures to identify aquatic toxicity due to heavy metals, pesticides, ammonia, surfactants and industrial chemicals. Dr. Miller has developed and published many innovative TIE approaches, including chemical toxicity fingerprinting, methods to assess the interactive effects of pesticides, and application of TIE methods to West Coast aquatic species. Dr. Miller is the co-inventor of a patented antibody-mediated chemical-specific process for identification of toxicity due to organophosphate and pyrethroid insecticides in aqueous matrices. Dr. Miller has developed and taught advanced TIE workshops at local and national scientific meetings. He is a charter member of SETAC and serves on the National SETAC TRE/TIE Expert Panel. Dr. Miller was selected as a member of the California State Water Quality Control Board/USEPA WET Training Panel and is currently authoring the WET regulatory guidance for USEPA Region 9. He is a Board Certified Toxicologist (DABT) and has published over 30 peer-reviewed articles, abstracts, and case studies in the area of environmental toxicology.

Education:

DABT -	Diplomat, American Board of Toxicology, 1981
Ph.D. -	University of California, Davis, CA, Environmental Toxicology, 1976
B.S. -	Chico State University, Chico, CA, Biological Sciences, 1969

Employment History:

1984-1986 *Principal Environmental Toxicologist,* ICI Americas, formerly Stauffer Chemical Company. Responsible for development and implementation of company-wide program to assess the environmental hazard of pesticides and industrial chemicals (total sales >$l.2 billion). Interacted with local, state, and federal regulatory agencies relating to environmental matters (testing requirements, plant discharge permits, pesticide registrations) related to Stauffer/ICI products. Responsible for contract administration of all environmental toxicology studies (annual budget >$1.2 MM).

Recent Peer Reviewed Publications

1. Wheelock, C.E., J.L. Miller, M.J. Miller, B.M. Phillips, S.J. Gee and B.D. Hammock. 2005. Effect of pyrethroid adsorption to testing containers upon observed toxicity to *Ceriodaphnia dubia* and *Hyalella azteca*. *Aquatic Toxicol.* 74:47-52.

2. Craig E. Wheelock, Jeff L. Miller, Mike J. Miller, Shirley J. Gee, Guomin Shan,and Bruce D.Hammock. 2004. Development of Toxicity Identification Evaluation (TIE) procedures for pyrethroid detection using esterase activity. *Environ. Toxicol. Chem.* 23:2699-2708.

3. Wheelock, C.E., J.L. Miller, M.J. Miller, B.M. Phillips, S.A. Huntley, S.J. Gee, R.S. Tjeerdema, and B.D. Hammock. 2005. Use of carboxylesterase activity to remove pyrethroid-associated toxicity to *Ceriodaphnia dubia* and *Hyalella azteca* in Toxicity Identification Evaluations (TIEs). *Envirn. Toxico. Chem* 25:973-984.

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USA. 496 p

5. Miller, J.L., M.J. Miller and V. de Vlaming. 2005. Use of Enzyme-Linked Immunosorbant Assay (ELISA) Procedures for measuring diazinon and chlorpyrifos in ambient monitoring and TIE studies. In: Norberg-King TJ, Ausley LW, Burton DT, Miller JL, Waller WT. *Toxicity reduction and toxicity identifications (TIE) for effluents, ambient waters and other aqueous media.* Society of Environmental Toxicology and Chemistry (SETAC). Pemsacola FL, USA. 496 p.

6. Miller, J.L., M.J. Miller and V. de Vlaming. 2005. Identification of causes of toxicity in urban creek stormwater. In: Norberg-King TJ, Ausley LW, Burton DT, Miller JL, Waller WT. *Toxicity reduction and toxicity identifications (TIE) for effluents, ambient waters and other aqueous media.* Society of Environmental Toxicology and Chemistry (SETAC). Pemsacola FL, USA. 496 p.

7. Miller, J.L., M.J. Miller and V. de Vlaming. 2005. Use of antibody-mediated procedures to identify and confirm the role of diazinon and chlorpyrifos in surface water toxicity. In: Norberg-King TJ, Ausley LW, Burton DT, Miller JL, Waller WT. *Toxicity reduction and toxicity identifications (TIE) for effluents, ambient waters and other aqueous media.* Society of Environmental Toxicology and Chemistry (SETAC). Pemsacola FL, USA. 496 p.

8. Miller, J.L., M.J. Miller, K. Larsen, P. Green and T. Young. 2005. V. de Vlaming. 2005. Identification of causes of toxicity to algae in Sacramento-San Joaquin delta. In: Norberg-King TJ, Ausley LW, Burton DT, Miller JL, Waller WT. *Toxicity reduction and toxicity identifications (TIE) for effluents, ambient waters and other aqueous media.* Society of Environmental Toxicology and Chemistry (SETAC). Pemsacola FL, USA. 496 p.

A list of additional publications and abstracts is available upon request.

Summary Resume of
Anne Jones-Lee, PhD (Formerly, R. Anne Jones)

Dr. Anne Jones-Lee, Vice President of G. Fred Lee & Associates, will work with Dr. G. F. Lee in conducting these studies. She has a BS degree in biology from Southern Methodist University, and a PhD in Environmental Sciences from the University of Texas at Dallas. For a period of 11 years she held university graduate-level teaching and research positions at several major US universities. She and Dr. G. F. Lee have worked together as a team since the mid-1970s, where they have published over 500 papers and reports on the results of their studies. Dr. Jones-Lee's PhD dissertation was concerned with assessing the release of phosphorus associated with US waterway navigation channel dredged sediments that are managed by open-water disposal of the sediments. This disposal method suspends some of the sediments in the water column, and thereby provides an opportunity for the phosphorus associated with these sediments to be more readily released to the water column, potentially leading to excessive fertilization of the waterbody.

EDUCATION

Ph.D. Environmental Sciences, University of Texas at Dallas, Richardson, TX, 1978. Areas of Specialization: Aquatic Toxicology/Chemistry, Aquatic Biology, Water Quality Evaluation and Management

M.S. Environmental Sciences, University of Texas at Dallas, Richardson, TX, 1975

B.S. Biology, Southern Methodist University, Dallas, TX, 1973

ACADEMIC AND PROFESSIONAL EXPERIENCE

CURRENT POSITION

Vice President, G. Fred Lee & Associates, El Macero, California

PREVIOUS POSITIONS

1984 - 1989 Associate Professor of Civil and Environmental Engineering (tenured), New Jersey Institute of Technology, Newark, NJ

1988 - 1989 Consulting Engineer, Ebasco-Envirosphere, Lyndhurst, NJ (part-time)

1984 - 1988 Director of Environmental Engineering Laboratories, Department of Civil and Environmental Engineering, NJIT, Newark, NJ

1982 - 1984 Research Associate and Lecturer, Department of Civil Engineering, Texas Tech University, Lubbock, TX

1982 Coordinator for Aquatic Biology, Fluor Engineers Advanced Technology Division, Irvine, CA

1978 - 1981 Research Assistant Professor, Department of Civil Engineering, Colorado State University, Fort Collins, CO

1973 - 1974 Research Technician, Frito-Lay Research and Development Laboratory, Irving, TX

SUMMARY OF PROFESSIONAL REPORTS AND PUBLICATIONS

Published more than 200 professional papers, and co-authored over 250 reports and occasional papers. Topic areas addressed include:

- Sources, significance, fate, and control of chemical contaminants in fresh water, marine, and estuarine systems
- Environmental impact of various types of wastewater discharges including mining, electric generating station, domestic, and industrial
- Causes and control of eutrophication; groundwater quality; impact of land disposal of municipal and industrial wastes; environmental impact of dredging and dredged sediment disposal; water quality modeling; hazard assessment of new and existing chemicals; water quality criteria and standards; water supply water quality; assessment of actual environmental impact of chemical contaminants on water quality; toxicity of sediments; impact of landfills on environmental quality

SUMMARY OF PROFESSIONAL PRESENTATIONS

Presented over 50 lectures and professional papers at professional society meetings, short courses, universities, public service groups, and national and international conferences.

AWARDS

Charles B. Dudley Award - American Society for Testing and Materials award for contribution to Hazardous Solid Waste Testing, "Application of Site-Specific Hazard Assessment Testing to Solid Wastes," published (1984).

1986 Best Paper of the Year - American Water Works Association Resources Division award for paper published in the Journal, "Is Hazardous Waste Disposal in Clay Vaults Safe?" (1986).

TEACHING EXPERTISE AND EXPERIENCE

Microbiological Aspects of Environmental Engineering
Introductory Chemical Aspects of Environmental Engineering
Aquatic Toxicology
Water and Wastewater Analysis
Introduction to Water and Wastewater Treatment
Introduction to Environmental Engineering
Faculty Director of Women in Science and Engineering Program (1988)