I. Executive Summary

a. **Ecological Model for the Sacramento-San Joaquin Delta and Suisun Bay.** Draft 1

Applicant: Dr. P. Lehman[1]
Collaborators: Dr. F. Chung[1], Dr. H. Rajbhandari[1], Dr. S. Bledsoe[2], Dr. E. Van Nieuwenhuyse[3]
[1]Department of Water Resources, [2] U. C. Davis, [3] Jones & Stokes Associates

b. The project will develop an ecological model for Sacramento-San Joaquin Delta and Suisun Bay from two mechanistic models 1) the DSM2-Qual - hydrodynamic and water quality model developed by Dr. H. Rajbhandari , Dr. G. Orlob and Dr. F. Chung at DWR and U. C. Davis, and 2) a population bioenergetic food web model developed by Dr. S. Bledsoe at U. C. Davis.

The objective of the project is to provide a well-defined tool to evaluate the relative effects of individual and combined restoration and management projects on the Bay-Delta ecosystem. Such a tool would help to restore aquatic habitat, ecosystem function and protect beneficial uses of the estuary. Habitats for which the model would be useful include: tidal perennial aquatic habitat, instream aquatic habitat and midchannel islands and shoals habitat. Because the model can predict streamflows, water quality and invertebrate biomass at the base of the food web, it is expected to be a useful tool for evaluating the habitat quality for all fishes in the estuary. Specific information the model would provide include streamflow, salinity, water temperature, turbidity, dissolved oxygen, organic loading, phytoplankton and zooplankton and benthic biomass and grazing rates, which are all important aspects of fish or invertebrate habitat. Without such a tool, CALFED must rely on more subjective approaches based on "expert" opinion or comparisons of dissimilar quantitative approaches.

c. The project will be a collaborative effort between principal investigators in the Department of Water Resources, U. C. Davis and Jones & Stokes Associates. They will be assisted by the Estuarine Ecology Team (EET), Bay-Delta Modeling Forum and interested stakeholders, who will provide critique and advice on Bay-Delta ecology and hydrodynamics.

The principal tasks of the project are (1) develop a list of the habitats, species and variables to be simulated (2) further calibrate and verify the DSM2-Qual model for chlorophyll *a*, organic carbon and nutrient concentrations for the entire the Delta and Suisun Bay, (3) parameterize and verify the food web model for zooplankton and benthos in the Delta and Suisun Bay. (4) interface the models so that the output of the water quality model provides input to the food web model, (5) make comparisons of model predictions with measured data for a wet, normal and dry water year, (6) develop user-friendly input and output procedures on the World Wide Web in order to enable ready use by agency scientists and stakeholder groups and (7) prepare reports documenting each model, model results for test years and user information.

This is a three year project. During the first year, both the water quality and food web sub-components of the model will be parameterized and verified with existing data and will be summarized in a progress report. During the second year, an interface will be developed between

the models and comparisons will be made between predicted and measured values for wet, normal and dry water years. Results will be summarized in a progress report. During the third year, a final report on the contents of the models and their capabilities will be completed and a user-friendly version of the model with user information will be uploaded to the World Wide Web.

d. CALFED and its member agencies are developing large-scale ecosystem management plans and restoration projects for the Bay-Delta estuary. Most of these future actions will affect the physical and chemical characteristics of the aquatic ecosystem including organic carbon concentrations, nutrient concentrations, turbidity, salinity and temperature, and will influence the abundance and distribution of phytoplankton, zooplankton and benthic organisms. Changes in water quality and food availability at the base of the food web will either directly or indirectly impact native and introduced fish populations, including Delta smelt, all salmon runs and striped bass. Although a number of complex models exist for simulating Bay-Delta hydrodynamics and resulting salinity and flow changes, there are no quantitative tools to assist in evaluating the combined impact of these management plans and restoration projects on changes in water quality and the food web. Thus, CALFED has a need for a management tool that could provide a standard base from which to evaluate the relative impacts of various scenarios on the water quality and food web in the Bay-Delta. Access to the model on the World Wide Web will provide ready availability of the model to CALFED, agencies and stakeholders.

e. Total cost : $ 453,725, over three years. No third party impacts are anticipated.

f. The project would be managed by Dr. P. Lehman at DWR. She was project manager for development of HydroQual's three species model, EcoAnalysis's phytoplankton species model and the DWR particle tracking model. She has also published papers on statistical models for phytoplankton biomass and species composition in the Bay-Delta. Dr. F. Chung is chief of Bay-Delta modeling at DWR. He has supervised development of Delta hydrodynamic models for over 10 years and was awarded a Hugo Fischer award for his contribution to hydrodynamic modeling in the estuary. He also assisted with development of the DSM2-Qual model. Dr. H. Rajbhandari is an engineer at DWR and developed the DSM2-QUAL model in conjunction with Dr. J. Orlob at U.C. Davis for his dissertation. Dr. S. Bledsoe is a professor in the Department of Civil and Environmental Engineering at U.C. Davis. His modeling work spans 30 years and includes a bioenergetic food web model for the Columbia River and EPA. Dr. E. Van Nieuwenhuyse is a consultant at Jones & Stokes and has modeled water quality in many rivers and lakes in California and Alaska.

g. The models would be submitted to periodic technical review by agency and academic experts in the IEP Estuarine Ecology Team and review at Bay-Delta Modeling Forum workshops.

h. The project is consistent with CALFED's desire to formulate and adaptively implement a scientifically based, ecosystem approach to restoration and management of the Bay-Delta. Coordination with other modeling and research efforts would be assured by interaction with the IEP EET team and the Bay-Delta Modeling Forum.

a. Ecosystem Model for the Sacramento-San Joaquin Delta and Suisun Bay

b. *Applicant*:
Dr. P. Lehman, Project Manager
Environmental Services Office
Department of Water Resources
3251 S Street
Sacramento CA 95816 plehman@water.ca.gov
(916) 227-7551, fax: (916) 227-7554

c. *Type of organization and tax status:* State Agency/Exempt

d. *Tax id*: NA
e. Contact person- same as above

f. *Collaborators:* Dr. F. Chung and Dr. H. Rajbhandari, Department of Water Resources, Dr. S. Bledsoe, University of California-Davis, and Dr. E. Nieuwenhuyse, Jones & Stokes Associates

g.*RFP project group type:* "Other Services"

III. Project Description

***a.* Project Description.**

The California Department of Water Resources (DWR) would like to facilitate development of an ecological model for the Sacramento-San Joaquin Delta and Suisun Bay. The ecological model would be a synthesis of two existing models: the DSM2-Qual water quality model developed at U.C. Davis and DWR and a population bioenergetics food web model being developed at U. C. Davis. The combined model would be developed by collaboration of modelers at DWR - Dr. Francis Chung, Dr. Hari Rajbhandari and Dr. Peggy Lehman, at U. C. Davis - Dr. Sam Bledsoe, and at Jones & Stokes Associates - Dr. E. Nieuwenhuyse. The agency and academic members of the IEP Estuarine Ecology Team (EET) would provide advise on water quality and food web issues including: water quality, phytoplankton, zooplankton, benthos and fish. Presentations at a Bay-Delta Modeling Forum (BDMF) technical workshop will be used to obtain advice from the modeling community. The resulting model would be uploaded to the World Wide Web for ready access by CALFED agencies and stakeholders.

The ecosystem model would benefit CALFED and the stakeholder community by providing a well-defined tool to evaluate restoration and management scenarios in the Bay-Delta. The model will also focus applied research by providing a tool for formulating hypotheses about how the ecosystem functions and how it may react to changes in physical, chemical or biological variables or ecosystem processes, and will contribute to development of effective and comprehensive monitoring programs in the estuary. Application of the model to toxic substance transport questions could also assist with current efforts to determine contaminant effects. All of these uses of the model will promote better understanding of the Bay-Delta ecosystem and will assist efforts to improve aquatic habitat and water quality and to restore ecosystem functions in Suisun Bay and the Delta. Ready access to the model and the supporting data bases via the World Wide Web will enable frequent use of the model by agency staff and stakeholder groups.

Approach:

Development of an ecosystem model is a difficult task. We propose to accomplish this task by coupling two existing models, the DSM2-Qual water quality model and a bioenergetics food web model. Differences in input and output requirement, unit differences and spatial and temporal resolutions will be reconciled and a list of selected habitats and species to be simulated will guide refinements of the models. We will receive periodic advice and review by the IEP EET team and will obtain further critique from a BDMF workshop. Capabilities of the model will be demonstrated through comparisons of measured and predicted physical, chemical and biological variables for wet, normal and critical water-year types. We will upload the final model and a user-friendly operations guide to the World Wide Web to allow application of the model to CALFED, agency and stakeholder projects. Details of each model are presented below:

DSM2-Qual water quality model:

DSM2 contains three separate modules: Hydro, Qual and PTM. DSM2-Hydro is a one-dimensional nonsteady-state hydrodynamic model, capable of simulating dynamic and tidally varying flows, which is a crucial part of any water quality modeling in the Delta. It has the

capability to handle rectangular, trapezoidal, and completely irregular channels. DSM2-Hydro has been recently calibrated for flows. It is continuously updated to reflect the most recent bathymetry data available to simulate the flow conditions in the Delta as closely as possible. It provides the circulation information for DSM2-Qual and DSM2-PTM.

DSM2-Qual is an estuarine transport model capable of simulating the dynamics of primary production including dissolved oxygen (DO), chlorophyll *a* concentration, temperature, biological oxygen demand (BOD), organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, dissolved phosphorus and conservative constituents such as total dissolved solids, and specific conductance (EC) etc. Because of its Lagrangian formulation, it is numerically suitable even for advection dominant systems like that of the Delta. It can handle dynamic variations of flows. Although on a "Delta-wide basis", the model has been calibrated only for EC, several interesting studies have been performed for the other constituents. Reaction kinetics in DSM2-Qual was validated by simulation of chlorophyll *a* and DO concentration and temperature in a hypothetical steady-state channel, and comparing the results with EPA's Qual2E.

A DO sag observed in the vicinity of Stockton on the San Joaquin River was simulated with the model during periods which included wide variations in tidal hydrodynamic conditions. The model was demonstrated to be capable of capturing diurnal variations of DO, chlorophyll *a* concentration, temperature and nutrients. In general, the results of this study established the capability of the DSM2-Qual to represent the important water quality processes in the entire estuarine environment of the Delta.

DSM2-Qual is much improved over a previous water quality model of the Delta developed by HydroQual. HydroQual's model structure required use of tidally averaged flows which, although generated by a hydrodynamic model, did not characterize important intratidal variations. The effect of neglecting these important hydrodynamic components was to limit simulated concentrations of constituents computed by the eutrophication model to temporal averages. Velocity fluctuations within a tidal cycle, as well as diurnal variation in loads and environmental conditions, e.g., temperature and salinity, can have significant effects on the extremes of BOD and DO. Further, this new model can describe the irregular geometry of the Delta channels instead of the rectangular or trapezoidal configuration used previously. This gives the model the capability of comparing shallow water and deep water habitat.

The model also has a mass tracking routine. It can be used to monitor how much of a mass of dye injected at a certain location reaches at other locations of interest after a certain period of time. The amounts of mass gained or lost due to specific biochemical transformations can also be calculated. This can help evaluate the impact of various sources on the water quality at a particular location.

DSM2-PTM is a particle tracking model which simulates the transport and fate of particles throughout the Delta. It uses one dimensional velocity results from DSM2-Hydro and then applies vertical and transverse velocity profiles to the individual particles traveling through the channels.

The bioenergetic food web simulation model:
The food web model, Ecotox, is a differential equation model which simulates the dynamics of the energetics (weight- Kleiber equation) and age structure (Von Foerster equations) of species populations in a spatially homogenous environment. Species are linked in a food web and population dynamics are based on fecundity linked to food availability and mortality linked to predator-prey relations and energy status (i.e. starvation). Food web links are controlled by a parametric who-eats-whom matrix and a dynamic size selection mechanism. The food web is driven by plant and/or detrital resources which may be contaminated with multiple chemical (toxic) substances. About 20 parameters are required to specify the energetic and population mechanisms for each population of the food web. Output of the model is a time series of projected population and biomass densities. Body burden of contaminants is traced through the food web populations and the processes of dietary, dermal and respiratory exposure, direct mortality (due to acute and/or chronic exposure), and reduction in foraging and reproductive rates are simulated. An additional 20 parameters are required to specify the toxicological mechanisms for each contaminant being simulated.

Three documents are available to describe the model; all are available from the first author at ljbledsoe@ucdavis.edu. Bledsoe and Megrey (1989) is a reviewed publication containing the basic population and energetic equations and an application to oceanic fish populations. Bledsoe (1996) is a technical report comprising a reference manual for ecotoxicological mechanisms, a users guide to the computer implementation, and an example hypothetical application to a toxicological risk assessment scenario in an agroecosystem. In addition, a brief (three page) statement (Bledsoe and Peterson 1997) describing an ongoing (July 97) application of the model to the food web associated with the Asian clam (Potamocorbula) in Suisun Bay is available (ljbledsoe@ucdavis.edu).

b. Geographic Boundaries.
The proposed model would encompass the legal Delta and Suisun Bay from Chipps Island to Carquinez Strait.

c. Expected Benefits.
The proposed project would benefit CALFED and the stakeholder community by providing a well-defined tool to evaluate individual and combined effects of restoration and management scenarios on the Bay-Delta ecosystem. Habitats for which the model are expected to be useful include: tidal perennial aquatic habitat, instream aquatic habitat and midchannel islands and shoals habitat. Because the model can predict streamflows, water quality and food availability at the base of the food web, it is expected to be a useful tool for evaluating the quality of habitat for all fishes in the estuary, including the fall, spring and winter run salmon, Delta smelt, splittail, steelhead trout, green sturgeon and striped bass. Specific information the model would provide include streamflow, salinity, water temperature, turbidity, dissolved oxygen, organic loading, phytoplankton and zooplankton and benthic biomass and grazing rates, which are all important aspects of fish or invertebrate habitat. In addition, many of these variables are important factors affecting aquatic vegetation.

The model will also assist CALFED by providing a tool for formulating hypotheses about how the

ecosystem functions and how it may react to changes in physical, chemical or biological variables or ecosystem processes, which lead to development of effective and comprehensive monitoring programs in the estuary. Application of the model to toxic substance transport questions could also assist with efforts to determine contaminant effects. All of these uses of the model will promote better understanding of the Bay-Delta ecosystem and will assist efforts to improve aquatic habitat and water quality and to restore ecosystem functions in Suisun Bay and the Delta. Access to the model and the supporting data bases via the World Wide Web will allow ready access to the models by agency staff and stakeholder groups for application to CALFED and agency projects.

d. Background and Technical Justification.

CALFED is considering a number of large scale management and restoration plans for the Bay-Delta that will affect physical and chemical characteristics of the water, and the quantity, transport and fate of sediments, nutrients and organic carbon, and the growth of algae, zooplankton and benthic organisms that are critical to the ecosystem health and beneficial uses of the Bay-Delta. Some restoration projects, such as the creation of set back levees or flooded islands in the Delta, are intended to create food rich nursery areas for fish and waterfowl, but it is unclear what their impact will be on water quality or food web dynamics. Other management scenarios, such as an isolated cross-Delta transfer facility, are intended to improve water quality and reliability south of the Delta, but it is unknown how they will affect water quality and food web processes within the Delta. How one project will enhance or detract from others must also be evaluated for dozens of projects under consideration in CALFED's Ecosystem Restoration Program Plan and other planning processes (e.g., CVPIA). Thus, there is a clear need for a ecosystem model that can be used as a management tool to provide standard criteria to evaluate the relative changes in water quality and lower food web dynamics throughout the Bay-Delta under different proposed management and project scenarios. Without such a tool, CALFED must rely on more subjective approaches based on "expert" opinion or comparisons of dissimilar quantitative approaches.

e. Proposed Scope of Work

The work will be completed in three phases over a period of three years. **Phase I**: The first year of the project, will be devoted to development of a Specification Document and refinement and parameterization of the DSM2-Qual model and the food web model. Phase I results will be periodically reviewed by the IEP EET team and described in a summary progress report. **Phase II**: The second year of the project, will include integration of the two models and evaluation of model results for different water-year types. Results will be summarized in a progress report and presented at IEP EET team meetings and a BDMF workshop. **Phase III**: The third year of the project, will include uploading the ecological model and user information to the World Wide Web and preparation of a final report detailing the model development and demonstrated model capabilities.

The three phases of the project have been divided into seven separate tasks described below:

Task 1. Develop model specifications

Differences between the models in terms of input and output requirements, units and spatial and temporal resolutions will be reconciled. In addition, a list of the habitats and associated species to

be simulated will be developed, with regard for the capabilities of the two model systems, the real ecological characteristics of the area, the state of knowledge of those characteristics and the practicalities and time-resource constraints of the project. These questions will be answered with assistance from the project advisors (IEP EET team etc.). The deliverable for this task will be a Specification Document which will be a blueprint for the further development of the two models and their combination into a single computer simulator.

Task 2. DSM2-Qual water quality model refinement
Considerable work has already been done on the DSM2-qual model. Although the model can predict chlorophyll *a* concentrations, the original model was calibrated to EC. Because chlorophyll a concentrations and other water quality variables are the focus this study, sensitivity analyses will be conducted for selected locations and habitats described in the Specification Document in Suisun Bay and the Delta in order to refine the rate coefficients related to chlorophyll *a* concentration and organic matter production.

Task 3. Parameterise and verify the food web model (FWM)
The purpose of this task is to parameterise the FWM for the various ecological habitats determined in the Specification Document (Task 1) and modify it as necessary for interface with DSM2-Qual . The FWM is presently intended for simulation of a spatially homogenous ecological habitat. The plan to extend it to the spatially diverse habitats simulated by DSM2-Qual is to parameterise multiple versions of FWM for selected points among the 496 channels, 416 junctions and 13 open water areas which comprise the spatial sites of the parent DWRDSM model. DSM2-Qual has a capability to simulate the transport and dynamics of "Arbitrary Non-Conservative Constituents" (p. 241, Rajbhandari 1995). These will be the advected organisms whose ecological dynamics are simulated by FWM. Conversely, FWM will calculate the oxygen and other nutrient uptake rates of the organisms of the food web and provide feedback to DSM2-Qual, where these terms are significant.

The organisms of the various food webs at the DSM2-Qual sites are either wholly advected (algae, microbes), partially advected depending upon flow and other variables (zooplankton) or transient (e.g., Delta smelt) spending only a part of their life cycle in any one habitat. A preliminary survey indicates that about 10 discrete food web types would suffice to discretely categorize the DSM2-Qual sites; each will have a combination of the three types of organisms among the entire food web. The FWM model will be parameterized to simulate, independently of the DSM2-Qual model, each of these food webs, using artificial but realistic driving functions.

The deliverable for this task will be the parameterized FWM's for the discrete habitats, and a report describing their implementation and preliminary analysis. The task will be completed with oversite and review as it is conducted by the IEP EET team and other project advisors, so that the final document will be ready for use in Task 4.

Task 4 Integrate Water Quality and Food Web Models.
Integration would require the incorporation of hydrodynamic transport, allochthonous and autocthonous carbon supply and other water quality variables from DSM2-Qual into the food web model. The linked models would then be recalibrated to incorporate feed back mechanisms. All

of this work would be based on the Specification Document developed in Task 1.

A subtask of the integration task will be to compare simple empirical relationships derived from existing data with model results at key locations in order to assist reformulation, calibration and verification of the model output and perspective on application of the model to CALFED projects.

Task 5. Water-year type comparison of model results.
The capabilities of the model will be demonstrated and evaluated by comparison of model output for selected key locations during wet, normal and critical water-year types. Model predictions will be compared with measured values and published ecological relationships during these water-year types. The results will included in the final report.

Task 6. Upload models and user information to the World Wide Web and Conduct Workshop.
The models, data sets and summaries of modeling results would be posted on the World Wide Web. A major aspect of this task is development of user-friendly input and output formats.

A one-day, BDMF technical workshop would be held in Sacramento to provide a forum for presenting and discussing the models and the preliminary modeling results. Information from the workshop would provide the basis for final model refinements and provide a forum for demonstrating the capabilities of the model.

Task 7. Prepare Final Report.
A final report presenting details of model assumptions, formulations, calibration and verification and a demonstration of modeling capabilities for different water-year types would be submitted to CALFED . Review comments will be solicited from CALFED, the IEP EET team, the BDMF and interested stakeholders.

f. Monitoring and Data Evaluation.
Performance of the models will be continually monitored by the collaborators and their staff during verification procedures. Comparisons of model results with simple regression models by Dr. Van Nieuwenhuyer would help to assess the accuracy and precision of the final model. In addition, a comparison of the completed model results for different water year types by Dr. Lehman would assess the ability of the models to capture the important water quality and biological conditions associated with different water-year types. The models would be available for technical review by agency and academic experts and will be reviewed periodically by the IEP EET team, which includes experts in estuarine biogeochemistry and phytoplankton, zooplankton, benthic invertebrate and fish ecology. The BDMF workshop would provide technical review and evaluation for final model refinement. Information gained during this workshop that can not be incorporated into the models under this grant and other review comments will be included in the final report.

***g.* Implementability.**
The project is fully implementable within the prescribed time and budgetary allowances.

IV. Costs and Schedule to Implement Proposed Project

a. **Budget Costs.** Total cost for the project is $ 453,725. Details are in Figure 1.

We would like to point out that much of the project has been or will be funded by sources other than CALFED. Development of the DSM2-Qual water quality model was done from funding by DWR and U. C. Davis, and the Bay-Delta Evaluation Program will contribute an additional $37,000 per year for this modeling work. The base model for the food web model was previously developed for EPA. In addition, the labor costs of advisors in the IEP EET team will be covered by agencies within IEP.

b. Schedule Milestones. See Figure 2.

c. Third Party Impacts. None.

V. Applicant Qualifications

Dr. Peggy Lehman at DWR would be Project Manager for the proposed project, advise on water quality and phytoplankton issues and assist with evaluation of model predictions for different water-year types. Dr. Lehman has been project manager for development of the HydroQual three species model, the EcoAnalysis phytoplankton species model and the DWR particle tracking model. She has published statistical models for phytoplankton biomass and species composition in the Bay-Delta and has worked on food web and water quality issues in the Bay-Delta for over 10 years.

Dr. Francis Chung at DWR would direct modeling associated with the DSM2-Qual model. Dr. Chung is chief of the DWR Delta Modeling Group and supervises development and application of hydrodynamic and water quality models for the San Francisco Bay-Delta, including the DWRDSM hydrodynamic model and the DSM2-Qual model. He has published many articles and reports on hydrodynamic modeling in the estuary and was awarded the Hugo B. Fischer award for his outstanding work in hydrodynamic modeling.

Dr. Hari Rajbhandari at DWR would further refine the DSM2-Qual model. Dr. Rajbhandari developed the DSM2-Qual model as a part of his dissertation work with Dr. Orlob at U. C. Davis. He has had eight years experience in the development and utilization of computerized mathematical models of hydrodynamics and water quality.

Dr. Louis J. (Sam) Bledsoe at U. C. Davis would be responsible for development of the bioenergetic food web model. Dr. Bledsoe is an Associate Research Engineer in the Department of Civil and Environmental Engineering at U. C. Davis with 30 years of experience in the development of complex ecosystem models. He developed a food web model for EPA and is currently developing an integrated biogeochemical model of the Columbia River Estuarine

Turbidity Maximum and a *Potamocorbula*-food web model for Suisun Bay.

Dr. Erwin Van Nieuwenhuyse at Jones & Stokes Associates would be responsible for assisting with verification of the water quality and food web models. Dr. Van Nieuwenhuyse has modeled water quality in a number of rivers and lakes in California as well as in the midwest and Alaska and has extensive experience in the compilation and analysis of large data sets.

Selected Articles and Reports:

Beamesderfer, R.D., B.E. Rieman, **L.J. Bledsoe** and S. Vigg. 1990. Management implications of a model of predation by a resident fish on juvenile salmonids migrating through a Columbia River reservoir. N. Amer. J. Fish. Mgmt. 10(3):290-304.

Bledsoe, L. J. 1977. Linear and non-linear approaches for ecosystem dynamic modeling, p. 283-298, In: B. C. Patten (ed.), Systems Analysis and Simulation in Ecology, Vol. 4., Academic Press, New York.

Bledsoe, L.J. 1996. A food web model for study of ecotoxicological effects- Draft for review. Tech. Rep., Univ. California - Davis, Dept. Civil & Env. Engr., Davis CA 95606. (Available from the author, ljbledsoe@ucdavis.edu)

Bledsoe, L. J., and B. W. Megrey. 1989. Chaos and pseudo-periodicity in the dynamics of a bioenergetic food web model. Am. Fish. Soc. Symp. 6: 121-137.

Chung, F. I., M. C. Archer and J. J. DeVeries. 1989. Network flow alogorithm applied to California aqueduct simulation. Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers, 115:131-147.

Chung, F. I. and O. Helweg. 1985. Modeling the California Water Project. Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers, 111:82-97.
Erickson, A.W., **L.J. Bledsoe** and B. Hanson. 1989. Bootstrap correction for diurnal activity cycle in census data for Antarctic seals. Marine Mammal Science 5(1): 29-56.

Chung, F. I. and L. Roig. 1989. Uses of mathematical models for the Sacramento-San Joaquin Delta. Specialty conference. American Society of Civil Engineers, Water Resources and Management, Proceedings of the 16th Annual Conference, pages 164-167, Sacramento, CA.

P. Hutton, N. Mahadevan and **F. Chung**. 1996. Simulating transport of trihalomethane precursors in the San Francisco Bay-Delta. North American Water and Environmental Congress 1996, American Society of Civil Engineers. Accepted for publication.

Lehman, P. W. 1992. Environmental factors associated with long-term changes in chlorophyll concentration in the Sacramento-San Joaquin Delta and Suisun Bay, California. Estuaries 15: 335-348.

Lehman, P. W. 1996. Changes in chlorophyll a concentration and phytoplankton community

composition with water-year type in the upper San Francisco Bay Estuary, p. 351-374. In J. T. Hollibaugh (ed.) San Francisco Bay: The Ecosystem. Pac. Div. Amer. Assoc. Adv. Sci., San Francisco, CA 94118.

Lehman, P. W. 1996. Water quality conditions in the Sacramento-San Joaquin Delta, 1970-1993. Environmental Services Office, Department of Water Resources, 3251 S Street, Sacramento, CA 95818. 102 p.

Lehman, P. W., and R. W. Smith. 1991. Environmental factors associated with phytoplankton succession for the Sacramento-San Joaquin Delta and Suisun Bay estuary, California. Estuarine, Coastal and Shelf Science 32: 105-128.

Orlob, G. T., A. E. Bale, **H. L. Rajbhandari** and M. Malagoli, 1991. Modeling Effects of Tidal Barrier Closure of Venice Lagoon. Water Science and Technology 24(6), 149-155.

Orlob, G. T., A. E. Bale, M. Malagoli and **H. L. Rajbhandari.** Computer Graphics for assessment of Eutrophication, Venice Lagoon: A Case Study, Proceedings of the NATO Advanced Research Workshop on Computer Aided Support System for Water Resources, Research and Management held in Ericeira, Portugal, September 1990.

Rajbhandari, H. L., and G. T. Orlob, 1991. A Water Quality Model for the San Diego River Estuary Live Stream Discharge Study, Report to ERC Environmental and Energy Services Company. Department of Civil Engineering, Univ. of California, Davis, 68 p.

Rajbhandari, H. L., and G. T. Orlob, 1990. Evaluation/Development of Water Quality Models for Waste Load Allocation in Estuarine Environments, Report to Regional Water Quality Control Board, San Francisco. Department of Civil Engineering, UC Davis, 79 p.

Rajbhandari, H. L., G. T. Orlob and **F. I. Chung**, 1996. Simulation of Dissolved Oxygen in Sacramento - San Joaquin Delta. Proceedings of North American Water and Environment Congress, ASCE, ed. C. T. Bathala.

Van Nieuwenhuyse, E. E. 1984. Relationships between suspended sediment, turbidity and light penetration in the Susitna River Basin, Alaska. Tech. Memorandum, Harza-Ebasco Susitna Joint Venture, Anchorage. 49 pp.

Van Nieuwenhuyse, E. E. 1985. Primary and secondary production in the middle Susitna River, Alaska. Technical Memorandum submitted to Harza-Ebasco Susitna Joint Venture, Anchorage. Arctic Environmental Information and Data Center (AEIDC), University of Alaska, Anchorage. 72 pp.

Van Nieuwenhuyse, E. E., and J. R. Jones. 1996. Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. Can. J. Fish. Aquat. Sci. 53: 99-105.

VI. Compliance with Standard Terms and Conditions

The applicants have reviewed and will comply with CALFED's standard terms and conditions as presented in Appendix D of CALFED's Request for Proposals. The non-Discrimination compliance form is attached.

Figure 1. Estim d Budget

Phase	Project Task	Investigator	Direct Salary and Benefits	Service Contracts	Overhead Labor	Material and Acquisition Contracts	Misc and other Direct Costs	Total Cost
I	Task 1. Develop model specifications and project management	Rajbhandari Bledsoe S.B. Assistant Lehman	0 0 0 10000	5000 10000 12000	5000 1000 1200 10000			
I	Task 2. DSM2-Qual model refinement	Rajbhandari Bledsoe		15000 10000	15000 1000			
I	Task 3. Parameterization of food web model	Rajbhandari Bledsoe S. B. Assistant		5000 15250 12000	5000 1525 1200		0 3000 0 0	
Subtotal			10000	84250	40925		3000	138,175
II	Task 4. Integrate water quality and food web models	Rajbhandari Bledsoe S. B. Assistant Van Nieuwenhuyser		18000 20000 24000 12000	18000 2000 2400		0 3000 0 0	
II	Task 5. Comparison of model results	Rajbhandari Bledsoe S. B. Assistant Lehman	15000	7000 15250 12000	7000 1525 1200 15000			
Subtotal			15000	108250	47125		3000	173,375
III	Task 6. Upload model to WWW, conduct workshop	Rajbhandari Bledsoe S. B. Assistant		13000 15250 12000	13000 1525 1200		0 3000 0	
III	Task 7. Prepare final report and administration	Rajbhandari Bledsoe S. B. assistant Van Nieuwenyuse Lehman	5000	13000 20000 12000 12000	13000 2000 1200 0 5000			
Subtotal			5000	97250	36925		3000	142,175
Total cost			**30000**	**289750**	**124975**		**9000**	**453,725**

Figure 2.	Schedule			
Phase	Project Task	Year 1	Year 2	Year 3
I	Task 1. Develop model specifications and project management			
I	Task 2. DSM2-Qual model refinement and prepare progres report			
I	Task 3. Development of food web model and prepare progress report			
II	Task 4. Inegrate water quality and food web models			
II	Task 5. Comparison of model results and prepare progress report			
III	Task 6. Upload model to WWW, conduct workshop			
III	Task 7. Prepare final report			

Item 8

NONDISCRIMINATION COMPLIANCE STATEMENT

COMPANY NAME
DEPARTMENT OF WATER RESOURCES

The company named above (hereinafter referred to as "prospective contractor") hereby certifies, unles specifically exempted, compliance with Government Code Section 12990 (a-f) and California Code o Regulations, Title 2, Division 4, Chapter 5 in matters relating to reporting requirements and th development, implementation and maintenance of a Nondiscrimination Program. Prospective contracto agrees not to unlawfully discriminate, harass or allow harassment against any employee or applicant fo employment because of sex, race, color, ancestry, religious creed, national origin, disability (includin HIV and AIDS), medical condition (cancer), age, marital status, denial of family and medical care leav and denial of pregnancy disability leave.

CERTIFICATION

I, the official named below, hereby swear that I am duly authorized to legally bind the prospectiv contractor to the above described certification. I am fully aware that this certification, executed on th date and in the county below, is made under penalty of perjury under the laws of the State of Californi

OFFICIAL'S NAME

DATE EXECUTED | EXECUTED IN THE COUNTY OF

PROSPECTIVE CONTRACTOR'S SIGNATURE

PROSPECTIVE CONTRACTOR'S TITLE

PROSPECTIVE CONTRACTOR'S LEGAL BUSINESS NAME
CALIFORNIA DEPARTMENT OF WATER RESOURCES

I —0 0 5 4 1 3

I-005413