The Transport And Dispersion Of Rafting Vegetation In The Sacramento−San Joaquin Delta

submitted to Science Program 2006

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lead investigators:
Stacey, Mark

Project Information And Executive Summary

The Transport And Dispersion Of Rafting Vegetation In The Sacramento−San Joaquin Delta

This is proposal #0053 for the Science Program 2006 solicitation.

Frequently asked questions and answers for this PSP are now available.

The submission deadline for this proposal has passed. Proposals may not be changed.

Instructions

Please complete the Project Information and Executive Summary Form prior to proceeding to the other forms contained on this website and required to be completed as part of your PSP application submittal. Information provided on this form will automatically support subsequent forms to be completed as part of the Science PSP submission process. Information provided on this form will appear in the Contacts and Project Staff, Task and Budget Summary, and Conflict of Interest forms.

Proposal Title: **The transport and dispersion of rafting vegetation in the Sacramento−San Joaquin Delta**

This field is limited to 255 characters. All proposal titles must be entered in title case. No abbreviations or acronyms will be accepted.

Applicant Information

Applicant Organization Name: **Berkeley, California University of**

Please provide the name of the organization submitting the application as follows: Davis, California University of; Fish and Game, California Department of; California Waterfowl Association, etc.

Applicant Organization Type:
public institution of higher education

eligibility

Below, please provide contact information for the representative of the applicant organization who is authorized to enter into a contractual agreement with the State of California and who has overall responsibility for the operation, management, and reporting requirements of the applicant organization. (This should be the same individual who signs the signature page.)

Salutation: **Ms.**
First Name: **Jyl**
Last Name: **Baldwin**
Street Address: **2150 Shattuck Ave. Room 313**
City: **Berkeley**
State or Province: **CA.**
Zip Code or Mailing Code: **94704−5940**
Telephone: **510/642−8117**
E−mail Address: **jbaldwin@berkeley.edu**

Below, please provide contact information for the primary point of contact for the implementation of the proposal. This person should be the same individual who is serving as the project Lead Investigator/Project Director.

Salutation: **Dr.**
First Name: **Mark**
Last Name: **Stacey**
Telephone: **510−642−6776**
E−mail Address: **mstacey@berkeley.edu**

Proposal Information

Total Amount Requested: $200,975

The figure represented above is provided by the total amount requested on your completed Task and Budget Summary Form. The applicant must ensure the amount indicated above is correct and equal to the total amount requested in the budget document uploaded via the Budget and Justification Form for this project.

Select one primary and up to three secondary topic areas that best apply to this proposal:

Aquatic Invasive (Exotic) Species (Primary)

Select up to five keywords to describe this project.

− ***agriculture***
− ***agricultural economics***
− ***agricultural engineering***
− ***agronomy***
− ***agro−ecology***
− ***benthic invertebrates***
− ***benthos***
− ***biochemistry***
− ***biological indicators***
− ***birds***
− ***channels and sloughs***
− ***climate change***
− ***conservation or agricultural easements***
− ***conservation program management***
− ***database management***
− ***ecotoxicology***
− ***economics***
− ***engineering***
− ***erosion control***
− ***environmental education***
− ***evapotranspiration***
− ***fish biology***
− delta smelt
− salmon and steelhead
− other species
− otoliths
− tagging
− ***fish management and facilities***
− ***flooded islands***
− ***floodplains and bypasses***
− ***forestry***
− ***genetics***
− ***geochemistry***
− ***geographic information systems (GIS)***
− ***geology***
− ***geomorphology***
− ***groundwater***
− ***human health***
X ***hydrodynamics***
− ***hydrology***
− ***insects***
− ***integrated pest management***
− ***integrated resource planning***
X ***invasive species / non−native species / exotic species***
− ***irrigation systems***
− ***land use laws and regulations***
− ***land use management***
− ***land use planning and policy***
− ***levees***
− ***mammals***
− ***microbiology / bacteriology***
− conceptual
− quantitative
− ***oceanography***
− ***performance measures***
− ***phytoplankton***

− *plants*
− terrestrial
X aquatic
X wetland
− *remote sensing / imaging*
− *reptiles*
− *reservoirs and lakes*
− *restoration*
− *riparian zone*
− *rivers and streams*
− *sediment*
− *soil science*
− *statistics*
− *subsidence*
− *sustainable agriculture*
− *trophic dynamics and food webs*
X *water operations (diversions, pumps, intakes, exports, barriers, gates, etc.)*
− *water quality*
− other
− temperature
− contaminants
− nutrients, organic carbon, and oxygen depleting substances
− salinity
− sediment and turbidity
− *water supply*
− *watershed assessment*
− *watershed management*
− *wetlands*
− *zooplankton*

Provide the geographic coordinates that best describe the center point of your project. (Note: If your project has more than one site, provide a center point that best captures the central location.)

Example:	Latitude:	38.575; must be between 30 and 45
	Longitude:	−121.488; must be between −120 and −130

Help for finding a geographic location.

Latitude: **38.051335**
Longitude: **−121.56774**

Provide the number miles radius from the center point provided above, to demonstrate the radius of the entire project.
20

Provide a description of the physical location of your project. Describe the area using information such as water bodies, river miles and road intersections.

Locations throughout the Delta, including Empire Cut, Middle and Old Rivers

Successful applicants are responsible for complying with all applicable laws and regulations for their projects, including the National Environmental Policy Action (NEPA) and the California Environmental Quality Act (CEQA). Projects funded through this PSP that tier off the CALFED Programmatic EIS/EIR must incorporate applicable mitigation strategies described in the CALFED Programmatic Record of Decision to avoid or minimize the project's adverse environmental impacts. Applicants are encouraged to review the Programmatic EIS/EIR and incorporate the applicable mitigation strategies from Appendix A of these documents for their projects.

If you anticipate your project will require compliance of this nature (ie applications for permits, other environmental documentation), provide below a list of these items, as well as the status of those applications or processes, if applicable. If you believe your project will not require these regulatory actions, please provide one or two lines of text outlining why your proposed project will not be subject to these processes. Further guidance is available in The Guide to Regulatory Compliance for Implementing CALFED Activities.

Not applicable

Is this proposal an application for next phase funding of an ongoing project funded by CALFED Science Program?
X No. **−** Yes.

If yes, identify the ongoing project:

Project Title:
CALFED Contract Management Organization:
Amount Funded:
Date Awarded:
Lead Organization:
Project Number:

Have primary staff and/or subcontractors of the project team (those persons listed on the Contacts and Project Staff form) received funding from CALFED for a project *not* listed above?
X No. **−** Yes.

If yes, list the projects below: (only list up to the five most recent projects)

Project Title:
CALFED Contract Management Organization:
Amount Funded:
Date Awarded:
Lead Organization:
Project Number:

Project Title:
CALFED Contract Management Organization:
Amount Funded:
Date Awarded:
Lead Organization:
Project Number:

Project Title:
CALFED Contract Management Organization:
Amount Funded:
Date Awarded:
Lead Organization:
Project Number:

Project Title:
CALFED Contract Management Organization:
Amount Funded:
Date Awarded:
Lead Organization:
Project Number:

Project Title:
CALFED Contract Management Organization:
Amount Funded:
Date Awarded:
Lead Organization:
Project Number:

Has the Lead Investigator, the applicant organization, or other primary staff or subcontractors of your project team ever submitted a proposal for this effort or a similar effort to any CALFED PSP?
− No. **X** Yes.

If yes, list the submission below: (only list up to the five most recent projects)

Project Title: **Hydrodynamics and Sediment Transport in a Shoal−Channel Estuary: The cycling of sediments in San Pablo Bay**
CALFED Program: **Science Program**
Date of PSP: **2004**

Project Title:

CALFED Program:
Date of PSP:

Project Title:
CALFED Program:
Date of PSP:

Project Title:
CALFED Program:
Date of PSP:

Project Title:
CALFED Program:
Date of PSP:

Note: Additional information on this or prior applications submitted −− or proposals funded −− may be required of applicants.

List people you feel are qualified to serve as scientific and/or technical reviewers for this proposal and are not associated with your organization or CALFED.

Full Name	Organization	Telephone	E−Mail	Expertise

Provide additional comments, information, etc. here:

Executive Summary

Provide a brief but complete summary description of the proposed project; its geographic location; project objective; project type, approach to implement the proposal; expected outcomes; and adaptive management approach and relationship to the Science Program goals. The Executive Summary should be a concise, informative, stand−alone description of the proposed project and be no longer than one page in length. Please note, this information will be made public on our website shortly after the closing date of this PSP.

The research we are proposing here is focused on developing a thorough, mechanistic understanding of how rafting vegetation, such as hyacinths or egeria, is transported in the Sacramento−San Joaquin Delta. Our approach is to examine in detail the forces that act on rafts of vegetation, and the resulting raft accelerations, to establish a predictive model of raft pathlines. Our model development will be built around a series of field experiments that include measurements of raft movement using GPS−logging drifters integrated into rafts, tidal and wind−forcing using a boat mounted current profiler and an anemometer, and direct estimation of the water−induced shear stress using a point velocity meter incorporated into the actual rafts. These field observations will be used to critically evaluate a numerical model of both channel (tidal) flows and resulting raft movement.

Our initial development will include a highly−resolved channel flow model, which will explicitly capture more lateral variability, including low velocity side "pockets", than is typically resolved with Delta−scale hydrodynamic models. Initially, this will allow us to carefully evaluate the quality of our raft−tracking calculations. Once the approach is established to be accurate, however, these high−resolution flows will be used to numerically calculate the effective advection and dispersion of rafts in the Delta channel under consideration. This analysis will be focused on parameterizing the effects on raft transport of structures and processes that are unresolved in typical Delta hydrodynamics models. An example of a process that is likely to be important to parameterize is the trapping and retention of rafts along the perimeter of channels due to off−axis wind forcing, and the resulting along−channel dispersion of rafts. In order to examine the effective advection and dispersion of rafts in Delta channels, we propose to pursue this combination of field and numerical studies of raft transport in locations of increasing complexity: first in idealized, straight channels, then in a natural, sinuous channel and a channel junction, and finally throughout the entire Delta.

Our research is strongly motivated by the desire to provide a predictive model of dispersion in the Delta for floating objects that respond to both wind and tidal forcing. Immediate applications involve the movement of hyacinth rafts and egeria to evaluate potential management strategies. Important future applications are likely to include consideration of other biological invasions, due to the potential for rafts to provide a transport pathway, and analysis of the movement of accidental or intentional releases of floating material in the Delta.

Contacts And Project Staff

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INSTRUCTIONS

Use this form to provide titles, affiliations, qualifications, and descrptions of roles of the primary and secondary project staff. Include any consultants, subcontractors and/or vendors. The Lead Investigator or Project Director, as identified in the Project Information and Executive Summary Form, is required to upload a PDF version of their resume. To complete the qualification field of this form, please provide a bulleted list of relevant project/field experience and any publications/reports that support your participation in the proposed project.

Information provided on this form will automatically support subsequent forms to be completed as part of the Science Program PSP submission process. Please note tht information you enter in this form will appear in the Task and Budget Summary and Conflict of Interest forms.

Information on subcontractor services must be provided even if the specific service provider has not yet been selected. If the specific subcontractor has not been identified or selected, please list TBD (to be determined) in the last name field and the anticipated service type in the title field (example: Fish Biologist).

Please provide this information before continuing to the Tasks and Deliverables Form.

Applicant

Berkeley, California University of
Ms. Jyl Baldwin
2150 Shattuck Ave. Room 313
Berkeley CA. 94704−5940
510/642−8117
jbaldwin@berkeley.edu

Lead Investigator/Project Director

Salutation: **Dr.**
Last Name: **Stacey**
First Name: **Mark**
Title: **Associate Professor**
Organization: **University of California, Berkeley**
Responsibilities: **Lead scientist, advising on and involvement with all aspects of research and reporting**
Resume:

You have already uploaded a PDF file for this question. Review the file to verify that appears correctly.

Mailing Address: **665 Davis Hall, MC: 1710**
City: **Berkeley**
State: **CA**
Zip: **94720−1710**
Telephone: **510−642−6776**
E−Mail: **mstacey@berkeley.edu**

Conflict Of Interest

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Instructions

To assist Science Program staff in managing potential conflicts of interest as part of the review and selection process, we are requesting applicants to provide information on who will directly benefit if your proposal is funded. Please provide the names of individuals who fall in the following categories and are not listed in the Personnel Form:

- Persons listed in the proposal, who wrote the proposal, will be performing the tasks listed in the proposal, or who will benefit financially if the proposal is funded; and/or
- Subcontractors listed in the proposal, who will perform tasks listed in the proposal, or will benefit financially if the proposal is funded.

Applicant
Submittor
Lead Investigator/Project Director
Primary Staff
Secondary Staff
Subcontractor

Provide the list of names and organizations of all individuals not listed in the proposal who helped with proposal development along with any comments.

Last Name	First Name	Organization	Role

Task And Budget Summary

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Instructions

Use the table below to delineate the tasks needed to carry out your proposal. Tasks in this form should support the narrative description of your project in your proposal document and the informa tion provided in your detailed budget spreadsheet. Each task and subtask must have a number, title, timeline, list of personnel or subcontractors providing services, and associated budget figure.

When creating subtasks, ensure that each activity is counted only once. Please note, the initial task of your table (Task 1) must present all project management/administrative activities supporting your overall proposal.

For proposals involving multiple agencies or organizations (including subcontractors), the table must clearly state the tasks and subtasks performed by each entity.

Task #	Task Title	Start Month	End Month	Personnel Involved	Description	Task Budget
1	Transport and Dispersion Observations	1	24	Stacey, Mark	Field-based observation of vegetation raft movement and transport, including analysis of force balance.	71,702
2	Development of Predictive Model	1	30	Stacey, Mark	Formulation and development of predictive, mechanistic model for the movement and dispersion of vegetation rafts. Calibration and verification using field observations from task 1.	86,385
3	Evaluation and Extensions	25	36	Stacey, Mark	Application of the modeling tool developed in task 2 to consideration of Delta-scale transport of rafting vegetation, including consideration of management strategies and responses.	42,888

total budget=$200,975

Detailed Budget Upload And Justification

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Using the budget provided via this link as a guide, please complete a budget for your proposal in the software of your choice (e.g. Excel). This document must be in a format and software that can be converted to PDF prior to uploading on the web system.

It is incumbant upon the applicant to fully explain/justify the significant costs represented in the attached budget. This information can be provided either in a text document and uploaded below, or included in your proposal text in a clearly defined budget justification section. If it is not abundantly clear to reviewers what project costs are commensurate with which efforts and benefits, the proposal may receive a poor review and denied funding.

Costs for each task described in the Task and Budget Summary Form and each staff or subcontractor described on the Contacts and Project Staff Form, must be included in your budget. The budget for Task One should represent project management activities, including but not limited to cost verification, environmental compliance, data handling, report preparation, project oversight, and public outreach. The total amount of your budget must equal the total amount represented on your Task and Budget Summary Form and the total budget amount represented on your Project Information and Executive Summary Form.

In a separate text document to be uploaded below, identify any cost share and other matching funds available to support your proposed project. If you identify cost share or matching funds, you must also describe them in the text of your proposal (see explanation of "cost share and other matching funds" in Section Two of the solicitation document).

CBDA may request additional information pertaining to the items, rates and justification of the information presented in your budget. Applications without completed budgets will not be considered for funding.

Uploading The Completed Budget Template

First, convert your completed Budget to a PDF file. Then, use the browse function to locate the PDF version of your document, select the document and click on the upload prompt below.

You have already uploaded this document. View it to verify that it appears as you expect. You may replace it by uploading another document

Uploading The Completed Budget Justification

First, convert your completed Justification text to a PDF file. Then, use the browse function to locate the PDF version of your document, select the document and click on the upload prompt below.

You have already uploaded this document. View it to verify that it appears as you expect. You may replace it by uploading another document

Uploading The Description Of Cost Share/Matching Funds

First, convert your completed Description of Cost Share/Matching Funds text file to a PDF file. Then, use the browse function to locate the PDF version of your document, select the document and click on the upload prompt below.

You have already uploaded this document. View it to verify that it appears as you expect. You may replace it by uploading another document

Schedule Of Deliverables

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Use the table below to delineate the key deliverables and the time necessary to complete them (in months from the date the project's grant agreement is executed). Each Science Program 2006 PSP grant recipient must provide the required minimum deliverables for each project. The required minimum deliverables for each funded proposal are as follows:

- Semi−annual report(s)
- Final Report
- One page project summary for public audience at beginning of project
- One page project summary for public audience upon project completion
- Project closure summary report or copy of draft manuscript
- Presentation at CALFED Science Conference
- Presentations at other events at request of CALFED Science Program staff
- Copy of all published material resulting from the grant

Deliverable	Description	Delivered By: # (In Months From Project Start Date)
Public Summary	One page public summary	1
Semi−annual report 1	semi−annual report, approx.5−10 pages	6
Semi−annual report 2	semi−annual report, approx.5−10 pages	12
Semi−annual report 3	semi−annual report, approx.5−10 pages	18
Semi−annual report 4	semi−annual report, approx.5−10 pages	24
Semi−annual report 5	semi−annual report, approx.5−10 pages	30
Final Report	final report, approx 10−15 pages	36
Public Summary	One page public summary	36

If you are unable to provide a Schedule of Deliverables as outlined above, please provide your justification of non−compliance in the text box provided below. The Science Program reserves the right to determine a proposal non−eligible based on an applicants inability to provide the materials requested above.

Letters Of Support Form

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Letters Of Support

Should you wish to provide letters of support for your proposed project, you must do so through use of this web form. Letters of support will be provided to independent, panel and public reviewers for reference as part of the overall review process. It is not mandatory to provide letters of support. Failure to do so will in no way affect the review or final determination of your application.

Submission Of These Materials.

To submit Letters of Support, you must do so as .PDF files. To upload these materials, use the browse function to locate the appropriate .PDF version of the documents, select the documents and click on the upload prompt below.

Please ensure your PDF file contains all letters you would like to submit. Individual files (or letters) will not be accepted by the system. The system is designed to receive one single file. Submittal of these documents are not mandatory for your application to be considered under the 2006 Science Program PSP. Failure to submit letters does not impact your ability to compile your proposal along with the supporting forms required for final submission and consideration under the Science Program 2006 PSP.

Letters Of Support	*Please upload a PDF version of your letters of support. To upload a document, use the "Browse" button to select the PDF file containing the document.*

The Transport and Dispersion of Rafting Vegetation in the Sacramento-San Joaquin Delta

1. Introduction and Motivation

San Francisco Bay and Delta is the most heavily biologically invaded site on the Pacific Coast, with more than 175 exotic species having established themselves (Cohen 2005). Previous invasive species have included benthic filter feeders (corbula amurensis), shellfish (Asian mitten crabs), and plant species (hyacinths, egeria). Economic impacts of these invasions are beginning to be seen throughout the Delta. Mitten crabs affect levee stability, seasonally developing egeria beds making large portions of the Delta unnavigable and hyacinth rafts block marinas, and may even potentially affect operations.

In this proposal, we examine the dynamics that determine the movement of rafts of vegetation and the associated dispersion of species. While this research effort has an immediate application to the prediction of dispersal of hyacinth rafts and egeria propagules, the capability to predict vegetation raft dispersal will be a useful tool in responding to future invasions, particularly because rafts of vegetation are known to be important transport mechanisms for many marine species (Aliani and Molcard 2003; Worcester 1994; Horvath and Lamberti 1997).

1.1 Dispersal of Marine Species

The dispersal of seeds and pollen from marine species is determined by the time the particles remain in suspension and the ambient circulation during that period (Ruckelshaus 1996). At the same time, however, rafts of vegetation (or, in the case of dead plant material, "wracks"), can provide an important mode of transport and dispersal (Minchinton 2006; Aliani and Molcard 2003). In a study of larval dispersion in Tomales Bay, for example, Worcester (1994) found that adult sea squirts were effectively transported more than 200 times further when secured to rafts of eelgrass than their planktonic larvae were. The importance of rafts to the transport and dispersal of other species may be even more pronounced when the transport is into new domains, such as in the case of zebra mussels entering new riverine habitats (Horvath and Lamberti 1997).

The distinction between planktonic transport and raft transport raises the important issue of scale in the analysis of dispersion of marine species (Kinlan et al. 2005). Pauchard and Shea (2006) argue for three scales at which dispersion should be analyzed: global long distance, regional long distance and short distance. Global long distance dispersal is strongly dominated by human-induced transport and has been increasing through the years as human travel patterns and global commerce have developed. Regional long distance dispersal is also largely human influenced, but is tied to specific "landscape corridors" (Pauchard and Shea 2006) such as rivers and roads. Finally, short distance dispersal is dominated by the local environment, with dispersion set by natural transport processes.

Applying this structure to invasions of San Francisco Bay and Delta, we can easily point to several examples of “global long distance” dispersion events (corbula amurensis, mitten crab). In an energetic environment like San Francisco Bay and Delta, however, the distinction between regional and short distance dispersal becomes blurred. Because of the extensive tidal dispersion in both the Bay and Delta, introduced species are rapidly dispersed by natural processes within the system, even to the regional (Bay-Delta) scale. In the analysis of the Delta, physical processes and the geometry of the Delta do, in fact, allow us to separate local and regional dispersion processes. This idea will be developed further in the next section, but we can think of “local” dispersion processes as those processes that act within a single Delta component: a channel or a junction; “regional” dispersion represents the aggregate effect of these components on the overall dispersal in the Delta. To summarize, we will consider “global long distance” dispersion events to be external perturbations to the ecosystem through the abrupt introduction of a new species, which are expected to be of relatively low frequency, but will have a disproportionate impact on the ecosystem (Trakhtenbrot et al. 2005). Our analysis will focus on “local” and “regional” dispersion within the Sacramento-San Joaquin Delta, emphasizing how rafts of vegetation are transported and dispersed by environmental processes.

Analysis and modeling of marine species dispersal has been pursued using statistical approaches based on genetic analysis (Kinlan and Gaines 2003), analysis of human behavior (Leung et al. 2006) and analysis of environmental transport (Aliani and Molcard 2003; Siegel et al. 2003; Anderson et al. 2005). The use of a mechanistic approach to predict the movement of marine propagules, however, has not been extensively applied, largely due to the fact that these processes act at large scales for oceanic dispersion, which creates great uncertainty in the validity of the results. When we consider dispersion at the scale of the Bay and Delta, however, environmental transport processes are dominant at a scale at which we can reasonably expect to pursue mechanistic modeling of how propagules respond to environmental forcing. There has been significant work looking at how planktonic species disperse in the Bay and Delta (and other similar systems), the work we propose here is distinct from these efforts due to our emphasis on rafts of vegetation, which respond to both wind and tidal forcing.

Leung et al. (2006) suggest that their analysis of boater behavior can be used to identify at-risk locations of invasion, which can then be targeted by management responses. We would anticipate a similar outcome, where predictive modeling of how vegetation rafts are likely to disperse can be used to both manage the rafting species themselves, as well as other species that may be using the rafts as a transport mechanism.

1.2 Dispersion in the Delta

While our focus in this proposal is how rafts of vegetation disperse in the Delta, we begin this technical discussion with a more fundamental description of scalar dispersion in the Delta. The Sacramento-San Joaquin Delta consists of a network of channels that are forced tidally from San Francisco Bay and by freshwater flow from the Sacramento River, the San Joaquin River, and other, smaller, “east side” rivers (Figure 1). Recent work on the hydrodynamics of the Delta (Burau 2006, e.g.) emphasizes the important role of Delta geometry, which consists of a network of intersecting channels, in establishing dispersion throughout the system. As an overview, the phasing of tidal flows in intersecting channels creates a highly dispersive environment, dominated by “tidal trapping”.

For the purposes of this proposal, we will define tidal trapping to be the dispersive process that is created by phase differences in channels in the Delta. In the original discussion of tidal trapping by Okubo (1973, also presented in Fischer et al. 1979), the analysis focused on the phase difference between a shallow side embayment and an estuary. Briefly, flow in the shallow regions of an estuary respond more quickly with respect to the reversing tidal pressure gradient and are therefore phase shifted relative to the deeper portions. The result is that, for example, a shallow side embayment may begin to ebb while the adjoining channel is still flooding (and vice versa). Such a phase difference between different portions of an estuary can lead to extensive along-estuary dispersion, where scalars enter the shallows early in a flood tide, are retained in the shallows for a period, but are then released back into the main channel late in the flood tide. Note that in the absence of side embayments or trapping regions, and neglecting density effects, the estuarine channel is characterized by oscillatory (tidal) shear dispersion (Fischer et al. 1979).

Applying this construct to the Delta, we expect tidal dispersion to be created by the interactions of the flows in the various channels throughout the Delta. It is useful to separate the Delta into regions that are expected to be dominated by tidal dispersion and those that are dominated instead by (oscillatory) shear dispersion. Defining a “segment” as the length of a channel between junctions, if the tidal excursion is longer than the length of a segment then tidal trapping – and the details of the phasing of flows in the channels that intersect – would be expected to dominate dispersion. Alternatively, if a segment is long compared to the tidal excursion, then shear dispersion within the segment would be dominant, except in those portions within a tidal excursion of a junction. When analyzing Delta dispersion, then, it is important to characterize both in-channel conditions (which would determine the along-channel shear dispersion) and the phasing of flows in junctions and their spatial structure, which is likely to be a dominant contributor to tidal trapping.

Taken as a whole, the interaction of tidal motions with the geometry of the Delta results in scalar dispersion throughout the Delta. The details of this dispersion are determined by the nature, extent and timing of the connection between Delta channels at the tidal timescale. To be clear, the net dispersion is not a result of time-averaged flows or average conditions; instead, it is the aggregate effect of the instantaneous flow fields (or streamlines) within channels and in channel junctions. The work we propose here, however, is not focused on how dissolved scalars disperse in the Delta, but rather how floating rafts of vegetation disperse. In the next section, we discuss how the dynamics of raft transport are likely to differ from those for traditional scalar analysis.

1.3 Dispersion of Rafting Vegetation in the Delta

As outlined in the previous section, tidal processes determine, to great extent, dispersion in the Delta. This dispersion is likely to be dominated by the interaction of channels in junctions, where Lagrangian transport asymmetries (i.e., a water parcel follows a different streamline on flood and ebb tides) are established. The extension of this analysis to consideration of floating rafts of vegetation requires consideration of how the rafts are coupled to wind forcing, as these rafts are accelerated by stresses on both their upper and lower surfaces (Figure 2). A conceptual model of raft transport is developed below (section 4), along with a complete analytic framework; here we note that the important description of raft transport is not water streamlines, nor is it necessarily the orientation of the wind. Instead, we require a knowledge of raft "pathlines" (Kundu 1996, e.g.), or the Lagrangian trajectory of floating rafts of vegetation. Developing the technical capability to predictively model these flow paths is the emphasis of the work that we propose here. An additional complexity is added to this analysis due to the potential for rafts to become "trapped" as they interact with the lateral edges of channels. The interaction of tidal and wind forcing will likely lead rafts to have an off-axis component to their motion, which will bring them to the perimeter of channels where they may be retained until the winds and/or tides change direction. We will refer to this dispersion mechanism as wind/tidal trapping, as it is analogous to the tidal trapping mechanism introduced by Okubo (1973).

Note that previous studies of dispersal of rafting vegetation or other marine species have not necessarily relied on a mechanistic approach (with the exception of some airborne dispersal analysis, Jongejans and Schippers 1999, e.g.). This is likely due to the scales under consideration, which have generally been quite large, and the associated uncertainties in transport at those scales. In the case of the Delta, however, the scale is appropriate for a mechanistic study of marine vegetation dispersal. The system is strongly dominated by tidal advection, and our ability to mechanistically model the tidal dynamics opens the possibility of layering a mechanistic vegetation model onto a hydrodynamic model. While our initial efforts will be focused on the movement of rafting vegetation, such as hyacinths and, to some extent, egeria, in the Delta, we anticipate moving into consideration of larger-scale systems, such as San Francisco Bay or open coastal regions, as well as the dispersal of other marine species.

2. Overview of Proposed Activity

The goal of the research proposed here is to develop a mechanistic model with the ability to predict the transport and dispersion of rafting vegetation in the Sacramento-San Joaquin Delta. Our intention is to be able effectively predict the movement of rafts of vegetation at the scale of channels, sub-regions of the Delta, and the Delta as a whole. The transport model we develop will driven by both wind-forcing and tidal-forcing, and will be run in conjunction with a hydrodynamic model of the Delta. The approach that we are taking, however, is to develop the vegetation transport model in a general sense, so that it may be coupled with any hydrodynamic model, with the coupling based only on the depth-averaged tidal velocities. In order to provide a general raft transport model, we will be pursuing an analysis of raft movement on both the tidal timescale and the subtidal (or residual) timescale.

An immediate application of this activity involves the management of hyacinth in the Delta, and potentially Egeria. Longer term, a predictive model of the dispersion of vegetation rafts will be valuable in responding to other invasions, including both rafting vegetation itself and marine fauna that may use rafts for long distance dispersal (Worcester 1994; Horvath and Lamberti 1997).

The pursuit of this model development raises the following general research questions:

(1) *What is the force balance that governs the movement of rafts of vegetation? What is the relative importance of winds and tides?*
(2) *How do the rafts interact with the edges of Delta channels? What are the implications for long-term transport and dispersion?*
(3) *What is the best description of raft transport and dispersion at the scale of a single Delta channel, channel junctions and for the Delta as a whole?*

In later sections, we will develop specific research questions that together will allow us to address these larger-scale questions, but these questions provide the motivation for the detailed development in later sections.

3. Relevance to CALFED Activity

In the PSP, a specific need is raised to understand the dynamics of biological invasions, including specific emphases on how exotic species affect Delta operations, management options for invasive species to date, and a consideration of the key factors that govern establishment of invasive species. The work we propose addresses a fundamental aspect of how both existing exotic species (particularly hyacinths and egeria) future invaders are will disperse and take hold in the Delta.

Through the development of a mechanistic and predictive model of vegetation raft transport, we will be able to analyze likely pathways for future invasions, as well as evaluate management options for rafting vegetation that has already taken hold in the Delta. By emphasizing a robust and flexible modeling approach, our analysis tools can be incorporated with a variety Delta hydrodynamic modeling approach for use in management decision making.

4. Conceptual Model and Analytic Framework

The background discussion presented thus far motivates the research that we describe in section 5. Before developing the details of our research approach, however, we present in this section a conceptual model for raft movement at three scales: within individual channels, in Delta subregions (channel junctions and loops), and the Delta as a whole. Following this conceptual description of how rafts are expected to move throughout the Delta, we present (section 4.2) a more complete analytic framework that will be used to shape the observational program we propose.

4.1 Conceptual Model

The Delta is a strongly tidally-forced environment, with energetic tidal flows exist in channels throughout the system and most, if not all, analysis of dispersion in the Delta has focused on the influence of tidal flows and the resulting tidal dispersion. In the case of rafting vegetation, however, interaction with wind forcing is pronounced, and the basic development of dispersion based on the tides is not sufficient to predict how floating vegetation rafts will be distributed in the system.

As is sketched in figure (2), rafts of vegetation will respond to both tidal velocities and winds. The shear stresses these flows create on the rafts define the net forcing, and the resulting acceleration of the vegetation. The implications for transport at the three scales we consider are discussed in the following subsections.

4.1.1 In-Channel Transport

Delta channels are, in general, narrow channels with the tidal flows dominantly along-channel. While there may be exceptions in regions of strong curvature (REF), for this conceptual development, we will assume that tidal flows will act to accelerate the vegetation along the channel axes.

The actual movement of the rafts, however, will be strongly influenced by the local winds. If the winds are aligned with the channel, then the accelerations induced by the wind will either reinforce those of the tides or oppose them – in either case, the movement of the vegetation will be primarily along the axis of the channel. When the wind and tides are aligned (say on a flooding tide in a east-west channel), the advection is accentuated over what a purely tidal model would predict. The reverse is true when the wind and tides are in opposition (on an ebbing tide in a east-west channel, e.g.), with advection reduced from the purely tidal model. The result is a net transport in the downwind direction, which is expected, but the magnitude of this transport is set by the tidally-averaged movement that results from the force balance acting within the tidal cycle.

If the wind is oriented across channel, however, the along-axis acceleration due to the tides will have a cross-channel component superposed on it due to the wind. In this case, the vegetation will be moved off-axis, and is likely to be trapped along the edges of the channel. While the rafts are trapped along the channel perimeter, the along-channel advection is greatly reduced – beyond what would be predicted by hydrodynamic models due to the strong coupling of the rafts to local topography (side pockets, etc.). Once trapped along the channel perimeter, rafts are likely to remain along the edge until a change in the wind forcing, a reversal in the tides, or large changes in free surface position due to the tides. The retention of these rafts for periods of time in regions outside the dominant advective region in the channel creates pronounced dispersion in the along-channel direction, which is similar to tidal trapping, but is a result of both tidal and wind forcing.

This discussion allows us to separate our description of in-channel vegetation transport into two limiting cases based on the orientation of the wind relative to the tides. First, in channels were the winds and tides are aligned (likely to be the east-west channels due to the dominant wind direction), movement of the vegetation is expected to be strongly advective, with limited dispersion. When the wind forcing is in the cross-channel direction, the channel will have much more limited advection, and will be strongly dispersive due to pronounced tidal/wind trapping along the channel edges.

4.1.2 Channel Junctions

One of the critical components of dispersion at the Delta (and regional) scale is how streamlines move through junctions. The development of tidal dispersion in the Delta is strongly tied to the phasing of flows in various Delta channels, and junctions provide the connection between these channels. As a result, models of scalar transport in the Delta must either (1) accurately resolve the tidal timescale movement in the junctions; or (2) effectively capture the longer timescale effects of these exchanges.

Subtle phase shifts between flows in intersecting channels can lead to extensive dispersion in the Delta, depending on how streamlines respond. Consideration of how streamlines move through channel junctions motivated a recent USGS study of the interaction of the Sacramento River with Georgiana Slough that used drifter releases to define Lagrangian transport and exchange.

Because they are coupled to both the wind forcing and the tidally-induced flows in the Delta, rafts of vegetation will not necessarily move with the streamlines that define water (and associated scalar) movement. As a result, previous analysis of dispersion of salt and other scalars does not extend to describe how vegetation propagules are likely to disperse in the Delta, particularly in view of the importance of specific channel junctions. Instead of following tidal flow streamlines through the intersections, raft pathlines will have a bias in the downwind direction that will increase eastward advection (assuming the wind is dominantly west-to-east) and, potentially, decrease dispersion due to the fact that rafts will persistently be biased to move downwind.

4.1.3 Delta scale

Due to differences in the transport processes for rafts and dissolved scalars, both within channels and in channel junctions, dispersion at the scale of the Delta as whole is likely to be fundamentally different from previous considerations. For dissolved scalars, the channels are largely advective with limited dispersive effects; the effective dispersion is set primarily by the channel junctions. Our conceptual model for the dispersion of rafts of vegetation is nearly the opposite: channels are likely to be strongly dispersive due to the effects of tidal/wind trapping of rafts along the edges of the channels and junctions are expected to be less dispersive due to a persistent transport bias in the downwind direction.

When we consider dispersion at the scale of the entire Delta, the implications of this shift in our conceptual picture of dispersion are uncertain. Clearly, we do not expect floating rafts of vegetation to disperse similarly to salt (or other dissolved scalars), but we need to examine how the combination of trapping (by both wind and tidal forcing) and advection (also by both winds and tides) results in Delta-scale transport and dispersion. Our goal is to establish the fundamental force balance acting on rafts of vegetation so that we may develop a predictive model of raft transport.

4.2 Analytic Details

To develop a mechanistic and predictive approach to predicting vegetation transport, we start from a consideration of the fundamental force balance that will describe the acceleration of a single raft. As is outlined in Figure 2, the raft experiences a shear stress on both its upper and lower interfaces, forced by the winds and the tides, respectively. We denote the depth-averaged water velocity as I, the wind speed at a measured height (to be determined) as u_a, and the velocity of the vegetation as u_v. Using drag coefficients to relate these mean velocities to the shear stresses, we arrive at the following expression for the net force acting on the vegetation:

$$F_{net} = \rho_w C_d^w \left|u_w - u_v\right|\left(u_w - u_v\right)A_v + \rho_a C_d^a \left|u_a - u_v\right|\left(u_a - u_v\right)A_v \qquad (1)$$

where C_d^w and C_d^a are the drag coefficients for the water-vegetation and vegetation-air interfaces respectively, A_v is the surface area of the raft, and ρ_w and ρ_a are the densities of water and air, respectively.

Defining the mass of the vegetation to be M_v, we can define the acceleration of the raft to be:

$$\frac{\partial u_v}{\partial t} = \frac{A_v}{M_v}\left(\rho_w C_d^w \left|u_w - u_v\right|\left(u_w - u_v\right) + \rho_a C_d^a \left|u_a - u_v\right|\left(u_a - u_v\right)\right) \qquad (2)$$

This equation provides us with a complete description of the acceleration and resulting unsteady raft velocity (u_v), but must be solved numerically due to the use of absolute values to ensure the proper sign on each of the stresses.

It is instructive to consider the steady-state solution of equation (2), for which we require that the two stress terms (air and water shear stresses) are equal and opposite. In this case, we no longer need to take the absolute value of the velocity difference, and we find:

$$\rho_w C_d^w \left(u_w - u_v\right)^2 = \rho_a C_d^a \left(u_a - u_v\right)^2 \qquad (3)$$

The solution to this equation for u_v leads to:

$$u_v = \frac{1}{1+\gamma}\left(u_a + \gamma u_w\right) \qquad (4)$$

where

$$\gamma = \sqrt{\frac{\rho_w C_d^w}{\rho_a C_d^a}} \qquad (5)$$

We note that in equation (4) if the water and air velocities are equal, the equation reduces to $u_v = u_a = u_w$, which would be required in steady state. In general, the velocity of the rafts of vegetation will reach a steady state velocity that is intermediate between the air and water velocities, with a weighting that depends on the ratio of the air and water drag coefficients.

To begin consideration of the net transport in a tidal channel, we can consider the case where u_w is sinusoidal, but the steady-state balance holds at any given time. Because the steady state solution in equation (4) is linear in the tidal water velocity, the net transport of vegetation will be determined by the residual tidal velocity and the mean wind velocity. That is, the tidally variable forcing will not enter into the net (or residual) advection. This result depends, however, on several important assumptions. First of all, the steady state solution is assumed to hold throughout the tidal cycle; lags in the response of the raft to changes in tidal forcing may lead to changes in the net transport. Secondly, the wind forcing is assumed to be constant. If the wind orientation or magnitude changes in time, it will lead to variations in how the tidal flow field is sampled by the raft, potentially altering the net transport. Third, the drag coefficients for both the air and water interfaces are assumed to be constant in time. If the drag coefficient depends in any way on the vegetation-air or vegetation-water velocity difference, the averaging over a tidal period would not hold due to the non-linear nature of the resulting solution. Finally, this result requires that the channel under consideration be homogeneous. If the channel orientation or cross-section changes along the tidal raft pathline, or if the raft encounters a channel junction within a tidal cycle, tidal averaging will not result in a zero mean.

Nonetheless, the equations presented here for both the time variable (equation 2) and steady state (equation 4) description of raft velocity provide an analytic basis for the field experiments described in the next section.

5. Approach

The primary goal of this research is to develop a mechanistic understanding of how vegetation rafts disperse in the Delta. To achieve this, we propose to undertake a series of focused field experiments to examine how hyacinth rafts move in response to various wind and tidal conditions, as well as how the local geometry may affect net transport. The conceptual model described in the previous section motivates the choices for study sites and timing, while the analysis in section 4.2 provides a framework within which we can understand the detailed analysis.

5.1 Methods: Field Experiments and Numerical Studies

We propose to directly examine the force balance presented in section 4.2 using a detailed, focused field study of the response of hyacinth rafts to wind and tidal forcing. The instrumentation is summarized in Figure (3) will consist of a set of GPS-logging drifters that we will incorporate into the hyacinth rafts themselves in order to provide a detailed, quantitative measure of how the raft velocities vary over the tidal and diurnal period. On two of the rafts, we will also include an ADV to measure stresses on the underside. Finally, a boat-mounted ADCP and anemometer provide direct measure of the forcing. Referring to equation (2), we will therefore have direct measures of u_v, u_w and

u_a. In order to estimate C_d^w, we will use the turbulent stresses measured by the ADV as a direct measure of the shear stress on the vegetation-water interface, from which we can define the drag coefficient as the ratio of the shear stress (per water density) to the depth-averaged velocity squared (Kim et al. 2000; Voulgaris and Trowbridge 1998; Talke and Stacey 2003). Following the experiment, we will take samples of the raft to estimate M_v, leaving us with C_d^a as the single unknown to be numerically evaluated in equation (2, or equation 4 if the raft velocity appears relatively steady). Each of these experiments will be of relatively short duration, on the order of a few hours, and will focus on the acceleration of the rafts by tidal and wind forcing and the retention of the rafts by trapping along the channel perimeter.

Our numerical model development will emphasize Lagrangian (particle-tracking) modeling, which will be based on the balance between tide-induced and wind-induced stresses. Using an explicit timestep (Ferziger and Peric 2001), equation (2) can be easily solved to calculate the movement of individual rafts based on prescribed depth-averaged water velocity and wind velocity. We propose to use a purely explicit approach for ease of implementation and incorporation into other modeling efforts, and because we don't expect the resulting stability constraints to be significant. If we find that the solution becomes numerically unstable, we will split the stress terms on the right hand side of equation (2) taking the element inside the absolute value as explicit, and the term inside parentheses as implicit. This splitting maintains a linear form for the implicit portion of the equation, and allows for a direct evaluation of the raft velocity (rather than an iterative solution for a non-linear equation).

The raft velocity equation will be solved in both horizontal dimensions along with a depth-averaged two-dimensional solution to the shallow water equations (Sanders and Katopodes 2000, Cheng et al. 1993). As the angle the wind makes with the channel increases, the wind stress will become less effective at driving along-channel advection of the rafts. Instead, wind forcing will lead to a lateral drift of the vegetation, which will cause changes in the along-channel advection indirectly, through a preferential sampling of near-shore (tidal) streamlines. An added complication here is the prospect for trapping of rafts along the channel edges. Our numerical development in this section will focus on a 2-dimensional representation of a tidal channel that includes lateral velocity variability, which will be forced through the inclusion of a lateral friction term. This channel flow structure is somewhat different from what usually results in Delta hydrodynamic modeling, since bottom friction is generally the only resisting stress. By layering a wind-induced lateral drift for the rafts onto this velocity structure, the rafts will sample the cross-sectional velocity structure with a bias on the downwind side of the channel. This will lead to a decrease in along-channel advection and may increase or decrease shear dispersion.

The result of this modeling effort will be an explicit evaluation of both along-channel and cross-channel movement of individual rafts. By tracking a large number of rafts numerically, our analysis will emphasize converting these individual-based transport pathlines, which will be validated by the associated field observations, into estimates of the net along-channel advection and dispersion for each of the Delta components outlined in the following subsections. This will allow us to parameterize the net advection and the effective dispersion of rafts so that we may include the effects of wind/tidal trapping and lateral velocity variability, even when the underlying hydrodynamic model doesn't permit explicit resolution of those processes due to either spatial or temporal averaging.

5.2 In-Channel Studies

In order to focus on the forces acting on the vegetation, and to minimize the complexity of the tidal flows, our first two field sites will be straight, uniform channels. The first will be oriented east-west to be aligned with the dominant wind direction, for which we expect to focus on Empire Cut (Figure 1), but may choose another east-west channel depending on the presence of temporary barriers at the eastern end of Empire Cut. In this nearly idealized channel flow, we will pursue the observational program described in section 5.1 (and in Figure 3) and couple it with a depth-averaged model of the hydrodynamics. Our emphasis in this analysis will be to define the effective drag coefficient for the air-vegetation interface, perhaps as a function of the air-vegetation velocity difference (if it appears to depend on this variable significantly). The specific questions we will focus on at this site are:

(1) What is the best parameterization of the air-vegetation drag coefficient?

(2) Does the mechanistic model developed in section 4.2 predict the movement of rafts of vegetation?

Our second idealized field site will examine how cross-channel winds create trapping along the channel perimeter, even for the case of a straight, uniform channel. Here we will choose a north-south channel (to be oriented across the dominant wind direction), which will likely be Fisherman's Cut (but could also be Three Mile Slough, Figure 1). In this channel, we can develop a deterministic, complete model of both the hydrodynamics and the response of the vegetation rafts to the hydrodynamics and the (cross-channel) winds. Our focus in this analysis will not be as much on the basic force balance, although we will continue to critically evaluate it, but rather on the dispersive effects of wind/tidal trapping. The specific question to be addressed here will be:

(3) What are the implications of cross-channel wind forcing on raft transport?

(4) What is the relative contribution of trapping of rafts along the perimeter of channels to along-channel dispersion of rafts?

Finally, we will choose one or two additional field sites to represent a more typical Delta channel to evaluate the advection and dispersion of rafts of vegetation along the Delta corridors. Candidate locations include Georgiana Slough, Old River and Potato Slough (Figure 1). In these channels, variation in the channel orientation along its length means that the limiting cases considered at our idealized sites (aligned winds and tides in Empire Cut; perpendicular winds and tides in Fisherman's Cut) will exist at various locations along the channel. The net effect of this complexity and variability on advection and dispersion of rafts will be the emphasis of our analysis in these channels. Using both the field observations and the two-dimensional numerical modeling approach, we will assess under what conditions and in which locations tidal/wind trapping is likely to be effective at retaining and dispersing vegetation rafts. It is our expectation that we will be able to identify likely "traps" based on the (local) orientation of the channel relative to the wind, the curvature of the channel, and length of channel with that orientation and curvature. Specifically, we will analyze:

> *(5) How does variation in channel orientation, curvature and cross-section effect transport and dispersion of vegetation rafts in the Delta?*

5.3 Channel Junctions

The connection between transport at the scale of individual channels and at the Delta scale depends critically on channel junctions and their implications for transport and dispersion. Subtle shifts in the phasing of flows in connecting channels, as well as uncertain lateral mixing and exchange in the junctions makes the dynamics of these points difficult to establish, even when considering dissolved constituents.

In the case of rafting vegetation, the strong coupling to wind forcing alters the dynamics in junctions, perhaps simplifying the analysis by biasing transport in the downwind direction. To evaluate the implications, we will examine in detail a few junctions that are representative of a range of Delta junctions. While the final choice of junctions for these experiments may be influenced by other research activity in the Delta (i.e., we will leverage other efforts in the Delta and coordinate when and where possible), two likely candidates are the junction of Three Mild Slough with the San Joaquin River (Figure 1) and the southern end of Fisherman's Cut, where it joins with False River (Figure 1).

The field experiments here will focus on how rafts navigate the junction, and will consist of repeated Lagrangian experiments as described in section 5.1. To be clear, we will release instrumented rafts of vegetation in one channel and track its flowpath through junction, then repeat the experiment at various phases of the tide. Our analysis here will be focused on:

> *(1) What determines which junctions are tidally-dominated vs. wind-dominated?*
> *(2) Can raft transport in junctions be reasonably simplified to be primarily in the downwind direction?*

5.4 Delta-Scale Analysis

Once we have confirmed the accuracy of our parameterization of raft movement given channel-averaged velocity and wind speed, we will perform a series of numerical experiments to evaluate how rafts of vegetation will disperse throughout the Delta. To pursue this analysis, we will integrate our vegetation transport model onto a Delta-scale hydrodynamic model, and include the effects of wind forcing, to examine the resulting dispersal of rafts of vegetation in the Delta. Our choice of hydrodynamic model likely be DSM2 (http://modeling.water.ca.gov/delta/models/dsm2/), because of its prominence in Delta applications, but we will also evaluate other options as the project goes along, particularly if new approaches begin to be more widely applied.

The resulting distribution of vegetation rafts, will be analyzed to assess transport at the scale of the Delta as a whole. Beyond just developing an understanding of how wind and tidal forcing manifest themselves in the dispersion of rafts, our analysis will be framed by several specific questions:

(1) *How do the channels and the junctions each contribute to raft dispersion at the Delta scale?*
(2) *What is the importance of wind/tidal trapping along the perimeter of channels to raft dispersion?*
(3) *Which regions of the Delta are most vulnerable to raft aggregation?*
(4) *Do the predicted distributions of rafts suggest any management strategies?*

The underlying hydrodynamic model, DSM2, also has a particle tracking capability (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/ptm/documentation.cfm). As we consider these four research questions, we will make comparisons between the particle trajectories predicted by this particle tracking model, which relies on only the tidal forcing, and those predicted by our raft model. This comparison will allow us to establish the importance of wind forcing to the overall transport of rafts (or other floating debris and objects) in the Delta.

6. Summary

The research we are proposing here is focused on developing a thorough, mechanistic understanding of how rafting vegetation, such as hyacinths or egeria, is transported in the Sacramento-San Joaquin Delta. Our approach is to examine in detail the forces that act on rafts of vegetation, and the resulting raft accelerations, to establish a predictive model of raft pathlines. Our model development will be built around a series of field experiments that include measurements of raft movement using GPS-logging drifters integrated into rafts, tidal and wind-forcing using a boat mounted current profiler and an anemometer, and direct estimation of the water-induced shear stress using a point velocity meter incorporated into the actual rafts. These field observations will be used to critically evaluate a numerical model of both channel (tidal) flows and resulting raft movement.

Our initial development will include a highly-resolved channel flow model, which will explicitly capture more lateral variability, including low velocity side "pockets", than is typically resolved with Delta-scale hydrodynamic models. Initially, this will allow us to carefully evaluate the quality of our raft-tracking calculations. Once the approach is established to be accurate, however, these high-resolution flows will be used to numerically calculate the effective advection and dispersion of rafts in the Delta channel under consideration. This analysis will be focused on parameterizing the effects on raft transport of structures and processes that are unresolved in typical Delta hydrodynamics models. An example of a process that is likely to be important to parameterize is the trapping and retention of rafts along the perimeter of channels due to off-axis wind forcing, and the resulting along-channel dispersion of rafts. In order to examine the effective advection and dispersion of rafts in Delta channels, we propose to pursue this combination of field and numerical studies of raft transport in locations of increasing complexity: first in idealized, straight channels, then in a natural, sinuous channel and a channel junction, and finally throughout the entire Delta.

Our research is strongly motivated by the desire to provide a predictive model of dispersion in the Delta for floating objects that respond to both wind and tidal forcing. Immediate applications involve the movement of hyacinth rafts and egeria to evaluate potential management strategies. Important future applications are likely to include consideration of other biological invasions, due to the potential for rafts to provide a transport pathway, and analysis of the movement of accidental or intentional releases of floating material in the Delta.

7. Qualifications

The PI's research program is broadly focused on transport and mixing in estuarine and coastal flows, and Stacey brings extensive experience in the Sacramento-San Joaquin Delta to this project. Perhaps most relevant has been experience with two previous CALFED funded projects (Selenium REF; Delta Hydrodynamics REF), which led to two Ph.D. student theses (Baek 2006; Sereno 2006). Much of the work of Sereno (2006) centered around the interaction between tidal- and wind-driven flows and submerged aquatic vegetation. In this analysis, the vegetation was fixed in place, and the stress at the flow-vegetation interface was measured and modeled (presented at CALFED Science Conference REF). More generally, Stacey's research activity broadly addresses mixing and transport in tidal systems, including consideration of the implications for long-term transport and dispersion in estuaries (Stacey et al. 1999, Stacey et al. 2001, Stacey and Ralston 2005).

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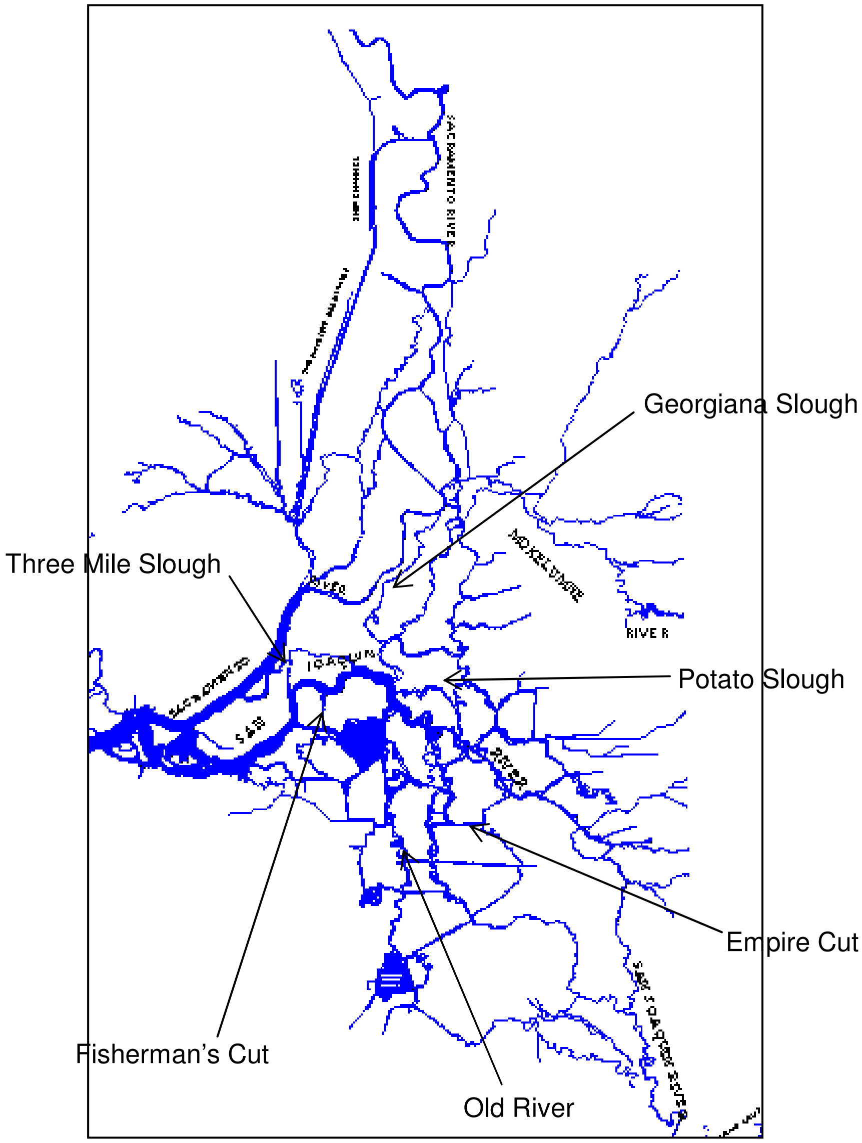

Figure 1: Delta map showing potential experiment locations. Empire Cut provides idealized east-west channel; Fisherman's cut an idealized north-south channel. Georgiana Slough, Potato Slough and Old River are candidates for analysis of "natural" channels. Analysis of transport in junctions may include the intersections of Three Mile Slough with the San Joaquin River and Fisherman's Cut with False River (south end of Fisherman's Cut).

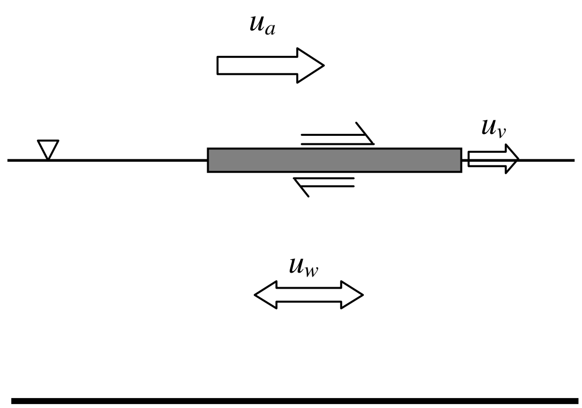

Figure 2: Schematic of raft forcing and definition of the velocity variables: u_w is the depth-averaged water velocity, u_a is the wind velocity at a specific height and u_v is the resulting velocity at which the vegetation raft moves.

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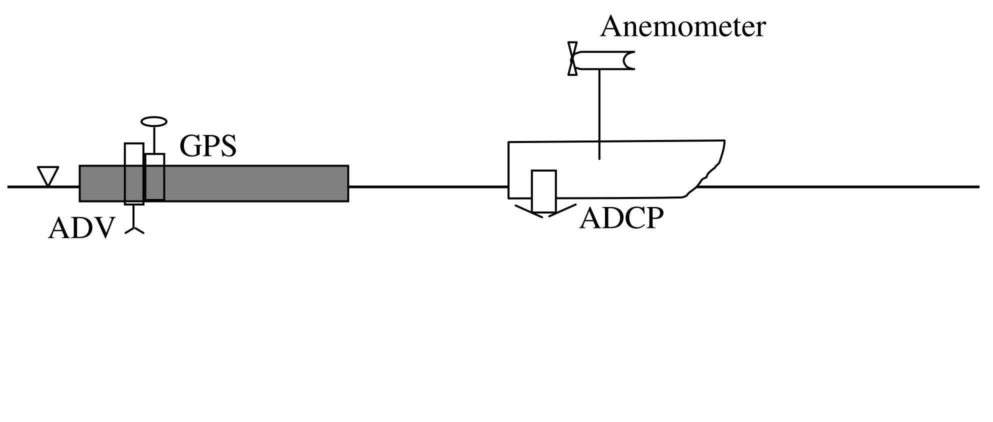

Figure 3: Field Experiment Schematic. An Acoustic Doppler velocimeter (ADV, Nortek Vector) and a GPS unit (internally logging "TAG", PME inc.) are incorporated into two rafts of vegetation (shaded block, only one raft shown). Boat-mounted measurements of water currents (acoustic Doppler current profiler, ADCP from RD Instruments) and wind velocity (anemometer) define the forcing of the raft by wind and tidal flows.

Mark T. Stacey

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EDUCATION:

1991	B.A.S.	*Stanford University* Dual degree in Physics and Political Science
1993	M.S.	*Civil Engineering, Stanford University* Environmental Fluid Mechanics and Hydrology
1996	Ph.D.	*Civil Engineering, Stanford University* Environmental Fluid Mechanics and Hydrology

ACADEMIC EXPERIENCE:

7/04-Present **Associate Professor**, Civil & Environmental Engineering, UC-Berkeley

7/99-6/04 **Assistant Professor**, Civil & Environmental Engineering, UC-Berkeley

1/99-6/99 **Assistant Research Engineer and Lecturer**, Civil and Environmental Engineering Department, UC-Berkeley

4/97-12/98 **Post-Doctoral Scholar**, Integrative Biology Dept., UC-Berkeley

PUBLICATIONS (COMPLETE LIST):

Fram, J.P., Martin, M.and **Stacey, M. T.** "Exchange between the coastal ocean and a semi-enclosed estuarine basin: Dispersive Fluxes," accepted for publication in *Journal of Physical Oceanography,* 2006.

Lucas, L.V., Sereno, D.M., **Stacey, M.T.**, Burau, J.R., Schraga, T.S., Lopez, C.B., Parchevsky, K.V., Parchevsky, V.P. "Intradaily variability in water quality in a shallow tidal lagoon: mechanisms and implications," accepted for publication in *Estuaries*, 2006.

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Monismith, S. G., Kimmerer, W., Burau, J. R. and **Stacey, M. T.**, "Structure and flow-induced variability of salt intrusion in San Francisco Bay," *J. Phys. Oceanogr.*, v.32(11), pp.3003-3019, 2002.

Stacey, M. T., Mead, K. S., and Koehl, M. A. R., "Molecule capture by olfactory antennules: Mantis shrimp," *J. Math. Biol*., v.44(1), pp. 1-30, 2002.

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Chan, N. Y., **Stacey, M. T.**, Smith, A. E., Ebi, K. L., and Wilson, T. F., "An empirical mechanistic framework for heat-related illnesses," *Climate Research*, v.16, pp.133-143, 2001.

Stacey, M.T., Cowen, E.A., Powell, T.M., Monismith, S.G., Koseff, J.R. & Dobbins, E., "Plume dispersion in a stratified, near-coastal flow: measurements and modeling," *Continental Shelf Research*, v.20, pp.637-663, 2000.

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Stacey, M.T., Monismith, S.G. & Burau, J.R., "Measurements of Reynolds stress profiles in tidal flows," *Journal of Geophysical Research*, v.104(C5), pp. 10933-10949, 1999.

SYNERGISTIC ACTIVITIES:

Professor Stacey's research on the fluid mechanics of estuaries and the coastal ocean, particularly San Francisco Bay and Delta, has led to a variety of related local, national and international activities that are illustrative of the broader impacts of his research activity:

(1) Served on several local advisory panels related to the dynamics of the San Francisco Bay-Delta system, including the committee to develop a conceptual model for Delta Regional Ecosystem Restoration Implementation Plan (DRERIP), the Suisun Marsh Levee Breach panel, and several CALFED review committees.
(2) Numerous invited lectures nationally and internationally, including the Gordon Research Conference on Coastal Ocean Circulation, CARTUM (EU-sponsored meeting in Wales), the Hudson River Foundation, and various universities.
(3) Developed courses at undergraduate and graduate level in the general field of environmental fluid mechanics, including estuarine and coastal transport and mixing and stratified fluid mechanics. Efforts led to being named a finalist for a University-wide Distinguished Teaching Award, being elected "Best Professor" by the civil engineering student group, and being named an "Unsung Hero" of the University.
(4) Elected Vice Chair for next GRC on coastal ocean circulation (assume chair position for the following meeting). Organizing committee for "Shelf Seas: Present understanding and future challenges" meeting in Wales, April 2006.

(5) Served on dozens of oral exam and thesis committees for students in Civil & Environmental Engineering, Earth & Planetary Science and Integrative Biology.

COLLABORATORS:

Vincenzo Casulli, University of Trento; Ralph Cheng, USGS; Wim Kimmerer, SF State; Jeffrey Koseff, Stanford University; Stephen Monismith, Stanford University; Tom Powell, UC Berkeley; Hal Batchelder, Oregon State; S. Geoffrey Schladow, UC Davis; Jim Hunt, UC Berkeley; John Dracup, UC Berkeley; Mimi Koehl, UC Berkeley; John Largier, Scripps Institute of Oceanography; Margaret McManus, UC Santa Cruz.

ADVISORS:

Ph.D.: Stephen G. Monismith, Stanford University.
Postdoctoral: Thomas M. Powell, University of California, Berkeley.

STUDENTS (COMPLETED):

David Ralston, Stefan Talke, Jon Fram, Seungjin Baek

STUDENTS (CURRENT):

Deanna Sereno, Maureen Martin, Mary Cousins, Lissa MacVean

POSTDOCTORAL RESEARCHERS:

Matt Brennan, Matt Reidenbach

PI: Mark Stacey

The Transport and Dispersion of Rafting Vegetation

Budget CalFed #0053

Dates 01/1/2007-12/31/2009

		Monthly Rate	# months			Yr 1	Yr 2	Yr 3	Summary
Personnel									
1	Prof. Stacey	10,056	1.0	Summer	100.00%	10,056	10,257	10,462	30,775
1	GSR V	3,543	9	Ac. Yr.	49.50%	15,784	16,100	16,422	48,306
		3,543	3	Summer	100.00%	10,629	10,842	11,058	32,529
	Total Personnel					**36,469**	**37,198**	**37,942**	**111,610**
Employee Benefits									
1	Principal Investigator				12.70%	1,277	1,303	1,329	3,908
1	Graduate Student Researcher, acad. Yr				1.30%	205	209	213	628
1	Graduate Student Researcher, summer				3.00%	319	325	332	976
	Total Employee Benefits					**1,801**	**1,837**	**1,874**	**5,512**
1	Tuition/fees per semester (resident)				4,656.00	9,312	10,243	11,268	30,823
0	Tuition/fee per semester (nonresident)					0	0	0	0
	Total Tuition/Fees					**9,312**	**10,243**	**11,268**	**30,823**
Equipment						0	0	0	0
						0	0	0	0
	Total Equipment					**0**	**0**	**0**	**0**
Travel									
	Domestic trips					1,000	1,000	1,000	3,000
	International trips					0	0	0	0
	Total Travel					**1,000**	**1,000**	**1,000**	**3,000**
Other Direct Costs									
	Materials and Supplies					7,000	5,000	1,000	13,000
	Publication Costs					0	1,000	2,000	3,000
	Consultant Services					0	0	0	0
	Computer Services						0	0	0
	Other					0	0	0	0
	Total Other Direct Costs					**7,000**	**6,000**	**3,000**	**16,000**
Subawa	With indirect cost					0	0	0	0
	Without indirect cost					0	0	0	0
	Total Subawards					**0**	**0**	**0**	**0**
	Total Direct Cost					**55,582**	**56,279**	**55,084**	**166,945**
	MTDC					**46,270**	**46,036**	**43,816**	**136,122**
	25% of MTDC (direct cost less tuition and fee					**11,568**	**11,509**	**10,954**	**34,031**
	TOTAL AMOUNT REQUESTED					**67,150**	**67,788**	**66,038**	**200,976**

PI: Mark Stacey

The Transport and Dispersion of Rafting Vegetation
Task 1
Agency CalFed
Budget Proposal #0053

		Monthly Rate	# months			1/1/07-12/31/07 Yr 1	1/1/07-12/31/08 Yr 2	1/1/07-12/31/09 Yr 3	Summary	Amount Per Hour	# of Hours Yr 1	Hours Yr 2	Hours Yr 3
Personnel													
1	Prof. Stacey	10,056	1.0	Summer	100.00%	10,056	0	0	10,056	$57.79	174.00	0.00	
1	GSR V	3,543	9	Ac. Yr.	49.50%	7,892	8,050	0	15,942	$20.36	387.59	20.77	
		3,543	3	Summer	100.00%	5,315	5,421	0	10,735	$20.36	261.00	20.77	
	Total Personnel					**23,263**	**13,471**	**0**	**36,733**	**Total Hours**	**822.59**	**41.54**	
Employee Benefits													
1	Principal Investigator				12.70%	1,277	0	0	1,277				
1	Graduate Student Researcher, acad. Yr				1.30%	103	105	0	207				
1	Graduate Student Researcher, summer				3.00%	159	163	0	322				
	Total Employee Benefits					**1,539**	**267**	**0**	**1,806**				
1	Tuition/fees per semester (resident)				4,656.00	4,656	5,122	0	9,778				
0	Tuition/fee per semester (nonresident)					0	0	0	0				
	Total Tuition/Fees					**4,656**	**5,122**	**0**	**9,778**				
Equipment						0	0	0	0				
						0	0	0	0				
	Total Equipment					**0**	**0**	**0**	**0**				
Travel													
	Domestic trips					1,000	1,000	0	2,000				
	International trips					0	0	0	0				
	Total Travel					**1,000**	**1,000**	**0**	**2,000**				
Other Direct Costs													
	Materials and Supplies					7,000	2,000	0	9,000				
	Publication Costs					0	0	0	0				
	Consultant Services					0	0	0	0				
	Computer Services						0	0	0				
	Other					0	0	0	0				
	Total Other Direct Costs					**7,000**	**2,000**	**0**	**9,000**				
Subawa	With indirect cost					0	0	0	0				
	Without indirect cost					0	0	0	0				
	Total Subawards					**0**	**0**	**0**	**0**				
	Total Direct Cost					**37,458**	**21,860**	**0**	**59,317**				
	MTDC					**32,802**	**16,738**	**0**	**49,540**				
	25% of MTDC (direct cost less tuition and fees					**8,200**	**4,184**	**0**	**12,385**				
	TOTAL AMOUNT REQUESTED					**45,658**	**26,044**	**0**	**71,702**				

PI: Mark Stacey

The Transport and Dispersion of Rafting Vegetation
Task 2
Agency CalFed
Budget Proposal #0053

		Monthly Rate	# months			1/1/07-12/31/07 Yr 1	1/1/07-12/31/08 Yr 2	1/1/07-12/31/09 Yr 3	Summary	Amount Per Hour	# of Hours Yr 1	Hours Yr 2	Hours Yr 3
Personnel													
1	Prof. Stacey	10,056	1.0	Summer	100.00%	0	10,257	0	10,257	$ 57.79	0.00	177.48	0.00
1	GSR V	3,543	9	Ac. Yr.	49.50%	7,892	8,050	8,211	24,153	$ 20.36	387.59	395.34	403.24
		3,543	3	Summer	100.00%	5,315	5,421	5,529	16,264	$ 20.36	261.00	266.22	271.54
	Total Personnel					**13,207**	**23,728**	**13,740**	**50,674**	**Total hours**	**648.59**	**839.04**	**674.79**
Employee Benefits													
1	Principal Investigator				12.70%	0	1,303	0	1,303				
1	Graduate Student Researcher, acad. Yr				1.30%	103	105	107	314				
1	Graduate Student Researcher, summer				3.00%	159	163	166	488				
	Total Employee Benefits					**262**	**1,570**	**273**	**2,105**				
1	Tuition/fees per semester (resident)				4,656.00	4,656	5,122	5,634	15,411				
0	Tuition/fee per semester (nonresident)					0	0	0	0				
	Total Tuition/Fees					**4,656**	**5,122**	**5,634**	**15,411**				
Equipment						0	0	0	0				
						0	0	0	0				
	Total Equipment					**0**	**0**	**0**	**0**				
Travel													
	Domestic trips					0	0	0	0				
	International trips					0	0	0	0				
	Total Travel					**0**	**0**	**0**	**0**				
Other Direct Costs													
	Materials and Supplies					0	3,000	0	3,000				
	Publication Costs					0	1,000	0	1,000				
	Consultant Services					0	0	0	0				
	Computer Services						0	0	0				
	Other					0	0	0	0				
	Total Other Direct Costs					**0**	**4,000**	**0**	**4,000**				
Subawa	With indirect cost					0	0	0	0				
	Without indirect cost					0	0	0	0				
	Total Subawards					**0**	**0**	**0**	**0**				
	Total Direct Cost					**18,125**	**34,419**	**19,646**	**72,190**				
	MTDC					**13,469**	**29,298**	**14,013**	**56,779**				
	25% of MTDC (direct cost less tuition and fees					**3,367**	**7,324**	**3,503**	**14,195**				
	TOTAL AMOUNT REQUESTED					**21,492**	**41,744**	**23,150**	**86,385**				

PI: Mark Stacey

The Transport and Dispersion of Rafting Vegetation

Task 3

Agency CalFed

Budget Proposal #0053

		Monthly Rate	# months			1/1/07-12/31/07 Yr 1	1/1/07-12/31/08 Yr 2	1/1/07-12/31/09 Yr 3	Summary
1	Prof. Stacey	10,056	1.0	Summer	100.00%	0	0	10,462	10,462
1	GSR V	3,543	9	Ac. Yr.	49.50%	0	0	8,211	8,211
		3,543	3	Summer	100.00%	0	0	5,529	5,529
	Total Personnel					**0**	**0**	**24,202**	**24,202**
Employee Benefits									
1	Principal Investigator				12.70%	0	0	1,329	1,329
1	Graduate Student Researcher, acad. Yr				1.30%	0	0	107	107
1	Graduate Student Researcher, summer				3.00%	0	0	166	166
	Total Employee Benefits					**0**	**0**	**1,601**	**1,601**
1	Tuition/fees per semester (resident)				4,656.00	0	0	5,634	5,634
0	Tuition/fee per semester (nonresident)					0	0	0	0
	Total Tuition/Fees					**0**	**0**	**5,634**	**5,634**
Equipment						0	0	0	0
						0	0	0	0
	Total Equipment					**0**	**0**	**0**	**0**
Travel									
	Domestic trips					0	0	1,000	1,000
	International trips					0	0	0	0
	Total Travel					**0**	**0**	**1,000**	**1,000**
Other Direct Costs									
	Materials and Supplies					0	0	1,000	1,000
	Publication Costs					0	0	2,000	2,000
	Consultant Services					0	0	0	0
	Computer Services						0	0	0
	Other					0	0	0	0
	Total Other Direct Costs					**0**	**0**	**3,000**	**3,000**
Subawa	With indirect cost					0	0	0	0
	Without indirect cost					0	0	0	0
	Total Subawards					**0**	**0**	**0**	**0**
	Total Direct Cost					**0**	**0**	**35,437**	**35,437**
	MTDC					**0**	**0**	**29,804**	**29,804**
	25% of MTDC (direct cost less tuition and fees					**0**	**0**	**7,451**	**7,451**
	TOTAL AMOUNT REQUESTED					**0**	**0**	**42,888**	**42,888**

Amount Per Hour		**# of Hours Yr 1**	**Hours Yr 2**	**Hours Yr 3**
$	57.79	0.00	0.00	181.03
$	20.36	0.00	0.00	403.24
$	20.36	0.00	0.00	271.54
Total Hours		**0.00**	**0.00**	**855.82**

Budget Justification

The primary budget expenses we request are salary and benefits for the personnel involved, including one month of summer salary support for the PI (Stacey) and stipend, tuition and fees for a graduate student researcher. The work described here will form the basis of the graduate student's Ph.D. research. Travel funds are requested in all three years. In years 1 and 2 these funds will be used to facilitate travel to the field site; in year 3, they will be committed to travel to a scientific conference. Materials and supplies expenses are requested in year 1 to develop the deployment platforms that will integrate the ADV and GPS units into the vegetation rafts and in year 2 for a computer and miscellaneous deployment expenses. This budget item also includes acquisition of a self-logging anemometer for use in the field experiments. In year 3, materials and supplies expenses will be used to facilitate publication and communication of our results. Finally, publication expenses are requested in years 2 and 3.

The research we propose here is highly leveraged by existing resources in the PI's lab. Four acoustic Doppler velocimeters and 10 GPS-logging drifters are available in the PI's lab for use in the proposed work, as are 2 acoustic Doppler current profilers.

These instruments will be available for use with the proposed research.
Further, a 10 foot whaler, will be used for the field activity.

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;ignature

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ailure to sign and submit this form will result in the application not being considered for inding. The individual submitting this proposal will receive e-mail confirmation as soon as this gnature page has been processed.

he individual signing below declares that:

- all representations in this proposal are truthful;
- the individual signing the form is authorized to submit the application on behalf of the applicant (if applicant is an entity or organization);
- the applicant has read and understood the conflict of interest and confidentiality discussion under the Confidentiality and Conflict of Interest Section in the main body of the PSP and waives any and all rights to privacy and confidentiality of the proposal on behalf of the applicant, to the extent provided in this PSP; and
- the applicant has read and understood all attachments of this PSP.

Proposal Title:	The transport and dispersion of rafting vegetation in the Sacramento-San Joaquin Delta
Proposal Number:	2006.01-0053
Applicant Organization:	Berkeley, California University of
Applicant Contact:	Ms. Jyl Baldwin

Applicant Signature [signature] **Date** 8-24-06

lelp is available: help@solicitation.calwater.ca.gov, +1 877 408-9310

Ve care about the data we collect. Please read our privacy policy.

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