A Calibration−Free Approach To Modeling Delta Flows And Transport

submitted to Science Program 2006

compiled 2006−11−09 17:44:06 PST

lead investigators:
Stacey, Mark
Bayen, Alexandre

Project Information And Executive Summary

A Calibration−Free Approach To Modeling Delta Flows And Transport

This is proposal #0042 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: **A Calibration−Free Approach to Modeling Delta Flows and Transport**

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: $390,869

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:

Environmental Water (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
X ***fish management and facilities***
− ***flooded islands***
− ***floodplains and bypasses***
− ***forestry***
− ***genetics***
− ***geochemistry***
− ***geographic information systems (GIS)***
− ***geology***
− ***geomorphology***
− ***groundwater***
− ***human health***
X ***hydrodynamics***
X ***hydrology***
− ***insects***
− ***integrated pest management***
− ***integrated resource planning***
− ***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
− aquatic
− 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: **38.168617**
Longitude: **−121.53624**

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.

Several locations in the Sacramento−San Joaquin Delta, including Georgiana Slough and Mildred Island

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
Jorg Imberger	**University of Western Australia Center for Water Research**	**+61 8 6488 3911**	**jimberger@cwr.uwa.edu.au**	**hydrodynamics**
Brett Sanders	**University of California, Irvine**	**(949) 824−4327**	**bsanders@uci.edu**	**modeling, quantitative**
Eric Feron	**Georgia Institute of Technology**	**404 894 3062**	**feron@gatech.edu**	**modeling, quantitative**

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.

In this research proposal, we describe work to develop and evaluate an integrated system for the prediction of Delta flows and transport in real−time that doesn't rely upon historical data sets for calibration and validation. The system consists of observational and computational components, along with real−time communication and coordination. The over−arching goal of the work is to allow for the prediction of Delta flows and transport at the timescale of days to weeks, even when there has been major changes to the Delta geometry (such as levee breaches).

The observational component of the work consists of a network of Lagrangian drifters that communicate to a base station in real−time to establish the instantaneous velocity field. The advantages of Lagrangian measurements are: (1) drifters can be rapidly and easily deployed in locations of interest, such as the position of outmigrating salmon, or adjacent to levee breaches; and (2) the Lagrangian velocity field is the important measure of net transport in a highly dispersive channel system like the Delta, where subtle phase differences between the various channels dominate the net transport and dispersion.

Computationally, we propose to develop an inverse approach to predicting Delta flows that does not rely on the specification of boundary conditions a priori, but rather estimates the necessary forcing based on observations in the interior of the domain. Our intention is to apply this method to Delta subregions in order to establish the net transport in particular locations of interest in the Delta. For most inverse modeling methods, flows would only be reasonably estimated during the period of observation, which would severely limit the applicability of the approach for management and operational decision making. Our formulation of the open boundary conditions, however, takes advantage

of the tidal dominance in the forcing and the inverse estimation of the boundary conditions focuses on defining the amplitude and phase of the important tidal harmonics. Combining these tidal parameters with a linear trend in the boundary conditions allows us to project both the boundary conditions and the resulting flows ahead of the observational period, perhaps to as long as several weeks or a month. The development of the inverse modeling approach will be based on two existing data sets: one collected in the vicinity of Mildred Island in September 2001, one collected at the intersection of the Sacramento River and Georgiana Slough in May 2004.

Finally, we propose an integrated experiment that incorporates both the drifter network and the inverse model calculations. We will choose a domain for this experiment that has existing instrumentation, given the current set of UVMs, we propose an experiment in the South Delta along Old and Middle Rivers, but we may adjust the location depending on other instrumentation in the Delta. This experiment will involve real−time data collection by the drifters, communication of that data with the base station, and the inverse estimation of boundary conditions leading to a projection forwards in time of flows in the local channels. Our goal here is to test the accuracy and reliability of a real−time, calibration−free approach to Delta flows, including a critical evaluation of the trade−offs between the veracity of our flow predictions and observational or computational expense. Finally, we will compare our ability to predict the local flow conditions to a traditional Delta−scale hydrodynamic model (most likely DSM2) to evaluate the potential for improved operational efficiency in the Delta.

Contacts And Project Staff

This is proposal #0042 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

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: **Involvement with and advising on research across all tasks; coordination 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**

All Other Personnel

Salutation: **Dr.**
Last Name: **Bayen**
First Name: **Alexandre**
Title: **Assistant Professor**
Organization: **University of California, Berkeley**
Position:

Co−PI
Responsibilities: **Advising on and involvement with all research tasks**
Qualifications:

See Resumes.pdf, submitted with the PI information.

List relevant project/field experience and publications/reports.

Conflict Of Interest

This is proposal #0042 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

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

This is proposal #0042 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

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	Inverse Model Development	1	24	Stacey, Mark Bayen, Alexandre	Development of inverse modeling approach to Delta flow and transport analysis. Emphasis is on utilization of existing data sets from the Sacramento River (at Georgiana Slough) and Mildred Island.	98,793
2	Drifter Network Development	1	18	Stacey, Mark Bayen, Alexandre	Development of real-time Lagrangian drifter network with communication capability within the fleet and between the drifters and a base station.	105,829
3	Integrated Realtime Experiment	19	30	Stacey, Mark Bayen, Alexandre	Deployment of drifter network (task 2) and integration with computational tools developed in task 1. Pursue realtime estimation and prediction of Delta flows and transport	107,470
4	Analysis and Evaluation	25	36	Stacey, Mark Bayen, Alexandre	All data and modeling results generated as part of tasks 1 and 3 will be analyzed in the context of operational strategies and efficiency for in-Delta facilities. Potential for real-time measurements, modeling, and response will be explored	78,777

total budget=$390,869

Detailed Budget Upload And Justification

This is proposal #0042 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.

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

This is proposal #0042 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.

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)
One page 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
One page 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

This is proposal #0042 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.

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.*

A Calibration-Free Approach to Modeling Delta Flows and Transport

1. Introduction and Motivation

The Sacramento-San Joaquin Delta is a critical component of the California water delivery system. High quality Sacramento River water enters the Delta from the north, but water for municipal consumption is largely extracted from the South Delta (Figure 1). The movement of this freshwater through the Delta, and its interaction with high salinity waters from San Francisco Bay and, in fact, from the San Joaquin River watershed are critical to establishing the quality of the water supply for a large fraction of California's population.

At the same time, predicting and managing flow and transport in the Delta are challenging due to the tidally-driven flows, the complex geometry of the system, and resulting high dispersion (Burau 2006). The inherent uncertainty in our understanding of how the system responds to and influences unanticipated events – such as levee failures, sudden changes in freshwater flows, or variable outmigration patterns – results in the system being operated conservatively, leading to potential inefficiencies in water distribution (Taugher 2005).

We propose here to develop a set of hardware and software tools that consists of a novel observational platform and an innovative modeling approach that will lead to both an improved ability to evaluate the state of Delta flow and transport in real time and a clearer understanding of the uncertainties in our predictions. Together, we anticipate a system that holds great potential to assist managers in responding to uncertain events at the short- to intermediate-timescales (on the order of days to weeks).

In this introductory section we provide additional background on Delta hydrodynamics, the approaches being pursued for modeling transport in the Delta, and the challenges that the system poses. Following this background discussion, we outline our specific research questions and their connection with CALFED's objectives. We then develop the details of our research approach.

1.1 Background on Delta Hydrodynamics

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). Focusing first on the tidal dynamics, a conceptual model has emerged (Burau 2006) that emphasizes the "looped" nature of the geometry. 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. In the absence of side embayments or trapping regions, and neglecting density effects, the estuarine channel is characterized by oscillatory shear dispersion.

In the Delta, tidal dispersion is created by the interactions of the flows in the various channels and subchannels. 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. Looking at Figure 1, we note that those segments that are likely to be more than 1 tidal excursion in length (based on a rough estimate of tidal velocity) are likely to be in the Northern Delta, and the majority of the Delta is likely to be dominated by tidal trapping. As a result, transport and dispersion in the Delta is exceptionally sensitive to subtle shifts in tidal phasing, and predictive models of net transport must accurately reflect the phasing of flows in each channel.

Taken as a whole, the interaction of tidal motions with the geometry of the Delta results in salt movement into the Delta. The extent of salt intrusion depends on freshwater flow, the effective dispersion coefficient for salt, and in-Delta operations. While freshwater flow and operations are generally well-defined (or selected), the effective dispersion coefficient is largely a calibration parameter, and is meant to capture the effects of tidal dispersion processes as outlined in this section.

1.2 Current Delta modeling and operations

Predictive modeling of the Sacramento-San Joaquin Delta is based on mechanistic analysis of the hydrodynamics at either the tidal or subtidal timescales. At the tidal timescale, hydrodynamic models of the Delta resolve the oscillatory flows in each Delta channel. Tidal trapping is explicitly resolved, but relies on accurate prediction of the phase differences in flows in the Delta channel network. Establishing the tidal phasing is usually based on calibration against historical data, and even there phasing is not an emphasis in the calibration. Even when resolving the full tidal timescale variability, the analysis of Delta conditions relies to great extent on consideration of subtidal timescale variability. With this approach, the influence of tidal dispersive processes is captured through the use of an integrated horizontal dispersion coefficient that reflects the integrated effect of subtle phase shifts in tidal velocity in intersecting channels. As such, the effective dispersion coefficient is a result of a calibration exercise against historical data sets.

In each case, the dependence on historical data sets to establish model veracity leads to a modeling system that is strongly tied to existing conditions. In the event of an abrupt change in the system, such as a levee breach or large adjustments in freshwater flow, the applicability of existing Delta models would be difficult, if not impossible, to establish. In the case of levee breaches or large changes in freshwater flow, the hydrodynamics of the Delta are likely to be characterized by subtle shifts in the relative phasing of tidal flows in the channels (Burau 2006, Sereno 2006). The net transport of scalars will depend on these phase shifts, and transport models will need to correctly predict these changes, for which models tied to historical data and current conditions will be poorly suited.

In the context of these modeling efforts, Delta facilities, including the delta cross-channel gate and the south Delta pumps, are operated to manage flows and transport at the Delta scale (in the case of managing salinity intrusion) and at the local scale (to prevent entrainment of out-migrating salmon smolt in the DCC). Uncertainties in the predictive capability of the current generation of Delta models, however, lead to conservative operational strategies, an example of which is outlined in the next section. While real-time modeling efforts are underway (http://modeling.water.ca.gov/delta/real-time/index.html), the approaches being pursued are based largely on mechanistic hydrodynamic models, and are therefore reliant upon calibration and validation against historical data sets.

1.3 Short and intermediate timescale responses to events

When uncertain and unanticipated events occur, managers are forced to make operational decisions to preserve water quality and secure the water supply in the South Delta. Because of uncertainties in our ability to predict transport and dispersion in the Delta at short and intermediate timescales, defined here as days to weeks, managers are forced to take a conservative approach, leading to potential inefficiencies in water distribution.

An example from June 2004 is the Jones Tract levee breach (location noted in Figure 1). In this instance, the levee failed during a period of only moderate flows, and was not associated with any storm or seismic event. Following the breach, a sediment plume was produced in the vicinity of the breach, and there were concerns about Bay-sourced saltwater moving into the Delta (Taugher 2005). The immediate management response in this case was to reduce exports in the South Delta by 80% (San Diego Union Tribune 2004), which served to both prevent entrainment of waters with high suspended sediments and decrease the likelihood of salinity intrusion into the Delta (Taugher 2005). Secondly, releases from upstream reservoirs were increased in order to offset the “gulp” of water created by the filling of Jones Tract with Delta waters. Finally, managers monitored Delta salinities to evaluate the consequences of both the breach and the response actions. After three days, it was determined that pumping could be resumed, but the three days of no pumping came at a cost of approximately $1 million/day.

This example illustrates the mismatch between current Delta modeling efforts and management of the system. There were no real-time modeling capabilities, and limited analysis of transport at the timescale of the management response to this event. The situation is not due to a failure in model development, but rather due to the type of models being pursued. Mechanistic hydrodynamic models that project the state of the system from some initial conditions require extensive calibration and the development and calibration of these models have largely focused on longer timescale dynamics.

The increasing availability of real-time data in the Delta, along with technological developments in sensors, communications, and modeling methods have created an opportunity to pursue a modeling and analysis system that is designed for these short and intermediate timescale events and responses. As we look ahead in the management of the Delta, we can say with certainty that we will face uncertain events. The nature, magnitude and extent of these events, however, are, by their nature, unknown. In the research we propose here, we begin the development of an integrated observational and modeling system that is designed to respond to uncertain events and allow management of the system at the timescale of hours, days and weeks to include a more complete technical evaluation than is available today.

2. Overview of Activity and Research Questions

Our proposed activity consists of two parallel development activities, one focused on an observational and communication system for rapidly deployable sensors and one focused on making use of the resulting observations in an evaluation and prediction of Delta flows and transport. The observational system will consist of a set of drifters that communicate both among themselves and with a base station in real time. The drifters will, initially, be outfitted with just a GPS sensor, which will provide real time measurements of Lagrangian (following a water mass) velocities for use in the modeling system. The platform we develop, however, will also be outfitted with salinity, temperature or optical backscatter (for suspended sediment) sensors to allow real time measurement of scalar concentrations. The choice of a Lagrangian system is based to some extent on the fact that more real time Eulerian (fixed) sensors are coming online in the Delta, but we also believe Lagrangian flow information may provide greater insights into the phasing between Delta channels and is likely to lead to better prediction of tidal dispersion in the Delta.

The modeling and analysis approach that we propose here consists of an “inverse” approach to hydrodynamic modeling, for which we do not depend on the specification of boundary conditions as in typical “forward” models (Cheng et al. 1993, e.g.). Instead, we use observations from the interior of our model domain (both existing Eulerian instruments in the Delta and our rapidly deployable drifters) to estimate tidal boundary conditions. The details of our modeling approach are outlined below (Section 4), but the overarching goal is to be able to project flows and transport in subsections of the Delta days or weeks into the future. These timescales are consistent with the timescales for management and operational decisions, and we believe that such a modeling platform could greatly improve the efficiency of Delta operations.

During the first year of our effort, the sensor platform development will be proceeding in parallel with the application of the inverse model to an existing data set from the intersection of the Sacramento River and Georgiana Slough (Burau, personal communication). This data set included both Eulerian and Lagrangian observations, and provides an excellent test case for the inverse approach that we are proposing. In the 2nd or 3rd year, we intend to perform an integrated experiment in the Central or South Delta (site choice discussed further below) that will involve both deployment of our drifters and real-time calculation and projection of the flow state using the inverse model. Together, these activities will let us pursue the following broad research questions:

1. *Under which conditions and in which locations can a calibration-free approach to predicting Delta flow and transport be applied effectively?*
2. *What is the tradeoff between the amount of data used for the estimation and accuracy in the resulting model?*
3. *What are the potential water savings (through increased operational efficiency) under various scenarios, including: (i) outmigrating salmon smolt; (ii) levee breach; (iii) unanticipated release in Delta waters.*

3. Relevance to CALFED goals

The goal of the Environmental Water research emphasis, as stated in the PSP, is to "effectively manage water projects in the Delta and upstream watershed to allocate water to protect and recover at risk fish species through both prescriptive standards and flexible, adaptive programs in a way that also provides reliable water supply and water quality." An example of these operations is the Delta Cross Channel gate, which, when closed, directs out migrating salmon smolt away from the Central Delta (retaining them in the Sacramento River). Closing the gate, however, also restricts the exchange of Sacramento River water into the central and south Delta, with negative implications for water supply and quality. This tradeoff, and others like it, requires that in-Delta facilities being used to provide environmental improvements be operated as efficiently as possible to provide the maximum benefit to water supply and quality without compromising environmental standards. Our efforts directly target these operational efforts by developing a methodology by which projections of local transport can be made at short timescales using easily deployed sensor technologies.

Beyond the specifically stated goal of protecting and recovering at-risk fish species, we believe that efficient operational responses to uncertain events, such as levee failures can, and should, be considered a component of managing the Delta water budget and the associated environmental impacts. If there are persistent inefficiencies in the operational response to events such as the recent Jones Tract breach, the water available to target at-risk species is reduced. Our research efforts are focused on improving overall operational efficiency in the Delta, which will have implications for both general habitat and fish population goals, as well as water supply and water quality goals.

4. Approach

In this section, we develop the details of our technical approach. As outlined briefly above, we are proposing to develop a real time observational system that can be rapidly deployed to locations of interest. At the same time, we will develop a real time, data-driven modeling framework, which, rather than being based on calibration by historical data sets, will use inverse methods to estimate boundary conditions and project flows and transport ahead on the timescale of days to weeks. The integration of these two efforts defines an approach to Delta modeling that is fundamentally different from existing approaches. Currently, Eulerian timeseries data are used in conjunction with mechanistic "forward" models of the Delta. This is an appropriate and effective method for forecasting the response of the system (with existing geometry) to long timescale events. In our approach, we use Lagrangian data (along with existing Eulerian measurements) with a calibration-free inverse approach to evaluating and predicting Delta flows and transport. Our emphasis is on developing the best possible estimate of transport at the timescale of days to weeks to aid in management and operational decision making.

This new approach to Delta modeling will hold a significant advantage over current approaches in its ability to analyze conditions at particular locations in the Delta, even in the event of large-scale changes to the Delta geometry. The timescales that we are focusing on will allow us to work towards flexible and dynamic operational decision making at tidal, daily, and weekly timescales, rather than relying on operational rules for these timescales. An immediate application of this analysis could involve operating the Delta Cross Channel gates (see below) in response to the presence and position of out-migrating salmon smolt. The computational tools we are developing can make use of any Lagrangian data; for now we are using GPS-logging drifters, but tagged fish or estimates of fish position and movement could also be incorporated.

In the subsections that follow, we outline the details of the research activity that we are proposing. Initially, we outline the details of the inverse modeling approach, then we describe the sensor network development. Finally, we briefly describe the nature of an integrated experiment in section 4.3.

4.1 Calibration-free, inverse modeling of existing data sets

Our goal in this initial development phase is to apply inverse techniques, which have been used for open ocean modeling (Bennett 1992) and channel control (Chen and Georges 1999; Sanders and Bradford 2002) to the Sacramento-San Joaquin Delta. The fundamental theories of inverse modeling have been developed in these other literatures, and we believe that applying these approaches to flow estimation in the Delta is a logical extension. In the oceanographic literature, open boundary condition estimation has been used to evaluate the influence of remote forcing (Bogden et al. 1996) or to adjust boundary conditions in a small scale model of a particular oceanographic feature (Gunson and Malanotte-Rizzoli 1996). As computational power has improved, however, small-scale coastal models have started to be more commonly coupled with larger scale regional or even global models to provide boundary condition information (e.g., Powell et al. 2006), which reduces or eliminates the need for inverse estimation of open boundary conditions. In the Delta, however, we are faced with the likely situation of having to estimate flows and transport with either (1) an unknown geometry for the system (in the case of levee breaches); or (2) uncertain forcing at the timescales of interest (in the case of sudden freshwater flows or out-migrating salmon). In these cases, we believe that inverse estimation of open boundary conditions provides the most appropriate method for estimating local flow conditions. The method forces any solution to be consistent with real-time observations, but also allow projection forward in time to provide predictive flows and transport over the timescales of a tidal cycle to days and perhaps weeks. These timescales are critical to the management of the Delta, and we believe that our proposed research holds great promise in the management of the Delta. In this section, we outline the details of the inverse modeling approach that we propose to pursue.

4.1.1 Adjoint Equations

Our development of the adjoint approach to boundary condition estimation will follow the development of Sanders and Katopodes (2000). In conservative form, the two-dimensional depth-averaged shallow water equations are (see, e.g. Sturm 2001):

$$\frac{\partial}{\partial t}(q_x)+\frac{\partial}{\partial x}\left(q_x^2/h\right)+\frac{\partial}{\partial y}\left(q_x q_y/h\right)=-\frac{\partial}{\partial x}\left(\frac{gh^2}{2}\right)+ghS_{0x}-ghS_{fx}$$

$$\frac{\partial}{\partial t}(q_y)+\frac{\partial}{\partial x}\left(q_x q_y/h\right)+\frac{\partial}{\partial y}\left(q_y^2/h\right)=-\frac{\partial}{\partial y}\left(\frac{gh^2}{2}\right)+ghS_{0y}-ghS_{fy} \qquad \text{(1a,b,c)}$$

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}(q_x)+\frac{\partial}{\partial y}(q_y)=0$$

where (q_x,q_y) are the depth-integrated flow in the (x,y) directions, h is the local depth, S_0 is the bed slope (S_{0x} in the x-direction, S_{0y} in the y) and S_f is the friction slope, which we will parameterize using a quadratic bottom friction with a drag coefficient as

$$S_{fx}=C_d\left(u^2+v^2\right)^{1/2}u/gh$$

$$S_{fy}=C_d\left(u^2+v^2\right)^{1/2}v/gh \qquad \text{(2a,b)}$$

By using a depth-averaged formulation, we are assuming that the water column is well-mixed, which is reasonable in most of the Delta, with the possible exception of deeper channels in the western Delta, the Stockton Deep Water Shipping Channel and some shallow water habitats (one example is discussed further below). Solution of these equations usually rest on the specification of initial conditions everywhere in the model domain and time variable boundary conditions at each open boundary. To develop a specific example, consider the channel network in Figure 3, which is the region of the Delta surrounding Mildred Island, and includes four open boundaries. In this subregion of the Delta, all four open boundaries are tidally driven, and flows in the interior respond to that boundary forcing. For traditional hydrodynamic modeling (Baek 2006, e.g.), surface elevation and velocity would need to be specified at all four boundaries as a function of time.

The goal of our inverse modeling effort is to generate the best estimate of the boundary conditions, given a set of observations in the interior of the domain (and possibly at some of the boundaries, depending on the region of interest). We define a cost function based on the mismatch between model and measured data as:

$$C_0 = \iiint \gamma_u (u_m - u_d)^2 f_u \, dxdydt \; + \iiint \gamma_v (v_m - v_d)^2 f_v \, dxdydt \; + \iiint \gamma_h (h_m - h_d)^2 f_h \, dxdydt \quad (3)$$

where u is velocity, h is depth, subscript m implies the modeled variable and d is the observed variable, γ is a weighting defined by the expected uncertainties in both the model and data and f is a mask that defines where observations are available for each variable. We now seek to define open boundary conditions that will minimize the model-data mismatch.

In order to reduce the complexity of the optimization problem, and to allow for projections forwards in time, we will assume that the time variability of the open boundary conditions is described by the superposition of tidal harmonics plus an offset and a linear trend. For the depth at the boundary, this can be written mathematically as:

$$h_b(t) = h_0 + h_L \frac{t}{T} + \sum_{k=1}^{N} h_k \sin(\omega_k t + \phi_k) \quad (4)$$

where h_0 is a constant offset, h_L is the coefficient that sets the magnitude of the linear trend and h_k, ϕ_k define the amplitude and phase for the k^{th} tidal harmonic (of frequency ω_k). The result is $2*N+2$ parameters to describe the time variability of depth at the boundary where N is the number of tidal harmonics included. A similar formulation will be made for the along-channel velocity component at the boundary and we will assume that the cross-channel velocity is zero at the boundary. The result is a total of $4*N+4$ parameters to describe each open boundary, which will be estimated using adjoint-based optimization. With this approach, we are not necessarily constrained to use this temporal decomposition during the period of observation. In order to extend our simulation beyond the observational period, however, we need to assume a temporal structure for the variation, see Figure 4. Our emphasis on tidal harmonics reflects the strong tidal forcing in the system, but the inclusion of a linear trend permits adjustment of the system to, for example, varying freshwater flow or changes in tidal prism due to levee breaches.

In order for the predicted flows to be physically acceptable, the shallow water equations (1a,b,c along with the definitions in 2a,b) must be applied as hard constraints on the optimization-based estimation of boundary conditions. While there are a variety of methods available for pursuing such a constrained optimization, we choose here to use the adjoint method, which provides a robust method for establishing how the cost function depends on the control parameters (in this case, the open boundary conditions). Also, the adjoint method is extremely general and enables the incorporation of arbitrary user-defined constraints in the given optimization problem. Using Lagrange multipliers to apply the governing equations as constraints leads to the adjoint equations (Sanders and Katopodes 2000):

$$\frac{\partial \lambda_x}{\partial \tau} - 2u\frac{\partial \lambda_x}{\partial x} - v\frac{\partial \lambda_y}{\partial x} - v\frac{\partial \lambda_x}{\partial y} - \frac{\partial \lambda_h}{\partial x} = g\frac{2u^2+v^2}{u\left(u^2+v^2\right)}S_{fx}\lambda_x + g\frac{u}{u^2+v^2}S_{fy}\lambda_y - \gamma_u\left(q_{xm}-q_{xd}\right)f_u$$

$$\frac{\partial \lambda_y}{\partial \tau} - u\frac{\partial \lambda_y}{\partial x} - u\frac{\partial \lambda_x}{\partial y} - 2v\frac{\partial \lambda_y}{\partial y} - \frac{\partial \lambda_h}{\partial y} = g\frac{v}{u^2+v^2}S_{fx}\lambda_x + g\frac{u^2+2v^2}{v\left(u^2+v^2\right)}S_{fy}\lambda_y - \gamma_v\left(q_{ym}-q_{yd}\right)f_v \qquad \text{(5a,b,c)}$$

$$\frac{\partial \lambda_h}{\partial \tau} + \left(u^2-gh\right)\frac{\partial \lambda_x}{\partial x} + uv\left(\frac{\partial \lambda_y}{\partial x} + \frac{\partial \lambda_x}{\partial y}\right) + \left(v^2-gh\right)\frac{\partial \lambda_y}{\partial y} = g\left(S_{0x} + \frac{7}{3}S_{fx}\right)\lambda_x + g\left(S_{0y} + \frac{7}{3}S_{fy}\right)\lambda_y + e_h$$

where λ_x, λ_y and λ_h are the three adjoint variables (associated with q_x, q_y and h), τ is a reversed time variable, $\tau = T_f - t$, the last terms in the first two equations represent the model error, with the variables as defined in (error equations) and $e_h = -\gamma_h\left(h_m - h_d\right)f_h$.

The solution method is to solve the "forward" equations (1a,b,c) from some initial time (T_0) to a final time (T_f), then use the resulting fields to solve the adjoint equations (5a,b,c) from T_f to T_0. The gradient of the cost function is then evaluated based on the results of both the forward and inverse integration. For example, the gradient of the cost with respect to the q_x boundary condition on an open boundary at $x = 0$ is:

$$\frac{\partial C}{\partial q_{xb}} = \iint_{x=0} (2u+v)\lambda_x \, dy\, dt \qquad (6)$$

with similar relationships for the gradients of the cost function with respect to the other flow boundary condition (q_y) and for the free surface position (h).

Based on these gradients, we can then use standard optimization techniques to perform an iterative estimation of the parameters. It may be possible for us to analytically define the Hessian of the cost function by taking the Jacobian of the gradient (one component of which is shown in equation 6). In this case, we can pursue a gradient descent algorithm that estimates the minimum of the cost function based on the local Hessian. As an alternative (or perhaps as a comparative study), we will apply the Broyden-Fletcher-Goldfarb-Shanno (Liu and Nocedal 1989; applied in Strub and Bayen 2006) method. This consists of the development of quasi-Newton methods in which the Hessian is approximated by a symmetric positive definite matrix. This avoids computing the Hessian at each step, which, if not possible analytically, would come at great computational expense. The BFGS automatically incorporates any hard constraints; an alternative is the use of logarithmic barriers, which we have successfully implemented in other cases (Bayen et al. 2006). The procedure is repeated and the algorithm iteratively converges to our best estimate of the boundary condition parameters. A very similar approach has already been used very successfully in systems biology (Raffard et. al, 2006) for parameter estimation.

Once the boundary condition parameters are prescribed, we will do a final forward model calculation using these boundary conditions to project flows and transport forwards in time over a longer timescale – extending an observation period of hours or days to a model forecast of weeks (Figure 4). An open question is how far forward in time such a projection is likely to be appropriate, which is something we will evaluate as part of the proposed research.

4.1.2 Numerical Solutions

The shallow water equations are among the most studied PDEs for numerical schemes, for which numerous classes of numerical schemes exist. In general, in using adjoint-based methods the same scheme can be used to solve both the direct and the adjoint problem. For example Strub and Bayen (2006) use upwind schemes for both problems. In the present case, we have a large panel of numerical schemes available; two classes of schemes seem particularly appealing. First, Godunov schemes have traditionally been developed for conservation laws (LeVeque 2002). In recent work (Strub and Bayen 2006), we showed how to incorporate weak boundary conditions in the numerical computations of the solution to conservation laws, a feature which will be very helpful in the present study. Another class of candidate schemes are kinetic schemes (Perthame and Simeoni, 2001), which also incorporate an efficient treatment of boundary conditions.

Our research activity will not, however, be dependent upon only this new numerical development. In the first year, we will also be applying and evaluating existing hydrodynamic modeling approaches, including TRIM (Cheng et al. 1993) and ROMS (Haidvogel et al. 2000). Our goal, however, is to develop a robust inverse modeling approach that is not dependent upon a particular hydrodynamic modeling technique. In general, the quality of our estimates of Delta flows and transport will depend primarily on the quality of the observations and the boundary condition estimation technique. This has motivated our choice of the adjoint method, combined with the harmonic temporal decomposition that will allow us to extend our estimates ahead of our observational period.

4.1.3 Existing Data Set 1: Mildred Island

Our first application for the inverse estimation of boundary conditions and flow estimation will focus on a comprehensive data set collected in September 2001 in Mildred Island (Figure 3). The emphasis of this experiment and the ensuing analysis was on the interior dynamics of the shallow water habitat and its connection with the adjoining channels. Instrumentation consisted of a suite of bottom-mounted current profilers both in the channels surrounding Mildred Island and in the interior (FIG MI). These profilers collected velocity data for nearly a 2 month period with a time resolution of 10-30 minutes. In addition to the flow measurements, conductivity-temperature-depth (CTD) sensors were deployed at each station to provide time series measurements of conductivity and temperature along with the local depth.

Analysis of the hydrodynamics of this data set (Baek 2006; Sereno 2006) has demonstrated that the interior of Mildred Island (MI) is strongly influenced by tidal forcing, wind forcing and atmospheric heating and cooling. While the northern part of MI remains largely well-mixed, the southern region experiences significant temperature stratification at the diurnal timescale. The channels surrounding MI, however, remain well mixed vertically, and a depth-averaged model should accurately represent the dynamics (except in extreme southern MI).

For our inverse model analysis, we will analyze the area shown in Figure (3), which leads to 4 open boundaries. With this choice of domain, we actually have direct observations of velocity and stage at or near 3 of the four open boundaries for our model domain (on the southern channel there is a UVM station just south of the region shown in Figure 3). We will not, however, use these data sets to define our boundary conditions. Instead, we will use observations in the interior of the domain (as sites noted in Figure 3) with the adjoint approach outlined in this section to estimate the boundary conditions at the four open boundaries. The timeseries that we develop for stage and velocity at the four boundaries will then be compared to the observations at those locations to assess inverse model performance.

Comparisons with observations at or near our open boundaries will allow us to evaluate the performance of the inverse approach in the estimation of local flow conditions. The analysis of this data set will allow us to examine several specific questions:

(1) *Can channel phasing and tidal propagation be estimated from a few Eulerian measurements in the interior of the domain?*

To address this question, we will examine the estimation of the boundary conditions in detail to determine whether the boundary conditions can, in fact, be uniquely determined from this collection of observations. Alternatively, there may be a degeneracy to the solution of the shallow water equations that can not be resolved with a few fixed measurement stations.

(2) *What are the minimal data requirements to reconstruct boundary information?*

To evaluate the minimal requirements, as well as the most valuable types of data, we will subsample the data set in time, space and by sensor type. In each case, we will evaluate the performance of the inverse model and the uncertainty in our estimates of the boundary conditions.

(3) *How far ahead (in time) of real-time observations can we reliably project Delta flows?*

The analysis of this question really has two components to it. The first involves the accuracy of our tidal boundary estimation method. One of the subsampling strategies will be to use the first part of the observed records to estimate the boundary forcing, then evaluate the performance of the model in the remainder of the measurement period. By adjusting the fraction of the observational record used for boundary estimation we can assess the ability of this approach to project forwards in time. The second component of this question involves the efficiency of the optimization and boundary condition estimation. If, for example, the computational aspects of our work take several days to complete, this will limit the timescale at which our projections will be applicable. There is a tradeoff inherent in this analysis: a rough estimate of the boundary conditions is likely to be achievable quickly, but the more refined an estimate we seek, the longer the computations will take. Our analysis of this question will explore this tradeoff between a quick, rough estimate of Delta flow patterns and a more refined estimate that take more computational effort.

4.1.4 Existing Data Set 2: Sacramento River and Georgiana Slough

An experiment performed by the USGS in May 2004 examined the flow dynamics in the vicinity of the Georgiana Slough on the Sacramento River (Figure 4) at a similar scale as the Mildred Island study. The experiment was focused on the flow division between the Sacramento River and Georgiana Slough on both flood and ebb tides. The observations included a timeseries of cross-sectional velocity measurements using a boat-mounted velocity profiler on transects upriver and downriver from Georgiana Slough (Figure 4). The centerpiece of this experiment, however, and the data most of interest to our analysis, was a series of releases of GPS-logging drifters. These drifters were not communicating their data in real-time, but were monitored from a small boat; after they moved through the domain of interest, they were picked up and released again. The release points were positioned upstream of the junction between the Sacramento River and Georgiana Slough (to the north on ebb tides, south on floods), and the drifter trajectories provide a detailed picture of the Lagrangian flow patterns in this complex – but critical – channel junction.

In applying our inverse analysis to this site and experiment, our emphasis will be on predicting the details of tidal phasing between the Sacramento River and Georgiana Slough, and, to some extent, the Delta Cross Channel. This particular junction is critical for out migrating salmon smolt, and the operation of the Delta Cross Channel gates could provide a direct application of our integrated system. The fact that this data set includes Lagrangian drifter trajectories allows us to consider a different set of specific questions from the Mildred Island data set in the previous question. These include:

(1) *What is value of Lagrangian drifter data for flow and transport estimation compared to Eulerian observations?*

It is our belief that Lagrangian observations may provide more information regarding how the channels are connected, and may prove to be more valuable in estimating the local flow conditions. We will evaluate this hypothesis by comparing the results of the inverse analysis using the Lagrangian and Eulerian observations separately.

(2) *How does the inverse modeling approach compare to traditional "forward" modeling in predicting the local tidal phasing and exchanges between the Sacramento River and Georgiana Slough?*

The USGS (specifically Pete Smith) is currently pursuing a three-dimensional "forward" model of the experiment period and location (Burau, personal communication). One of our goals will be to compare the performance of our inverse approach to that model's ability to predict local flow conditions. The use of a depth-averaged approach for the inverse model may confound this comparison to some extent, due to the fact that the USGS is pursuing a three-dimensional model to resolve the secondary circulation in the Sacramento River.

4.2 Lagrangian drifter network development

In parallel with the analyses of existing data sets, we will also be developing the technical capability to collect real-time drifter data and integrate that data into real-time flow state estimation using the inverse approaches outlined in the previous section. In order to achieve the proposed goals, we will need to develop our own drifter network, which will incorporate adequate sensing and communication equipment. In this project, we focus on the development of a system of networked sensors, including drifters that can adjust their vertical position. Each of these sensors will communicate wirelessly between one another and with a base station that is networked through the internet to a computer cluster doing predictions of flows and fluid state.

Design and testing of the prototype drifter. We will follow the standard steps in developing technology for autonomous robotics applications. The prototype envisioned for this study will be inspired of the design of a vertical profiler built at the ENSIETA Engineering School, France within the SWARM project, in which Prof. Bayen was involved through the Department of Defense in France. This vehicle, shown in Figure 5 was designed by a group of undergraduate students supervised by PhD students. Constructing a similar vehicle at Berkeley is a realistic goal for the two year time frame envisioned for this phase of the project. We will follow the steps outlined below:

- Definition of specifications of the vehicles for operational needs (already completed).
- Optimized selection of hardware components to build the architecture (in progress, see next section).
- Software simulation of the envisioned architecture, both for software specific issues and evolution of the vehicle in its environment.
- Assembly of the components. Hardware in the loop simulations, hybrid simulations, for each of the modules of the architecture, and for the full architecture.
- Testing procedures: full architecture outside of its environment.
- Testing of the vehicle in its environment (remotely controlled), autonomous simulations. This first batch of testing will be done at the Richmond Field Station (at UC Berkeley) to ensure favorable conditions for testing this equipment (no currents).
- Testing of the vehicle at the actual deployment site.

Specifications for the prototype drifters. We will follow the specifications below, which are representative of the equipment we want to put onboard the drifters:

- GPS: ublox AEK-4H ANTARIS GPS Evaluation Kit. This evaluation kit will allow us to test and use a 4 Hz GPS module, one of ublox's newest products.
- ISM Datalink: Microhard Inc. MHX920 Development Kit. This development kit contains everything needed to build a data link between a single drifter and a ground station. We may not use the Microhard MHX920 system for the final implementation (possible issues: range and interference on the 900 MHz band) but for ease of development of the first prototype it is the best choice.
- Acoustic Pinger: RJE International ULB-350. This self-powered pinger will greatly improve our chances of recovering a prototype should something go wrong in the field.
- Computation and Control: gumstix connex 400xm primary module gumstix netMMC storage communication module Kingston 1GB MMC card gumstix. The gumstix standalone Linux systems are compact, common, and cheap.
- ADC Board: Custom.
- Battery: Lithium Ion, specific brand not chosen
- Pump: Jabsco 18220-1123 12V Ballast Pump.

- Emergency Blow System: Cole-Parmer EW-98619-24 Solenoid Valve.
- Safety Supervisor: Custom. This circuit will monitor the battery power, a watchdog signal from the gumstix computer, its own standalone timer, and perhaps the pressure sensor output. Should anything go wrong, it will activate the emergency compressed air system to empty the ballast tank. This will hopefully improve the recovery chances greatly in case of in-field failure.
- Pressure / Temperature / Conductivity Sensor Sea-Bird Electronics 37SI-1b. This sensor package will most likely be replaced on the final implementation, but for a first prototype it is the fastest and lowest-risk option. Internal electronics handle the sensor conditioning and control, and the professionally calibrated and configured sensors will greatly shorten our development time. Disadvantages: price, mass (2.6 kg in air), size (cylinder, approx. 40 cm long, 7 cm diameter).
- Turbidity (optical backscatter) Sensor Seapoint Turbidity Meter. Unlike the Sea-Bird module, this sensor will probably be in the final version as well. Its size and mass are reasonable, the price is acceptable.
- Chassis Custom construction out of PVC pipe or Delrin.
- Inertial navigation sensor: CloudCap Technology "Crista" OEM Sensor Head. 3 axis gyros & accelerometers, max 300 deg/s, 100 Hz bandwidth.

Predictive capabilities and inverse modeling through centralized power computing. Finally, we propose a novel architecture for centralized power computing, networked with distributed embedded sensing. This architecture is depicted in Figure 7. The drifters are the actual sensing platforms for the network, but what makes this sensor network so powerful is the computational core used for the predictive capabilities, which will enable the fleet to accomplish its missions. The computer cluster, running at UC Berkeley will provide predictions of the currents and contaminant transport or other scalar fields of interest for this project, through direct simulations. For feature tracking applications, the prediction of feature evolution can be achieved through solutions of the advection-diffusion equation, using inverse modeling results to define the advective field, with level set methods (Mitchell et al. 2005).

4.3 Central/South Delta Experiment

Late in year 2, or perhaps early in year 3, we will perform a test deployment of the sensor network, and evaluate the level of integration with inverse analysis that is possible. We anticipate working in the Central or South Delta, with a site to be chosen based on the availability of Eulerian flow measurements. Given the current set of UVM stations, we would anticipate focusing our efforts in Old and Middle River, but if other stations come on-line – or some go off-line – we will adjust our plans accordingly.

To make this example more concrete, we note in figure 1 a candidate model domain, which is co-located with the Middle River and Old River UVM stations. In this Delta sub-region, we will deploy several (~5-6) pressure sensors in the channels. Each will be along the edge of a channel, and will have a floating communication buoy to which it is tethered. Then, we will release our network of drifters and begin collecting real-time data from them in real-time at the base station. The base station will communicate with the computational cluster at UC Berkeley to estimate flow state and project flow trajectories. These projections will be compared, after the fact, with Eulerian measurements from the region.

5. Evaluation

Our intention in this proposed work is to develop a tool for rapidly estimating Delta flows and transport, which is at the same time robust, generic, and accurate. An important aspect of our work, therefore, is to critically evaluate the performance of our observational and modeling system relative to other modeling options. This will be the emphasis in the third year of our proposed work.

First, we will analyze the internal trade-offs within our approach. For example, the quality of our flow estimates will clearly improve the more data we incorporate into our analysis. Furthermore, the estimation of the boundary conditions (through optimization) will improve if the iterative procedure is given more time to converge. This is also a main motivation for using the BFGS method, which provides cheaper computational costs through approximations of the Hessian matrix, and for which optimized code is available. As part of this evaluation stage, therefore, we will examine how the cost function, particularly the data-model mismatch, varies with respect to both the amount of data used in the estimates and the computational cost. Through this analysis, which is essentially an analysis of the convergence properties of our optimization, we will evaluate what level of investment in observations and in computation is appropriate for predictive analysis of Delta flows and transport.

Once we understand the trade-offs within our analysis approach between accuracy and observational or computational investment, we will focus our attention on comparisons between our approach and other, traditional modeling approaches. This evaluation will be built around the analysis described in section 4.3, but will also be compared to DSM2 predictions of flow and transport in the region in question.

6. Summary

In this research proposal, we describe work to develop and evaluate an integrated system for the prediction of Delta flows and transport in real-time that doesn’t rely upon historical data sets for calibration and validation. The system consists of observational and computational components, along with real-time communication and coordination. The over-arching goal of the work is to allow for the prediction of Delta flows and transport at the timescale of days to weeks, even when there has been major changes to the Delta geometry (such as levee breaches).

The observational component of the work consists of a network of Lagrangian drifters that communicate to a base station in real-time to establish the instantaneous velocity field. The advantages of Lagrangian measurements are: (1) drifters can be rapidly and easily deployed in locations of interest, such as the position of outmigrating salmon, or adjacent to levee breaches; and (2) the Lagrangian velocity field is the important measure of net transport in a highly dispersive channel system like the Delta, where subtle phase differences between the various channels dominate the net transport and dispersion.

Computationally, we propose to develop an inverse approach to predicting Delta flows that does not rely on the specification of boundary conditions a priori, but rather estimates the necessary forcing based on observations in the interior of the domain. Our intention is to apply this method to Delta subregions in order to establish the net transport in particular locations of interest in the Delta. For most inverse modeling methods, flows would only be reasonably estimated during the period of observation, which would severely limit the applicability of the approach for management and operational decision making. Our formulation of the open boundary conditions, however, takes advantage of the tidal dominance in the forcing and the inverse estimation of the boundary conditions focuses on defining the amplitude and phase of the important tidal harmonics. Combining these tidal parameters with a linear trend in the boundary conditions allows us to project both the boundary conditions and the resulting flows ahead of the observational period, perhaps to as long as several weeks or a month. The development of the inverse modeling approach will be based on two existing data sets: one collected in the vicinity of Mildred Island in September 2001, one collected at the intersection of the Sacramento River and Georgiana Slough in May 2004.

Finally, we propose an integrated experiment that incorporates both the drifter network and the inverse model calculations. We will choose a domain for this experiment that has existing instrumentation, given the current set of UVMs (ultrasonic velocity meters – measures of cross-sectionally integrated flow in Delta channels), we propose an experiment in the South Delta along Old and Middle Rivers, but we may adjust the location depending on other instrumentation in the Delta. This experiment will involve real-time data collection by the drifters, communication of that data with the base station, and the inverse estimation of boundary conditions leading to a projection forwards in time of flows in the local channels. Our goal here is to test the accuracy and reliability of a real-time, calibration-free approach to Delta flows, including a critical evaluation of the trade-offs between the veracity of our flow predictions and observational or computational expense. Finally, we will compare our ability to predict the local flow conditions to a traditional Delta-scale hydrodynamic model (most likely DSM2) to evaluate the potential for improved operational efficiency in the Delta.

7. Qualifications

The investigators proposing this work bring complementary skills and experience to this activity. First, Stacey has extensive experience with estuarine dynamics and transport, including local experience in the Sacramento-San Joaquin Delta. Two Ph.D. students have pursued research in the Delta looking at channel-shallow interactions, the effects of submerged aquatic vegetation on flow and transport, and the influence of atmospheric forcing on Delta transport (Baek 2006; Sereno 2006). 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).

Bayen brings extensive expertise with control and parameter estimation in systems described by partial differential equations (Bayen et. al. 2004, 2006). The emphasis chosen in his research focuses on efficient computational methods for the solution of these problems, including the development of novel numerical and optimization schemes. The generality of the methods developed is reflected by the variety of applications tackled by his algorithms: transportation networks, systems biology and manufacturing (Lobaton and Bayen 2006, Schubert et. al. 2006, Strub and Bayen, 2006). Currently, Bayen has two Ph.D. students pursuing research on adjoint-based optimization. In parallel, Bayen also provides an expertise in the development of embedded software which will be implemented in the drifters to be developed in this project (Margulici and Bayen, 2006).

8. Figures

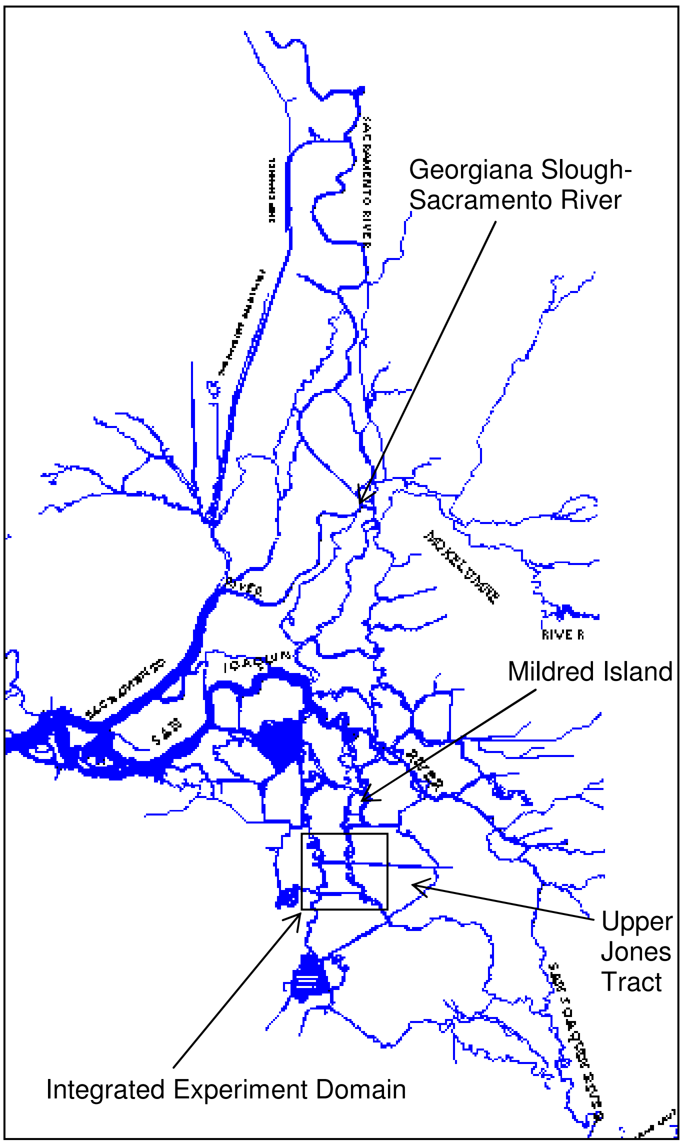

Figure 1: Delta map marking locations of existing data sets (Georgiana Slough-Sacramento River Junction, Mildred Island) and proposed experiment location (Old River and Middle River – proposed model domain marked by rectangle).

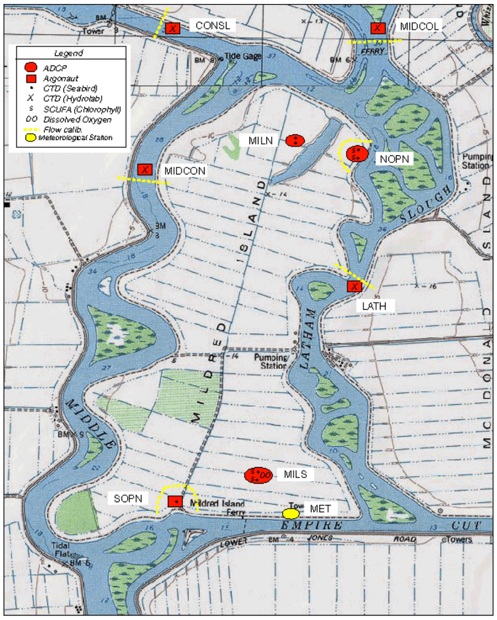

Figure 2: Mildred Island instrument stations (Courtesy of Jon Burau, USGS). Red circles denote current profiler and multiple conductivity-temperature-depth (CTD) sensors. Red squares mark locations of depth-integrated velocity measurements and single CTD measurement.

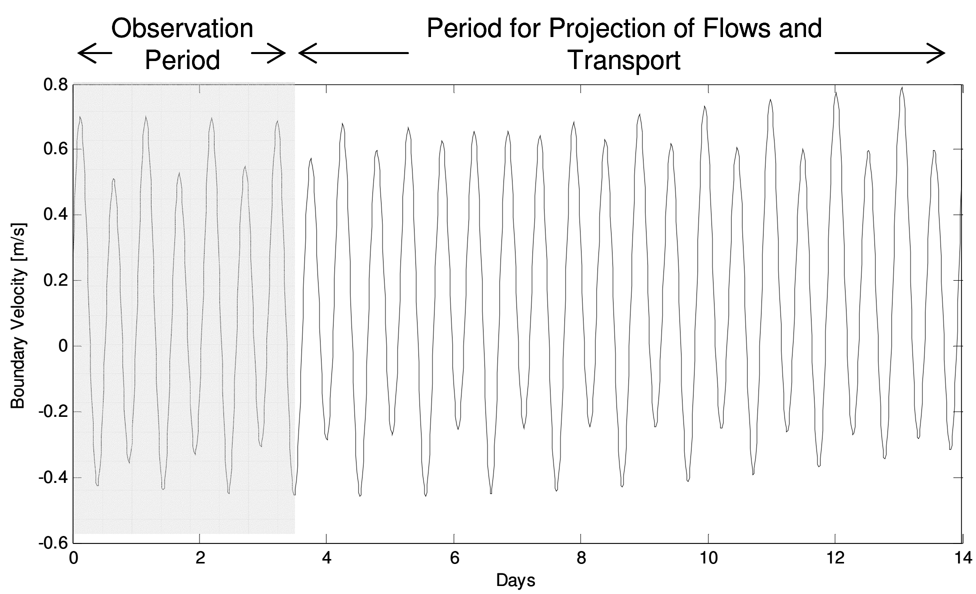

Figure 3: Sketch of boundary condition estimation and projection. Shaded period is observation period with inverse estimation of boundary conditions. Remainder of period is based on projection using estimated harmonic constants and linear trend.

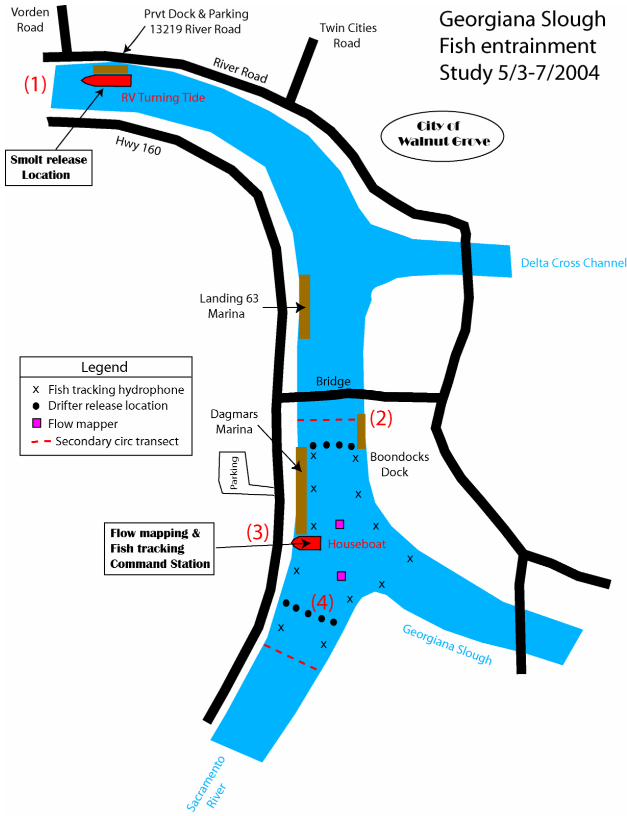

Figure 4: Georgiana Slough-Sacramento River experiment sketch (Courtesy of USGS). Drifters were released at black circles and tracked as they moved through the channel junction. Additional cross-sectional velocity measurements were made along red dotted lines.

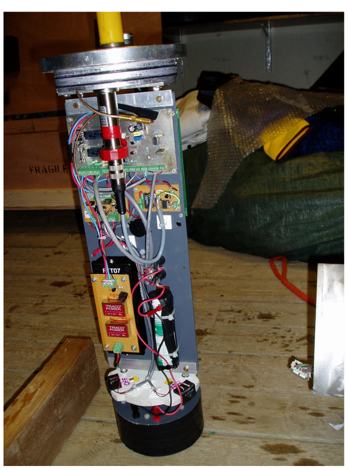

Figure 5: Drifter built jointly by Ph.D. and undergraduate students for the SWARM project, EECS Department, ENSIETA Engineering School, Ministere de la Defense, France.

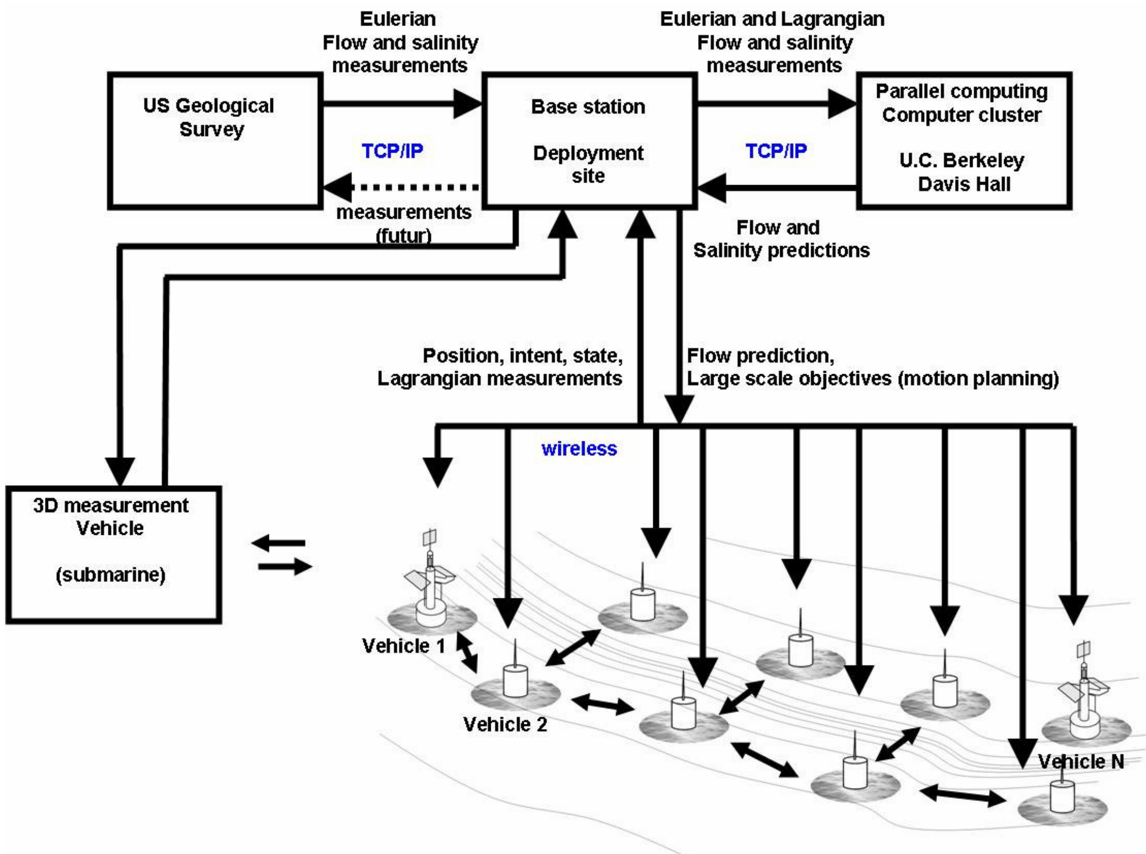

Figure 6: Architecture for the implementation and deployment of the fleet of drifters. Existing Eulerian measurements (noted here as "US Geological Survey") can already be downloaded. The scope of the current proposal includes the drifter network and the computing component (upper right corner of figure).

9. Literature Cited

Baek, S. 2006. "The hydrodynamics of a shallow tidal lagoon: The influence of atmospheric forcing on transport and mixing," Ph.D. thesis, UC-Berkeley.

Bayen, A., Raffard, R. and Tomlin, C.J. 2004. "Network congestion alleviation using adjoint hybrid control: application to highways", Hybrid Systems: Computation and Control (R. Alur, G. Pappas, Eds.), Lecture Notes in Computer Sciences 2993, pp. 95-110, Springer-Verlag.

Bayen, A., Raffard, R. and Tomlin, C.J., 2006. "Adjoint-based control of a new Eulerian network model of Air Traffic Flow", *IEEE Transactions on Control Systems Technology,* 14(5), Sep. 2006.

Bennett, A.F. 1992. Inverse methods in Physical Oceanography. Cambridge University Press, 364 pp.

Bogden, P.S., Malanotte-Rizzoli, P. and Signell, R. 1996. "Open-ocean boundary conditions from interior data: Local and remote forcing of Massachusetts Bay," *J. Geophys. Res.*, v.101(C3), pp. 6487-6500.

Burau, J.R. 2006. "Transport in the Delta, a regional perspective: The role of geometry," *Presentation at IEP Meeting*, Asilomar, CA February 2006.

Chen, M.-L. and Georges, D. 1999. "Nonlinear optimal control of an open-channel hydraulic system based on an infinite-dimensional model", *Proceedings of the 38th IEEE Conference on Decision and Control*, 1999, Volume: 5, pp. 4313-4318.

Cheng, R.T., Casulli, V. and Gartner, J.W. 1993. "Tidal, residual, intertidal mudflat (TRIM) model and its applications to San Francisco Bay, California," *Est. Coast. Shelf Sci*., v.36(3), pp.235-280.

Fischer, H.B., List, E.J., Koh, R.C.Y., Imberger, J. and Brooks, N.H. 1979. Mixing in Inland and Coastal Waters. Academic Press. 226 pp.

Gunson, J.R. and Malanotte-Rizzoli, P. 1996. "Assimilation studies of open-ocean flows 1. Estimation of initial and boundary conditions," *J. Geophys. Res*., v.101(C12), pp. 28,457-28,472.

Haidvogel, D.B., H.G. Arango, K. Hedstrom, A. Beckmann, P. Malanotte-Rizzoli, and A.F. Shchepetkin 2000. "Model Evaluation Experiments in the North Atlantic Basin: Simulations in Nonlinear Terrain-Following Coordinates," *Dynamics of Atmospheres and Oceans*, v.32, pp.239-281.

LeVeque, R.J., 2002. Finite Volume Methods for Hyperbolic Problems, Cambridge University Press.

Liu, D.C. and Nocedal, J., 1989. "On the limited memory BFGS method for large scale optimization", *Mathematical Programming*, 45(1-3).

Lobaton, E. and Bayen, A., 2006. "Modeling and optimization of single flagellum bacterial motion", submitted to the *American Control Conference*, 2006.

Margulici, J.-D. and Bayen, A. 2006. "Optimal Sensor Requirements", CCIT / Caltrans technical report, TS-603.

Mitchell, I., Bayen, A. and Tomlin, C.J., 2005. "Computing Reachable sets for continuous dynamic games using level set methods", *IEEE Transcations on Automatic Control,* 50(7), pp. 947-957, July 2005.

Okubo, A. 1973. "Effect of shoreline irregularities on streamwise dispersion," *Neth. J. Sea Res.*, v.6, pp.213-224.

Perthame, B. and Simeoni, C., 2001. "A kinetic scheme for the Saint-Venant system with a source term", *Calcolo*, 38(4), 201-231.

Powell, T.M., Lewis, C.V.W., Curchitser, E.N., Haidvogel, D.B., Hermann, A.J. and Dobbins, E.L., 2006. "Results from a three-dimensional, nested biological-physical model of the California Current System and comparisons with statistics from satellite imagery," *J. Geophys. Res*., v.111(C7), Art. No.C07018.

Raffard, R. L., Amonlirdviman, K., Axelrod, J.D., and Tomlin, C.J., 2006. "Parameter Identification via the Adjoint Method: Application to Protein Regulatory Networks", to appear in the *IEEE Conference on Decision and Control*, 2006, San Diego, CA.

San Diego Union Tribune 2004. "Levee break near Stockton floods fields, threatens water quality," Associated Press Report, June 4, 2004.

Sanders, B.F. and Katopodes, N.D. 2000. "Adjoint sensitivity analysis for shallow-water wave control," *J. Eng. Mech*., v.126(9), pp. 909-919.

Sanders, B.F. and Bradford, S.F. 2002. "High-resolution, monotone solution of the adjoint shallow-water equations," *International J. Num. Meth.*, v. 38, pp.139-161.

Schubert, B., Pannequin, J., and Bayen, A., 2006. "Melt phase boundary control for fabrication of features for theormoplastic micro hair arrays", submitted to the *American Control Conference*, 2006.

Sereno, D. 2006. "The Dynamics of Shallow Water Habitats in the Sacramento-San Joaquin Delta," Ph.D. thesis, University of California, Berkeley.

Stacey, M.T., Monismith, S.G. & Burau, J.R., 1999. “Observations of turbulence in a partially stratified estuary,” *Journal of Physical Oceanography*, v.29(8), pp. 1950-1970.

Stacey, M. T., Burau, J. R., and Monismith, S. G., 2001. “Creation of residual flows in a partially stratified estuary,” *J. Geophys. Res*., v.106(8), pp.17013-17037.

Stacey, M.T. and Ralston, D.K., 2005. “The Scaling and Structure of the Estuarine Bottom Boundary Layer,” *Journal of Physical Oceanography*, V.35(1), pp. 55-71.

Strub, I. and Bayen, A. 2006. “Weak formulation of boundary conditions for scalar conservation laws: an application to highway modeling”, to appear in the *International Journal on Robust and Nonlinear Contro*l, 2006.

Strub, I. and Bayen, A. 2006. “Optimal control of air traffic networks using continuous flow models”, *AIAA Conference on Guidance, Control and Dynamics,* AIAA Paper 2006-6228, Aug. 2006.

Strub, I. and Bayen,A. 2006 “Continuous adjoint methods and optimal control of Eulerian Air Traffic Networks”, to appear at the *IEEE Conference on Decision in Control*, Dec. 2006, San Diego, CA.

Sturm, T.W. 2001. Open Channel Hydraulics. McGraw-Hill Science/Engineering/Math. 512 pp.

Taugher, M. 2005. “Delta in Decline: Levees put Delta in danger”, *Contra Costa Times*, Dec.27, 2005.

Mark T. Stacey

Work Address
665 Davis Hall
Berkeley, CA 94720-1710
(510) 642-6776
mstacey@berkeley.edu

Home Address
42037 Via San Gabriel
Fremont, CA 94539
(510) 440-9280

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.

Ralston, D.K. and **Stacey, M.T.** “Shear and Turbulence Production over a Subtidal Channel,” accepted for publication in *Journal of Marine Research, v.64*, pp.147-171, 2006.

Ralston, D.A. and **Stacey, M.T.** “Longitudinal mixing and lateral circulation in the intertidal zone,” *Journal of Geophysical Research*, v.110(C7), Article C07015, 2005.

Ralston, D.K. and **Stacey, M.T.** “Stratification and turbulence in a subtidal channel through intertidal mudflats,” *Journal of Geophysical Research*, v.110(C8) Article C08009, 2005.

Stacey, M.T. and Ralston, D.K., “The Scaling and Structure of the Estuarine Bottom Boundary Layer,” *Journal of Physical Oceanography*, V.35(1), pp. 55-71, 2005.

Rueda, F.J., Schladow, S. G., Monismith, S. G. and **Stacey, M.T.**, “On effects of topography on the generation of currents in a large multi-basin lake”, *Hydrobiologia*, v.532, pp.139-151, 2005.

Talke, S. A. and **Stacey, M. T.**, “The Influence of Oceanic Swell on Flows Over an Estuarine Intertidal Mudflat in San Francisco Bay,” *Estuarine, Coastal and Shelf Science*, v. 58(3), pp. 541-554, 2003.

Fong, D.A., and **Stacey, M.T.**, "Horizontal dispersion of a near bed coastal plume," *Journal of Fluid Mechanics*, v.489, pp.239-267, 2003.

Stacey, M.T. "Estimation of dispersive transport of turbulent kinetic energy from acoustic Doppler current profiler data," *J. Atmos. Ocean. Tech.*, v.20(6), pp.927-935, 2003.

Lacy, J.R., **Stacey, M. T.**, Burau, J. R., and Monismith, S. G., "The interaction of lateral baroclinic forcing and turbulence in an estuary," *J. Geophys. Res.*, v.108(C3), art.no. 3089, 2003.

Rueda, F. J., Schladow, S. G., Monismith, S. G., and **Stacey, M. T.,** "The internal dynamics of a large polymictic lake. Part I: Field Observations," *ASCE J. of Hydraulic Engineering*, v.129(2) , pp. 82-91, 2003.

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.

Stacey, M. T., Burau, J. R., and Monismith, S. G., "Creation of residual flows in a partially stratified estuary," *J. Geophys. Res.*, v.106(8), pp.17013-17037, 2001.

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.

Stacey, M.T., Monismith, S.G. & Burau, J.R., "Observations of turbulence in a partially stratified estuary," *Journal of Physical Oceanography*, v.29(8), pp. 1950-1970, 1999.

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

Alexandre M. Bayen

Assistant Professor, Department of Civil and Environmental Engineering
711 Davis Hall, University of California at Berkeley, Berkeley, CA 94720-1710
Tel: (510) 642-2468, Fax: (510) 643-5264, bayen@berkeley.edu
http://www.ce.berkeley.edu/∼bayen/

Professional background

- *Assistant Professor*, Systems Engineering Program, Civil and Environmental Engineering, University of California at Berkeley — Mar. 2005 - present
- *Major, Research Director*, Autonomous Navigation Laboratory, Délégation Générale pour l'Armement, Ministère de la Défense, Vernon, France — Jan. 2004 - Mar. 2005
- *Visiting Scientist*, NASA Ames Research Center — Jan. 2001 - Dec. 2003
- *Research Assistant*, Aeronautics and Astronautics, Stanford University — Sep. 1998 - Dec. 2003
- *First Lieutenant*, Ecole Polytechnique, Palaiseau France — Sep. 1996 - Sep. 1998
- *Second Lieutenant*, 6th Maintenance Unit Regiment, French Forces in Germany, Landau in der Pfalz (Germany) — Sep. 1995 - Sep. 1996

Academic preparation

- **Stanford University**, Stanford, Aeronautics and Astronautics, Ph.D. — Jan. 2004
- **Stanford University**, Stanford, Aeronautics and Astronautics, M.S. — June 1999
- **Ecole Polytechnique**, France, Applied Mathematics, Eng. Deg. — July 1998

Awards and Honors

- *W. Ballhaus Prize for outstanding doctoral thesis in Aeronautics and Astronautics*, Stanford University — June 2004
- *2003 Outstanding Automatica Reviewer* — Dec. 2003
- *Computer Science Theory Seminar Award*, Stanford University — June 2004
- *DGA Fellow*, Ministère de la Défense, France — 1998-2002
- *Novosibirsk State University - Ecole Polytechnique Summer Fellowship*, Russia — 1997
- *National Defense Medal* from the French Armed Forces for outstanding service in Germany, with three citations — June 1996

Research Interests

- *Control, estimation and optimization of distributed parameter systems*
  - Adjoint-based optimization of partial differential equations
  - Optimal control algorithms for partial differential equations
  - Hamilton-Jacobi theory
- *Network control and analysis*
  - Combinatorial optimization algorithms for real-time control networks
  - Modeling of congested networks using hybrid system theory
  - Lagrangian and Eulerian sensor networks
- *Large scale infrastructure systems*
  - Highway networks
  - Water distribution networks
  - Air traffic control automation

Research Experience

Ministère de la Défense, Vernon, France 2004

Major, Director of the Autonomous Navigation Laboratory

In charge of building an unmanned aerial vehicle and robotics laboratory, with the goal of creating a testbed of autonomous vehicles (helicopters, ground robots within a sensor network). Supervised 18 people (Ph.D. and M.S. students, undergraduates, engineers, technicians and interns). Development of real-time combinatorial optimization algorithms for networks of heterogeneous agents.

Stanford University, Palo Alto, CA 2000-2003

Research Assistant, Hybrid Systems Laboratory (advisor: Pr. Claire J. Tomlin)

Doctoral Thesis research. Developed modeling architecture and control methodology for networks of hybrid systems. Developed polynomial time task scheduling algorithms for multiple vehicle network automation. Derived sufficient conditions for network congestion avoidance. Generated provably safe collision avoidance control laws for aircraft. Designed methodology for control of networks of systems driven by partial differential equations.

NASA Ames, Moffett Field, CA 2000-2003

Visiting Scientist, Automation Concepts Research Branch (advisor: Dr. George Meyer)

Applied my models and algorithms for networks to the National Airspace System, in particular to controller synthesis in En Route airspace, and for the online scheduling of aircraft. Validated these models against Enhanced Traffic Management System (ETMS) data.

Stanford University, Palo Alto, CA 1998-2000

Research Assistant, Unsteady Flow Phys. and Aeroacoustics Lab. (advisor: Pr. Sanjiva Lele)

Performed stability analysis of a pair of two-scale contrarotative wake vortices using spectral Bessel decomposition. Designed code for simulation and control of wake destruction.

Ecole Polytechnique, ONERA, INRIA, Palaiseau, France 1997-1998

Research Assistant, Département de Mécanique, DAFE (advisor: Dr. Laurent Jacquin)

Designed and manufactured fiberglass laminar airfoils. Completed wind tunnel testing of airfoils and numerical simulations (INRIA code ns2ke) to observe transition to turbulence.

Government and Industry Experience

Zentr Deriev' Otrabotki, S.A., Vladivostok, Russia Fall 1997

Test Engineer

Performed resistance and fatigue tests on wood structures for a furniture factory.

Ministère de la Défense, France 1995-1996

Second Lieutenant, 6th Maintenance Unit Regiment, Landau, Germany.

Coordinated French-German military operations in Landau, Germany. Assumed interim Captain functions (150 soldiers and civilians). Current rank: Major.

Other activities

- *Co-founder* of the Bureau for Cultural Exchanges with Russia, Ecole Polytechnique, 1997
- *Languages*, English (fluent), French (native), German (fluent), *Oberstufe Prüfung Diploma*, highest honors, Goethe Institut, 1998, Russian (read, written, spoken), Intensive intermediate Russian, Novosibirsk State University, Russia, 1997.
- *Concert soloist* (piano), with the Ecole Polytechnique Symphony Orchestra, Paris, France, 1998
- *Nonacademic writing* (in French), quarterly Alumni magazine of the Ecole Polytechnique, and Government Executive Bulletin (CAIA), Ministère de la Défense
  - "Academic research and defense in the US: a successful symbiosis", Eng. section Jan. 2005
  - "The Paris Catacombs", History section Jan. 1998

– “Franz Liszt: when piano goes beyond the frontiers of music”, Arts section Mar. 1997
– “Gyorgy Cziffra, a spiritual son of Liszt?”, Arts section Jan. 1997

Five publications most relevant to the topic

- A. Bayen, R. Raffard and C. Tomlin, “Adjoint-based control of a new Eulerian network model of Air Traffic Flow”, *IEEE Transactions on Control Systems Technology*, 14(5), pp. 967-982, September 2006.
- I. Mitchell, A. Bayen and C. Tomlin, “Computing Reachable sets for continuous dynamic games using level set methods”, *IEEE Transactions on Automatic Control*, 50(7), pp. 947-957, July 2005.
- C. Tomlin, I. Mitchell, A. Bayen and M. Oishi, “Computational techniques for the verification and control of hybrid systems”, *Proceedings of the IEEE*, 91(7), pp. 986-1001, July 2003.
- A. Bayen, E. Cruck and C. Tomlin, “Guaranteed overapproximations of unsafe sets for continuous and hybrid systems: solving the Hamilton-Jacobi equation using viability techniques”, *Hybrid Systems: Computation and Control* (C. Tomlin and M. Greenstreet, Eds.), Lecture Notes in Computer Science 2289, pp. 90-104, Springer-Verlag, Mar. 2002.
- C. Robelin, D. Sun, G. Wu and A. Bayen, “MILP control of aggregate Eulerian network airspace models”, *Proceedings of the 2006 American Control Conference*, pp. 5257-5262, Jun. 2006.

Five related publications

- J.-P. Aubin, A. Bayen, N. Bonneuil, P. Saint-Pierre, *Elements of Viability Theory*, to appear, Springer-Verlag, 2007.
- A. Bayen, P. Grieder, G. Meyer and C. Tomlin, “Lagrangian delay predictive model for sector-based air traffic flow”, *AIAA Journal on Guidance, Control and Dynamics*, 28(5), pp. 1015-1026, September-October 2005.
- A. Bayen, C. Tomlin, Y. Ye and J. Zhang, “An approximation algorithm for scheduling aircraft with holding time ”, *Proceedings of the 43rd IEEE Conference on Decision and Control*, pp. 2760-2767, Dec. 2004.
- R. Raffard, S. Waslander, A. Bayen and C. Tomlin, “Cooperative distributed control for a multi-agent Eulerian air traffic network”, *Proceedings of the AIAA Conference on Guidance, Navigation and Control*, AIAA Paper 2005-6050, Aug. 2005.
- A. Bayen, C. Tomlin, Y. Ye and J. Zhang, “MILP formulation and polynomial time algorithm for an aircraft scheduling problem”, *Proceedings of the 42nd IEEE Conference on Decision and Control*, pp. 5003-5010, Dec. 2003.

Synergistic activities

- *Journal referee:* IEEE Transactions on Automatic Control, IEEE Transactions on Control Systems Technology, IEEE Transactions on Intelligent Transportation Systems, ASCE Journal of Infrastructure Systems, AIAA Journal on Guidance, Control and Dynamics, IFAC Control Engineering Practice, Air Traffic Control Quarterly, Automatica, International Journal on Robust and Nonlinear Control, International Game Theory Review.
- *Conference referee:* Conference on Decision and Control (CDC), American Control Conference (ACC), 4th-8th International Workshop Hybrid Systems: Computation and Control, AIAA Conference on Guidance, Control and Dynamics.
- *Member of the organizing committee*, 5th International Workshop Hybrid Systems: Computation and Control (HSCC).

PI: Mark Stacey
Co-PI: Alexandre Bayen

Agency CalFed 2006
Budget Proposal #042

Calibration-Free Approach Modeling

	Monthly Rate	# months		1/1/07- 12/31/07 Yr 1	1/1/08- 12/31/08 Yr 2	1/1/09- 12/31/09 Yr 3	Summary
Personnel							
1 PI	10,056	1.0 Summer	100.00%	10,358	10,669	10,989	32,016
1 Co-PI	8,600	1.0 Summer	100.00%	8,858	9,124	9,397	27,379
1 Postdoc	0	0	0.00%	0	0	0	0
1 Postdoc	0	0	0.00%	0	0	0	0
				0	0	0	0
2 GSR IV	3,137	9 Ac. Yr.	50.00%	28,233	28,798	29,374	86,404
	3,137	3 Summer	100.00%	18,822	19,198	19,582	57,603
				47,055	47,996	48,956	144,007
1 Undergrad	0	0 Ac. Yr.	0.00%	0	0	0	0
1 Undergrad	0	0 Summer	0.00%	0	0	0	0
				0	0	0	0
TOTAL PERSONNEL				**66,271**	**67,789**	**69,342**	**203,402**
Employee Benefits							
2 Principal Investigator			12.70%	2,440	2,514	2,589	7,543
0 Postdoc			23.00%	0	0	0	0
2 Graduate Student Researcher, acad. Yr			1.30%	367	374	382	1,123
2 Graduate Student Researcher, summer			3.00%	565	576	587	1,728
0 Undergraduate acad yr			1.30%	0	0	0	0
0 Undergraduate, summer			3.00%	0	0	0	0
Total Employee Benefits				**3,372**	**3,464**	**3,558**	**10,394**
1 Tuition/fees per semester (resident)		full	0.00	0	19,508	21,460	40,968
1 Tuition/fees per semester (resident)		Partial 25-44%	0.00	0	0	0	0
1 Tuition/fee per semester (nonresident)		full	0.00	0	0	0	0
1 Tuition/fee per semester (nonresident)		Partial 25-44%	0.00	47,656	0	0	47,656
Total Tuition/Fees				**47,656**	**19,508**	**21,460**	**88,624**
TOTAL BENEFITS				**51,028**	**22,972**	**25,018**	**99,018**
TOTAL PERSONNEL & BENEFITS				**117,299**	**90,761**	**94,361**	**302,420**
Equipment				0	0	0	0
				0	0	0	0
TOTAL EQUIPMENT				**0**	**0**	**0**	**0**
Travel							
Domestic trips				0	2,000	2,000	4,000
International trips				0	0	0	0
TOTAL TRAVEL				**0**	**2,000**	**2,000**	**4,000**
Other Direct Costs							
Materials and Supplies				11,000	7,000	0	18,000
Publication Costs				0	1,000	2,000	3,000
Consultant Services				0	0	0	0
Computer Services				0	0	0	0
Other				1,000	1,000	1,000	3,000
TOTAL OTHER DIRECT COSTS				**12,000**	**9,000**	**3,000**	**24,000**
Subawards With IDC - first $25,000				0	0	0	0
TOTAL SUBAWARDS				**0**	**0**	**0**	**0**
TOTAL DIRECT COSTS				**129,299**	**101,761**	**99,361**	**330,420**
							0
MDTC				**81,643**	**82,253**	**77,901**	**241,796**
25% of MTDC (direct cost less tuition and fees)				**20,411**	**20,563**	**19,475**	**60,449**
TOTAL AMOUNT REQUESTED				**149,710**	**122,324**	**118,836**	**390,869**

PI: Mark Stacey
Co-PI: Alexandre Bayen

Agency CalFed 2006
Budget Proposal #0042
Task 1

Calibration-Free Approach to Modeling

	Monthly Rate	# months		1/1/07-12/31/07 Yr 1	1/1/08-12/31/08 Yr 2	1/1/09-12/31/09 Yr 3	Summary	Amount Per Hour	# of Hours Yr 1	Hours Yr 2	Hours Yr 3
Personnel											
1 PI	10,056	1.0 Summer	52.00%	5,179	5,334	0	10,513	$57.79	89.61	92.30	
1 Co-PI	8,600	1.0 Summer	52.00%	4,429	0	0	4,429	$49.43	89.61		
1 Postdoc	0	0	0.00%	0	0	0	0				
1 Postdoc	0	0	0.00%	0	0	0	0				
				0	0	0	0				
1 GSR IV	3,137	9 Ac. Yr./	50%/25%	14,117	7,199	0	21,316	$18.03	783.03	399.31	
	3,137	3 Summer	100%/50%	9,411	4,800	0	14,211	$18.03	522.00	266.22	
				23,528	11,999	0	35,527				
1 Undergrad	0	0 Ac. Yr.	0.00%	0	0	0	0				
1 Undergrad	0	0 Summer	0.00%	0	0	0	0				
				0	0	0	0				
TOTAL PERSONNEL				**33,136**	**17,333**	**0**	**50,469**	**Total Hours**	**1484.25**	**757.83**	
Employee Benefits											
1 Principal Investigator			12.70%	1,220	677	0	1,898				
0 Postdoc			23.00%	0	0	0	0				
1 Graduate Student Researcher, acad. Yr			1.30%	184	94	0	277				
1 Graduate Student Researcher, summer			3.00%	282	144	0	426				
0 Undergraduate acad yr			1.30%	0	0	0	0				
0 Undergraduate, summer			3.00%	0	0	0	0				
Total Employee Benefits				**1,686**	**915**	**0**	**2,601**				
1 Tuition/fees per semester (resident)		full	0.00	0	4,877	0	4,877				
1 Tuition/fees per semester (resident)		Partial 25-44%	0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)		full	0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)		Partial 25-44%	0.00	23,828	0	0	23,828				
Total Tuition/Fees				**23,828**	**4,877**	**0**	**28,705**				
TOTAL BENEFITS				**25,514**	**5,792**	**0**	**31,306**				
TOTAL PERSONNEL & BENEFITS				**58,650**	**23,125**	**0**	**81,775**				
Equipment				0	0	0	0				
				0	0	0	0				
TOTAL EQUIPMENT				**0**	**0**	**0**	**0**				

		1/1/07- 12/31/07 **Yr 1**	1/1/08- 12/31/08 **Yr 2**	1/1/09- 12/31/09 **Yr 3**	
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	3,000	0	0	3,000
	Publication Costs	0	0	0	0
	Consultant Services	0	0	0	0
	Computer Services	0	0	0	0
	Other	0	0	0	0
	TOTAL OTHER DIRECT COSTS	**3,000**	**0**	**0**	**3,000**
Subawards	With IDC - first $25,000	0	0	0	0
	TOTAL SUBAWARDS	**0**	**0**	**0**	**0**
	TOTAL DIRECT COSTS	**61,650**	**23,125**	**0**	**84,775**
					0
	MDTC	**37,822**	**18,248**	**0**	**56,070**
	25% of MTDC (direct costs less Tuition/Fees)	**9,456**	**4,562**	**0**	**14,018**
	TOTAL AMOUNT REQUESTED	**71,106**	**27,687**	**0**	**98,793**

PI:	**Mark Stacey**	**Agency CalFed 2006**		**Calibration-Free Approach to Modeling**								
Co-PI:	**Alexandre Bayen**	**Budget Proposal**	**#0042**									
		Task 2										

	Monthly Rate	**# months**			1/1/07- 12/31/07 **Yr 1**	1/1/08- 12/31/08 **Yr 2**	1/1/09- 12/31/09 **Yr 3**	**Summary**	**Amount Per Hour**	**# of Hours Yr 1**	**Hours Yr 2**	**Hours Yr 3**
Personnel												
1 PI	10,056	1.0	Summer	100.00%	5,179	0	0	5,179	$ 57.79	89.61		
1 Co-PI	8,600	1.0	Summer	100.00%	4,429	4,562	0	8,991	$ 49.43	89.61	92.30	
1 Postdoc	0	0		0.00%	0	0	0	0				
1 Postdoc	0	0		0.00%	0	0	0	0				
					0	0	0	0				
1 GSR IV	3,137	9	Ac. Yr.	50.00%	14,117	7,199	0	21,316	$ 18.03	81.13	41.38	
	3,137	3	Summer	100.00%	9,411	4,800	0	14,211	$ 18.03	54.09	27.58	
					23,528	11,999	0	35,527				
1 Undergrad	0	0	Ac. Yr.	0.00%	0	0	0	0				
1 Undergrad	0	0	Summer	0.00%	0	0	0	0				
					0	0	0	0				
	TOTAL PERSONNEL				**33,136**	**16,561**	**0**	**49,696**	**Total Hours**	**314.44**	**161.26**	**0.00**
Employee Benefits												
1 Principal Investigator				12.70%	1,220	579	0	1,800				
0 Postdoc				23.00%	0	0	0	0				
1 Graduate Student Researcher, acad. Yr				1.30%	184	94	0	277				
1 Graduate Student Researcher, summer				3.00%	282	144	0	426				
0 Undergraduate acad yr				1.30%	0	0	0	0				
0 Undergraduate, summer				3.00%	0	0	0	0				
	Total Employee Benefits				**1,686**	**817**	**0**	**2,503**				
1 Tuition/fees per semester (resident)			full	0.00	0	4,877	0	4,877				
1 Tuition/fees per semester (resident)			Partial 25-44%	0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)			full	0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)			Partial 25-44%	0.00	23,828	0	0	23,828				
	Total Tuition/Fees				**23,828**	**4,877**	**0**	**28,705**				
	TOTAL BENEFITS				**25,514**	**5,694**	**0**	**31,208**				
	TOTAL PERSONNEL & BENEFITS				**58,650**	**22,255**	**0**	**80,904**				
Equipment					0	0	0	0				
					0	0	0	0				
	TOTAL EQUIPMENT				**0**	**0**	**0**	**0**				

1/1/07- 1/1/08- 1/1/09-

		12/31/07 Yr 1	12/31/08 Yr 2	12/31/09 Yr 3	Summary
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	8,000	0	0	8,000
	Publication Costs	0	0	0	0
	Consultant Services	0	0	0	0
	Computer Services	0	0	0	0
	Other	1,000	500	0	1,500
	TOTAL OTHER DIRECT COSTS	**9,000**	**500**	**0**	**9,500**
Subawards	With IDC - first $25,000	0	0	0	0
	TOTAL SUBAWARDS	**0**	**0**	**0**	**0**
	TOTAL DIRECT COSTS	**67,650**	**22,755**	**0**	**90,404**
					0
	MDTC	**43,822**	**17,878**	**0**	**61,699**
	25% of MTDC (direct cost less tuition and fees)	**10,955**	**4,469**	**0**	**15,425**
	TOTAL AMOUNT REQUESTED	**78,605**	**27,224**	**0**	**105,829**

PI: Mark Stacey
Co-PI: Alexandre Bayen

Agency CalFed 2006
Budget Proposal **#0042**
Task 3

Calibration-Free Approach to Modeling

	Monthly Rate	# months			1/1/07- 12/31/07 **Yr 1**	2/1/08- 12/31/08 **Yr 2**	1/1/09- 12/31/09 **Yr 3**	**Summary**	**Amount Per Hour**	**# of Hours Yr 1**	**Hours Yr 2**	**Hours Yr 3**
Personnel												
1 PI	10,056	0.5	Summer	100.00%	0	5,334	0	5,334	$ 57.79		92.30	
1 Co-PI	8,600	0.5	Summer	100.00%	0	4,562	0	4,562	$ 49.43		92.30	
1 Postdoc	0	0		0.00%	0	0	0	0				
1 Postdoc	0	0		0.00%	0	0	0	0				
					0	0	0	0				
1 GSR IV	3,137	9	Ac. Yr.	50.00%	0	14,399	14,687	29,086	$ 18.03		798.66	814.63
	3,137	3	Summer	100.00%	0	9,599	9,791	19,390	$ 18.03		532.44	543.09
					0	23,998	24,478	48,476				
1 Undergrad	0	0	Ac. Yr.	0.00%	0	0	0	0				
1 Undergrad	0	0	Summer	0.00%	0	0	0	0				
					0	0	0	0				
TOTAL PERSONNEL					**0**	**33,894**	**24,478**	**58,372**	**Total Hours**		**1515.6995**	**1357.72**
Employee Benefits												
1 Principal Investigator				12.70%	0	1,257	0	1,257				
0 Postdoc				23.00%	0	0	0	0				
1 Graduate Student Researcher, acad. Yr				1.30%	0	187	191	378				
1 Graduate Student Researcher, summer				3.00%	0	288	294	582				
0 Undergraduate acad yr				1.30%	0	0	0	0				
0 Undergraduate, summer				3.00%	0	0	0	0				
Total Employee Benefits					**0**	**1,732**	**485**	**2,217**				
1 Tuition/fees per semester (resident)		full		0.00	0	9,754	10,730	20,484				
1 Tuition/fees per semester (resident)		Partial 25-44%		0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)		full		0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)		Partial 25-44%		0.00	0	0	0	0				
Total Tuition/Fees					**0**	**9,754**	**10,730**	**20,484**				
TOTAL BENEFITS					**0**	**11,486**	**11,215**	**22,701**				
TOTAL PERSONNEL & BENEFITS					**0**	**45,380**	**35,693**	**81,073**				
Equipment					0	0	0	0				
					0	0	0	0				
TOTAL EQUIPMENT					**0**	**0**	**0**	**0**				

		1/1/07- 12/31/07 Yr 1	2/1/08- 12/31/08 Yr 2	1/1/09- 12/31/09 Yr 3	Summary
Travel					
	Domestic trips	0	1,000	0	1,000
	International trips	0	0	0	0
	TOTAL TRAVEL	**0**	**1,000**	**0**	**1,000**
Other Direct Costs					
	Materials and Supplies	0	7,000	0	7,000
	Publication Costs	0	0	0	0
	Consultant Services	0	0	0	0
	Computer Services	0	0	0	0
	Other	0	500	500	1,000
	TOTAL OTHER DIRECT COSTS	**0**	**7,500**	**500**	**8,000**
Subawards	With IDC - first $25,000	0	0	0	0
	TOTAL SUBAWARDS	**0**	**0**	**0**	**0**
	TOTAL DIRECT COSTS	**0**	**53,880**	**36,193**	**90,073**
	MDTC	**0**	**44,126**	**25,463**	**69,589**
	25% of MTDC (direct cost less tuition and fees)	**0**	**11,032**	**6,366**	**17,397**
	TOTAL AMOUNT REQUESTED	**0**	**64,912**	**42,558**	**107,470**

PI: Mark Stacey
Co-PI: Alexandre Bayen

Agency CalFed 2006
Budget Proposal #0042
Task 4

Calibration-Free Approach to Modeling

	Monthly Rate	# months			1/1/07-12/31/07 Yr 1	1/1/08-12/31/08 Yr 2	1/1/09-12/31/09 Yr 3	Summary	Amount Per Hour	# of Hours Yr 1	Hours Yr 2	Hours Yr 3
Personnel												
1 PI	10,056	1.0	Summer	100.00%	0	0	10,989	10,989	$57.79	0.00	0.00	190.14
1 Co-PI	8,600	1.0	Summer	100.00%	0	0	9,397	9,397	$49.43	0.00	0.00	190.13
1 Postdoc	0	0		0.00%	0	0	0	0				
1 Postdoc	0	0		0.00%	0	0	0	0				
					0	0	0	0				
1 GSR IV	3,137	9	Ac. Yr.	50.00%	0	0	14,687	14,687	$18.03	0.00	0.00	814.63
	3,137	3	Summer	100.00%	0	0	9,791	9,791	$18.03	0.00	0.00	543.09
					0	0	24,478	24,478				
1 Undergrad	0	0	Ac. Yr.	0.00%	0	0	0	0				
1 Undergrad	0	0	Summer	0.00%	0	0	0	0				
					0	0	0	0				
TOTAL PERSONNEL					**0**	**0**	**44,864**	**44,864**	**Total Hours**			**1737.99687**
Employee Benefits												
1 Principal Investigator				12.70%	0	0	2,589	2,589				
0 Postdoc				23.00%	0	0	0	0				
1 Graduate Student Researcher, acad. Yr				1.30%	0	0	191	191				
1 Graduate Student Researcher, summer				3.00%	0	0	294	294				
0 Undergraduate acad yr				1.30%	0	0	0	0				
0 Undergraduate, summer				3.00%	0	0	0	0				
Total Employee Benefits					**0**	**0**	**3,074**	**3,074**				
1 Tuition/fees per semester (resident)			full	0.00	0	0	10,730	10,730				
1 Tuition/fees per semester (resident)			Partial 25-44%	0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)			full	0.00	0	0	0	0				
1 Tuition/fee per semester (nonresident)			Partial 25-44%	0.00	0	0	0	0				
Total Tuition/Fees					**0**	**0**	**10,730**	**10,730**				
TOTAL BENEFITS					**0**	**0**	**13,804**	**13,804**				
TOTAL PERSONNEL & BENEFITS					**0**	**0**	**58,668**	**58,668**				
Equipment					0	0	0	0				
					0	0	0	0				
TOTAL EQUIPMENT					**0**	**0**	**0**	**0**				

		1/1/07- 12/31/07 **Yr 1**	1/1/08- 12/31/08 **Yr 2**	1/1/09- 12/31/09 **Yr 3**	**Summary**
Travel					
	Domestic trips	0	1,000	2,000	3,000
	International trips	0	0	0	0
	TOTAL TRAVEL	**0**	**1,000**	**2,000**	**3,000**
Other Direct Costs					
	Materials and Supplies	0	0	0	0
	Publication Costs	0	1,000	2,000	3,000
	Consultant Services	0	0	0	0
	Computer Services	0	0	0	0
	Other	0	0	500	500
	TOTAL OTHER DIRECT COSTS	**0**	**1,000**	**2,500**	**3,500**
Subawards	With IDC - first $25,000	0	0	0	0
	TOTAL SUBAWARDS	**0**	**0**	**0**	**0**
	TOTAL DIRECT COSTS	**0**	**2,000**	**63,168**	**65,168**
					0
	MDTC	**0**	**2,000**	**52,438**	**54,438**
	25% of MTDC (direct cost less tuition and fees)	**0**	**500**	**13,109**	**13,609**
	TOTAL AMOUNT REQUESTED	**0**	**2,500**	**76,277**	**78,777**

Budget Justification

The primary budget expenses we request are salary and benefits for the personnel involved, including one month of summer salary support for each PI (Stacey and Bayen) and stipend, tuition and fees for two graduate student researchers. The proposed activity will form the basis of the graduate students Ph.D. research, with one emphasizing the inverse modeling approach and one focusing on the development and utilization of the drifter network. Travel funds are requested in years 2 and 3 to facilitate both the field experiments (primarily in year 2) and attendance at scientific conferences (primarily in year 3). Materials and supplies expenses are requested in year 1 for acquisition of a both a field and computational laptop, and funds in years 1 and 2 will be committed to development of the drifter network. Publication costs are included in years 2 and 3 and funds to cover miscellaneous expenses and general communication are included across all years.

The research we propose here is highly leveraged by existing resources in the PIs' labs. The basis for the drifter network will be 10 GPS-logging drifters that are available in one of the PI's lab (Stacey). Computationally, resources on the UC-Berkeley campus, including a parallel computer cluster, will be available for the inverse modeling activity. For the field experiment, all necessary instrumentation (beyond the drifter network developed as part of this work) is available in Stacey's lab (acoustic profilers, conductivity-temperature-depth sensors, pressure sensors), as is a 10 foot whaler that will be committed to the field activity.

Signature

The applicant for this proposal must submit this form by printing it, signing below, and faxing it to +1 877-408-9310. Send exactly one form per transmission.

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

The 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: A Calibration-Free Approach to Modeling Delta Flows and Transport
Proposal Number: 2006.01-0042
Applicant Organization: Berkeley, California University of
Applicant Contact: Ms. Jyl Baldwin

Applicant Signature [signature]

Date 8-24-06