CASCaDE: Computational Assessments of Scenarios of Change for the Delta Ecosystem

CALFED Science Program Grant
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* For a list of cited references, see original proposal at https://solicitation.calwater.ca.gov/solicitations/2004.01/reports/public_proposal_compilation?proposal_id=0084

Statement of Work

1. Project Purpose

Agencies of the CALFED Bay-Delta Program (CALFED) have accepted a challenge of California resource management that is unprecedented in scope and complexity. CALFED programs will invest many billions of taxpayer dollars over decades to attain multiple, often conflicting, goals of resource allocation. Decisions made within CALFED have enormous potential impacts on California's $30 billion agricultural industry, quality of life of its growing population, and sustainability of diverse communities of native species and their supporting ecosystem functions. While the cost and scope of CALFED programs are large, the outcomes of cumulative CALFED actions are highly uncertain. For this reason, CALFED has embraced the principle that its goals of stabilizing water supplies, providing safe drinking water and restoring ecosystems can best be attained with investments in science building toward a mechanistic understanding to guide design and anticipate the potential outcomes of costly actions. This research project was conceived as a step toward a long view (Carpenter 2002)* of CALFED actions. The urgency of a long view comes from the certainty that forces influencing water supply and water and habitat quality in the Sacramento-San Joaquin Rivers and Delta will change in the future.

- A recent assessment, based on a conservative rate of CO_2 emissions and two independent global climate models, projects that California's statewide annual temperature will increase by more than 1°C by the mid-21st century (Hayhoe et al. 2004). Projected thermal expansion of the oceans and melting of polar ice will raise sea level 9-13 cm, annual snowpack in the Sierra Nevada Mountains will decline by 26-40%, and April-June reservoir inflow will decline by 11-24% as a result of reduced snowfall and earlier snowmelt. The combination of earlier runoff and higher sea levels will increase the risk of flooding (Hayhoe et al. 2004) and levee failures in the Delta more catastrophic than the 2004 levee break that flooded Jones Tract (http://www.publicaffairs.water.ca.gov/newsreleases/2004/jones04.cfm). Water demand will increase and landscapes will continually evolve as California's population adds 15 million people during the 30-year time frame of the CALFED Ecosystem Restoration Program (http://calwater.ca.gov/Programs/EcosystemRestoration/Ecosystem.shtml). Trends of reduced sediment input to the Delta (Wright and Schoellhamer 2004) and erosion of San Francisco Bay (Jaffe et al. 1998) will continue. And the Delta landscape will be transformed by structural changes designed to create new habitats or hold or transfer water (http://www.delta.dfg.ca.gov/erpdeltaplan/).

2. Project Description

Hypotheses

Design of this study is built from hypotheses that: (1) California's hydrology will change during the 21st century in response to global warming; (2) ecosystem structure and function will respond to changes in California's water supply, population, land use, sea level, constructed habitats and storage-conveyance facilities, and potential levee failures; (3) sufficient information is available to project plausible ranges of change in each of these forcings; (4) climatic, hydrologic, hydrodynamic, water-quality, geomorphic and ecosystem processes are linked in the Bay-Delta-River-Watershed system (henceforth referred to as the **BDRW system**), and thus models to project future conditions there must also be linked; and (5) strategic planning by

CALFED will benefit from mechanistic, ecosystem-scale projections of future forcings and responses, posed as plausible scenarios of system change.

Conceptual Model

The research project described here is based on a conceptual model built from the following principles:

- San Francisco Bay, the Sacramento-San Joaquin Delta, their tributary Rivers and Watersheds are one system of interconnected landscapes.
- The primary linkage medium between these landscapes is surface water including precipitation, runoff, streamflow, and effects of storage, conveyances, consumption, and estuary-ocean exchanges.
- These hydrologic processes are primary drivers of change in the chemical, sedimentological, and biological properties of the BDRW system (and therefore the outcomes of CALFED actions).
- BDRW hydrologic processes will change during the 21st century due to altered global-scale external forcings and regional-to-local scale internal forcings.
- External forcings will reach the BDRW from the atmosphere (as variable air temperature, solar radiation, winds, precipitation, pressure) and from the coastal ocean (regional currents, sea level, tides, temperature).
- Internal forcings include modifications of land use (associated with economic and population trends), structural alterations within the Delta (levee failures, new storage or conveyance facilities or constructed habitats), and altered water operations.
- The overarching conceptual model guiding this project is that: (a) hydrologic processes in the BDRW system will be altered by changes in both external and internal forcings; and (b) system-level effects will include a cascading set of interconnected changes in Bay-Delta hydrodynamics and transports, sediment supplies and geomorphology, habitat and water quality, and distributions and abundance of native and alien species.

We propose to modify and link numerical models of key processes to explore likely responses to plausible future changes in the external and internal forcings that drive BDRW ecosystem dynamics. The changes to be considered will take the form of three types of scenarios (described in more detail below):

- Climate Change
- Population and Land Use Change
- Delta Configurational Change

The cascading effects of changes under these scenarios will be followed as they propagate from the climate system to watersheds to river networks to the Delta and San Francisco Bay.

Plan of Work

The approach links, hierarchically, seven project elements. Along with an eighth category, Project Administration, these constitute the **Statement of Work tasks** (see Task Table, pp.17-18):

① Climate Modeling and Downscaling
② Sacramento-San Joaquin Watershed and San Francisco Bay Modeling
③ Delta Modeling: Hydrodynamics with Temperature and Phytoplankton
④ Sediment, Geomorphology and Tidal-Habitat Modeling

⑤ Fate and Effects of Selenium, Mercury, Silver and Cadmium
⑥ Invasive Species– *Potamocorbula*, *Corbicula*, and *Egeria*
⑦ Native and Alien Fish Population Trends
⑧ Project Administration

These elements are described in the remainder of this section.

Climate Modeling and Downscaling ①

Investigators – Michael Dettinger, Daniel Cayan, Noah Knowles

Problem – General-circulation models (GCMs) of the global climate project that increasing concentrations of atmospheric greenhouse gases will result in a warmer California (Cubasch and Meehl 2001), with temperature increases ranging from about 2 to 5°C by the end of the 21st Century. Projections of future precipitation in California are much more scattered, with most models yielding relatively small precipitation increases or decreases. These changes are projected in the midst of a general tendency for the hydrologic cycle to intensify, so wet episodes become wetter and dry episodes become drier with global warming. Moreover, paleoclimate reconstructions indicate that long and frequent droughts have been more common in California in past centuries, so a return to drought-rich conditions is a plausible scenario of California's 21st century climate. Related to climate change is the potential for warming-related rise in sea level, projected to be 20 to 90 cm by the end of the 21st century (Church and Gregory 2001).

The likely responses of California's watersheds, rivers, and (some) ecosystems to projections of future temperatures and precipitation have been studied and simulated in previous studies (e.g. Gleick 1987; Jeton et al. 1996; Knowles and Cayan 2002, 2004; Dettinger et al. 2004). Earlier snowmelt and runoff, larger and more frequent winter floods, and much drier summertime soil and riverine conditions are projected under all plausible scenarios. A more complete assessment of the potential impacts of climate change on the BDRW system requires inclusion of responses by the high-altitude and low-altitude, managed and unmanaged parts of the watershed and estuarine system, and inclusion of sea-level projections that are consistent with the climatic changes. Realistic projections of 21st Century conditions require inclusion of other forces of change that will occur concurrently with climate change, including population growth and alterations of Delta plumbing. We will identify and characterize linkages from climatic change to meteorological, hydrological, and sea-level responses as the starting place for multidisciplinary assessment of the future BDRW ecosystem.

We will develop several detailed climate-change scenarios, two serving as bookends representing the outer reaches of up-to-date projections, and a third scenario reflecting a future climate with more frequent or sustained droughts and warming, motivated by paleoclimatic results that suggest that such droughts have occurred more than once in California's past:

- Climate Scenario 1: large warming and sea-level rise, fairly stable precipitation
- Climate Scenario 2: small warming and sea-level rise, fairly stable precipitation
- Climate Scenario 3: medium warming and sea-level rise, extended droughts

Tools/Analyses – GCMs simulate climate on coarse (200 km) spatial grids. As part of efforts at Scripps Institution of Oceanography funded by the California Energy Commission, we have been collecting and analyzing simulations of 21st Century climate over California by almost a dozen different GCMs (Dettinger in press). These ongoing efforts will inform our decisions as to the most robust choices of climate scenarios for the proposed study. The collection of simulations will provide the daily-to-monthly climate series that will be "downscaled" for use in this study. Downscaling is the process of interpolating large-scale climate projections down to the local scales (1-10 km) necessary for input to watershed and hydrologic models. Some previous studies have used high-resolution regional climate models nested within the output from a GCM (e.g., Leung et al. 2004). We have examples of such "dynamically downscaled" scenarios from previous studies by the PIs, but, at present, dynamically downscaled scenarios are restricted to snapshots of a decade or so of future climate (by their high computational expense) rather than the continuous 200-yr scenarios that are needed for the proposed study. Thus we will primarily use examples of dynamically downscaled climate-change scenarios to help validate more readily generated statistically downscaled scenarios. Statistical downscaling methods include weather-typing approaches (e.g., Dettinger and Cayan 1992), stochastic weather generators (e.g., Jeton et al. 1996), multiple-regression methods (e.g., Wilby and Dettinger 2000), and deterministic mappings (e.g., Dettinger et al. 2004). Statistical methods are trained to adjust various GCM outputs to match selected statistics of real-world weather observations. In the present study, a new version of the downscaling method of Dettinger et al. (2004) will be the starting point; under the auspices of the California Energy Commission-funded studies mentioned earlier, other, more physically based statistical methods may be developed and used to provide the required downscaled scenarios. The drought scenario will be produced from the historical record as conditioned by paleoclimate reconstructions to achieve specific scenario designs (e.g., Tarboton 1995).

Required Inputs – Climate-change projections for the 21st Century are available as monthly series of surface-air temperatures and precipitation from about eight coupled ocean-atmosphere GCM models (e.g., from http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html). At present, we propose to acquire daily outputs from the National Center for Atmospheric Research's PCM and the British Hadley Center's HadCM3 models which yield, respectively, some of the coolest and warmest climate projections. We will choose among current models to best represent the current range of projected warming rates; thus the specific choice of models may change as our understanding and analysis of available climate-change projections evolves (Dettinger, in press).

Outputs – will be downscaled climate scenarios in the form of daily weather series at 200 stations for the 20th and 21st Century, with concurrent and consistent sets of sea-temperature and sea level variability and trends. A large number of stations specifically chosen to meet the input needs of the other modeling elements described below will be included among the 200 sites; but other sites that may be of use to other aspects of the CALFED Science Program also may be included. Climate variables will include daily surface-air temperature and precipitation, solar insolation, surface humidity, and sea level rise near the mouth of San Francisco Bay. Weather time series for each climate scenario will be the starting place for assessing BDRW responses.

Along with the specific climate-change scenarios described earlier, the overall statistics of an ensemble of as many up-to-date projections as can be obtained of 21st Century climate in the Bay-Delta watershed will be derived by the methods of Dettinger (in press), so that the likelihoods of the particular scenarios provided to the other project elements can be determined and communicated. For example, we will determine what percentage of all projections lie "between" the warmer and cooler scenarios; we will determine what percentage of projections fall between the drier and "unchanged" precipitation scenarios. These measures of the likelihoods of the scenarios will provide a crucial context for the uncertainty characterizations in the rest of the study, a context that all recent "bookending" studies of climate-change impacts in California have lacked. Additional scenarios that reflect other parts of the distribution of available climate-change projections will be provided to project elements that can use them. The primary climate scenarios described above will also be provided, online, to other studies that want to parallel our efforts.

Sacramento-San Joaquin Watershed and San Francisco Bay Modeling ②a,b

Investigators – Noah Knowles, Daniel Cayan, Michael Dettinger, Dave Peterson (with consultation from Hugo Hidalgo, DWR Modeling Support Branch, and USBR Division of Planning)

Problem – Changes in climate, land use, and freshwater demand must be translated into downstream hydrologic changes in order to produce a meaningful assessment of their ecological impacts. This element will develop and apply modeling tools to assess responses of the watershed and estuary to the three climate-change scenarios described above, in addition to Delta configuration change and human population/land use change scenarios (described below). Watershed models will simulate responses of streamflow and temperature above and below major reservoirs, and salinity of Delta inflows. An estuarine model will be used to assess responses of salinity and residual currents in San Francisco Bay.

Tools/Analyses –

②**a Hydrologic Model.** At the core of this project element, the Bay-Delta Watershed Model (BDWM) is a physically based model of hydrologic processes that generate streamflow. It operates at a daily time step with primary inputs of precipitation and air temperature (Knowles 2000). The model simulates hydrologic variability in the entire Sacramento-San Joaquin watershed at a spatial resolution of 4 km. All model parameters are determined from fundamental physical considerations of soil properties, land cover, and topography, so BDWM requires minimal calibration and is uniquely well suited for studies of non-historical hydrologic scenarios as in this study. It is also computationally efficient, enabling the numerous simulations required to evaluate uncertainty (see below). The model simulates snow accumulation and ablation (using Tarboton and Luce 1996) and soil moisture fluxes, and contains a river routing component that integrates streamflow from throughout the watershed to determine total outflow.

An operations component will be coupled to BDWM, using DWR's CALSIM II (http://modeling.water.ca.gov/hydro/model/index.html). Changes in CALSIM hydrological inputs corresponding to the different scenarios will be derived from hydrologic simulations using the BDWM. These altered inputs will then be used by Dr. Hugo Hidalgo of Scripps Institution of Oceanography to drive CALSIM, and the results will be compared with outputs from a "base run" using unchanged inputs, providing an assessment of the role of management in translating upstream changes in hydrology, freshwater demand, and land use into downstream impacts, including changes in Delta inflows. The DWR Modeling support branch has agreed to provide additional assistance in validating and interpreting output from the CALSIM runs. The CALSIM simulations will also provide projections of the likely responses of Delta-inflow salinities to the scenarios evaluated. The USBR Division of Planning has agreed to apply their reservoir- and stream-temperature model RST to assess temperature changes under each scenario. The USBR model uses inputs of air temperature at selected stations, output from the CALSIM model, and monthly average reservoir inflow temperatures to compute monthly reservoir and stream temperatures at and below major reservoirs. Future reservoir inflow temperature variations will be estimated by developing statistical models of historical high-altitude stream-temperature responses to factors including air temperature and fractions of inflow composed of snowmelt and rainfall, and applying those models to the future climate projections.

②**b SF Bay Model.** The BDWM has been linked to the UP estuarine model (Uncles and Peterson 1995), which calculates daily salinity and axial residual currents in San Francisco Bay and Delta. The UP model reproduces patterns of salinity variability at weekly to interannual time scales over a wide range of flow regimes (Knowles et al. 1997), and is computationally efficient enough to allow the numerous runs needed to evaluate ensembles of climatic scenarios, allowing evaluation of uncertainty. The model has been used to assess the potential estuarine impact of the projected upstream 2060 hydrologic changes. These results do not yet include effects of sea level rise, management adaptations, or potential Delta configurational changes, all of which will be included in the proposed scenario evaluations, providing a more complete assessment of the interactions of the various potential influences and their ultimate impact on the estuary.

Required Inputs – For each climate-change scenario, estimates of sea level, sea temperature, air temperature, specific humidity, insolation, and precipitation over the watershed will be provided as described in the climate element①. The land-use/population change scenarios require forecasts of changes in the watershed including urbanization, farmland conversion, and changes in freshwater demand patterns due to population trends. This information will be obtained through DWR Modeling Support Branch for projected 2030 conditions (these data are currently in preparation for Bulletin 160-04, the California Water Plan Update: http://www.waterplan.water.ca.gov/b160/indexb160.html). For scenarios where in-Delta effects on Delta outflow are deemed significant, output from Delta TRIM③ will drive the UP model; otherwise outflows from BDWM②**a** will drive UP directly.

Outputs – will be salinity and residual currents throughout the estuary, inflows from the watershed via the Sacramento, San Joaquin, and "east side" rivers, and flow rates, salinities, and temperatures in the rivers of the watershed. Flows, temperatures, and estuarine salinities will be simulated daily for the 20th and 21st centuries to provide representations not only of trending conditions, but also of plausible daily-interdecadal variations in the altered system. The hydrologic and estuarine models will provide altered salinity, inflows, and temperatures at the Delta boundaries for use in the Delta modeling element③. Projected changes in streamflow rates, temperatures, and salinity in the watershed will be used by the sediment-geomorphology④, contaminants⑤, invasive species⑥ and fish⑦ elements in addition to more detailed outputs produced by the Delta modeling element③.

In addition to the outputs corresponding to the specific scenarios described above, the ensembles of up-to-date climate projections described in the climate element① will be used to drive corresponding ensemble simulations of the BDWM, CALSIM II, and UP models. This will allow provision of ensemble outputs of Delta inflow and river and estuarine salinity, among other quantities, to those project elements that can use them. Further, these ensemble runs will allow characterization of the specific scenario outputs from these models in terms of the quantitative "bookending" probabilities described in the climate element①, allowing the estimates of uncertainty to be propagated more completely to other project elements.

Delta Modeling: Hydrodynamics with Temperature and Phytoplankton ③

Investigators – Nancy Monsen, Lisa Lucas, James Cloern, Postdoctoral position to be hired (with consultation from Mark Stacey)

Problem – The Delta is the central hub that links hydrologically driven variability in the watersheds and rivers to the estuary. It supplies drinking water to 23 million Californians, is habitat for native species, provides a conduit supplying water to the State Water Project (SWP) and Central Valley Project (CVP), sustains diverse agriculture in farmlands protected from inundation by vulnerable levees, and will be transformed by CALFED actions to build new habitats and water storage-conveyance facilities.

Climate-driven hydrologic change and sea level rise will potentially lead to profound changes in hydrodynamic processes within the Delta, including those controlling water transport, quality and temperature. In addition, anthropogenic changes, including new Delta structures, and catastrophic levee failure may also occur during the next 50 years and could significantly change transport through the Delta. We will apply a high-resolution hydrodynamic model (Delta TRIM) that runs in 2-D (depth-averaged) or 3-D mode to assess transport, water quality and temperature responses to the prescribed scenarios of climate change, population and land use change, and physical changes to the Delta. These scenarios will help assess the significance of changes in circulation due to climate and population change compared to those due to physical changes in the Delta.

Tools/Analyses –There will be three separate yet interconnected modeling components: a) Delta hydrodynamic modeling (stage, velocity, and scalar transport), b) temperature modeling, and c) phytoplankton dynamics (modeled as biomass and primary production). The core routines in Delta TRIM are the TRIM3D hydrodynamic model (Casulli and Cattani 1994) and the transport routines developed by Gross et al. (1999). Delta TRIM computes tidal-scale water motions using a fine scale (50 m) computation grid that resolves currents and stage in the small, interconnected channels characteristic of the Delta. Monsen (2001) incorporated Delta-specific operations such as gate operations, pumping and agricultural diversions and returns into the TRIM3D model, and created the associated bathymetric grid. The model has been calibrated and verified (depth-averaged 2D mode) by comparing model results to measurements throughout Suisun Bay and the Delta for several time periods spanning a range of inflows and operational manipulations.

Dr. Mark Stacey (University of California Berkeley) and graduate students are currently developing a temperature model (based on Rosati and Miyakoda 1988) coupled to TRIM3D for analysis of heating and cooling in Mildred Island, a sub-domain of the Delta. The temperature model is being calibrated against an extensive dataset collected from a current CALFED-funded study, but it has not been extended to the complete Delta domain.

We propose to also model trends in Delta phytoplankton biomass and production because previous studies have demonstrated that phytoplankton primary production is the most important source of organic matter fueling secondary production in the Delta (Jassby and Cloern 2000). Phytoplankton biomass is the dominant food supply to the Delta's planktonic food webs that produce forage for larval and juvenile fish (Sobczak et al. 2002). Delta-wide primary production is low compared to estuaries globally, and this damped food-supply function leads to food limitation of freshwater zooplankton such as cladocerans (Mueller-Solger et al. 2003). Delta-wide primary production has declined significantly in the past three decades (Jassby et al. 2002), and we will apply an existing model (TRIM-BIO) to project future changes under the set of scenarios prescribed above. TRIM-BIO is a depth-averaged hydrodynamic model (TRIM2D) with incorporated depth-averaged phytoplankton dynamics, developed by Lucas et al. (1999) to study interactions between hydrodynamic processes and phytoplankton dynamics in shallow estuaries. Modeling work under a current CALFED grant involves adapting the TRIM-BIO biological module for use with the TRIM3D hydrodynamic model for two sub-domains of the Delta (Franks Tract and Mildred Island). The biological module will calculate the time- and space-dependent photosynthesis, respiration and growth rate of phytoplankton, as well as consumption by zooplankton and benthic consumers, while they are transported through the Delta domain. Phytoplankton growth and losses to grazing will be modeled as by Lucas et al. (2002) and Lucas and Cloern (2002).

We have selected TRIM3D as the base Delta hydrodynamic model for a variety of reasons. First, the hydrodynamic code and transport routines appear extensively in the peer-reviewed literature. Gross et al. (1999) showed that the transport scheme conserves mass, a key attribute for biological models. Second, the model is multidimensional. This allows us to better represent exchange between the shallow water environments and the channels. Third, depth-dependent friction factors are used to calibrate TRIM3D. Because this tuning factor is globally valid, specific regions within the Delta TRIM domain do not have special tuning coefficients. Therefore, bathymetric changes to the system can be modeled without invalidating the model calibration. Fourth, Lucas has previously demonstrated the ability to couple phytoplankton and hydrodynamics with TRIM for a South Bay application (Lucas et al. 1999a, Lucas et al. 1999b). Fifth, the work of linking the temperature module with TRIM is already in progress.

The first phase of the Delta modeling effort will involve model enhancements required to address the climate change scenarios. 1) The bathymetric grid for the Delta TRIM model will be improved and the Sacramento River boundary relocated so the model can use flow input data from BDWM② and calculate transport through the Yolo Bypass. Once the bathymetry grid is modified to include the Yolo Bypass, the Delta TRIM model will be re-calibrated and verified using existing datasets from several time periods spanning a range of inflows and operational manipulations. 2) The domain of the temperature module will be expanded from the current sub-domain around Mildred Island to include the proposed extended domain of Delta TRIM (Delta, Suisun Bay, and the Yolo Bypass). The temperature module will be calibrated and verified in 2D (depth-averaged) mode against water temperature measurements throughout the Delta using light attenuation as the tuning parameter. 3) The phytoplankton modeling will also be expanded to include the full Delta TRIM domain. In the second phase of the Delta modeling effort, the models will be used as a tool to investigate both physical and climate changes to the system. Because Delta TRIM is highly resolved spatially, the model runs will be limited temporally to a 3-6 month period for each scenario. Errors associated with the Delta modeling element of this project will be determined by comparing model output for historical cases with measurements for simulation periods that encompass both wet and dry seasons and a range of habitats (e.g. deep channels, shallower open water areas). Calculated velocity, stage, flow, salinity, temperature, and phytoplankton biomass from the base hydrodynamic model, temperature module, and biological module will be compared with local- and Delta-scale measurements. These data will include measurements from previous studies including current CALFED-funded measurements in the Mildred Island, Franks Tract, and Three Mile Slough. We will also use data from the USGS flow network and IEP'S Environmental Monitoring Program (stage, salinity and temperature stations throughout the Delta). Metrics to be used for quantifying the comparisons may include magnitude and phase errors derived from harmonic analysis for tidally influenced parameters (e.g. flow, stage) and bulk quantities such as net flow and tidally or spatially averaged salinity, temperature, and chlorophyll.

Required inputs and outputs are described in the following.

<u>Base Delta TRIM hydrodynamic model</u>

Inputs – Two scenarios of altered Delta bathymetric configuration will be compared to the baseline Delta physical configuration of 2003 using historical data to drive hydrologic boundary conditions. The first scenario of intentional channel transformation is based on structural changes described in the CALFED Conveyance Program Multi-Year Program Plan. The second scenario of unintentional reconfiguration depicts catastrophic levee failure from a large earthquake, based on the CALFED Levee System Integrity Program Plan. Delta TRIM is driven by boundary conditions of river inflow (provided either from historical data or BDWM②**a**), and tide stage at Martinez (provided either from historical data or the climate element①). Time-varying salinity at the upstream and downstream boundaries for the climate change scenarios will be provided by BDWM②**a** and UP②**b**, so this model will process inputs from three prescribed physical representations of the Delta and output from three models driven, ultimately, by GCMs.

Outputs – For each (3-6 month) simulation experiment, Delta TRIM will compute tidal and residual current speeds and directions, stage, salinity, source water mixture, and residence time across a 50-m grid over the full Delta domain. These outputs will provide projections of the future Delta under the scenarios described, including the following responses: timing and duration of Yolo Bypass inundations, salinity and source-water mixture at municipal intakes or export pumps, transport routes and rates throughout the Delta.

Temperature model

Inputs – Meteorological data (air temperature, wind speed, and solar radiation) determine the heat input to the temperature module. The Delta TRIM hydrodynamic model is used to determine horizontal transport.. For the physical change scenarios, observed temperatures at stations near each boundary and meteorological data from stations within the Delta will drive the model. GCMs① will provide the meteorological data. The USBR model②**a** will provide river boundary temperature data. GCMs, coupled with historical temperature profiles in SF Bay, will be used to develop statistical models to drive the western (bayside) temperature boundary condition.

Outputs – Temperature modeling will provide seasonal temperature distributions throughout the Delta. Temperature distributions are key information for both the invasives⑥ and the fish⑦ elements of this project. Key questions to be addressed are: 1) How do shifts in timing and flow through the Yolo Bypass change the heat budget of the Delta, and) 2)What regions of the Delta will become warmer or cooler compared to the base case?

Phytoplankton model

Inputs – Effective phytoplankton growth is a function of water depth, water temperature, solar irradiance (PAR), light attenuation coefficients (derived from suspended sediment concentrations), nutrient concentrations, benthic grazing rates, and zooplankton grazing rates. As with the temperature model, Delta TRIM drives transport of phytoplankton biomass. For the physical change scenarios, observed meteorological data will provide solar radiation, and light attenuation coefficients will be estimated from existing field data. For the climate change scenarios, GCMs① will provide meteorological data and the sediment transport element④ of this project will assist with estimation of light attenuation coefficients. Zooplankton grazing estimates will be based on the work of Lopez et al. (in review). Nutrients will be assumed replete for all scenarios, based on assessement of IEP monitoring data demonstrating that nutrients rarely limit algal growth in the Delta (Jassby et al. 2002). Boundary conditions for phytoplankton biomass transport into the system will be based on discrete and continuous chlorophyll a measurements by CDWR near the domain boundaries. Benthic grazing estimates will be based on an extensive survey of the benthos performed during a current CALFED-funded project, as modified by the invasive species element⑥ of this project. The phytoplankton-modeling element will provide a check on the phytoplankton biomass estimated within STELLA⑥ for developing benthic grazing rates.

Outputs – For scenarios resulting in extreme changes in transport rates (i.e. residence times),turbidity, grazing, or average water depth, we will calculate projected changes in the distribution and export of phytoplankton biomass. Phytoplankton primary productivity (PP) is the major metric by which we will compare various scenarios to the current Delta, thus questions we propose to answer include: 1) For a given scenario, does PP increase or decrease? 2) If PP increases, where (geographically, mechanistically) does the increase come from? 3) If PP decreases, what is the mechanism? Hydrodynamic flux, grazing, and growth rates will be quantitatively compared to generate a mass balance and answer these questions.

Sediment, Geomorphology and Tidal-Habitat Modeling ④

Investigators – David Schoellhamer, Bruce Jaffe, and Neil Ganju

Problem – Sediment transport and geomorphology are fundamental to the creation and maintenance of tidal habitats. The prescribed scenarios will affect the evolution of San Francisco Bay-Delta tidal habitats. We will link separate models of Delta sedimentation, sediment supply to the estuarine subembayments, and subsequent ocean exchange, sediment redistribution, and geomorphic evolution within the estuary. The models will be as simple as possible so that we can hindcast 130 years of bathymetry data, simulate 100 years into the future, and run numerous simulations to evaluate uncertainty, simulate stochastic hydrology, and evaluate multiple scenarios.

Tools/Analyses – We will construct and link models to compute: (1) Delta sedimentation– changes to the Delta sediment budget by Wright and Schoellhamer will be estimated by estimating loads and distribution as a function of freshwater inflows. (2) Sediment supply to the subembayments of the estuary– this is the primary factor affecting geomorphic evolution and habitat creation. A one-dimensional or modified Uncles-Peterson multi-box model (Lionberger 2003) will be used. (3) Sediment deposition and redistribution within subembayments of the estuary– the public-domain ROMS model (http://marine.rutgers.edu/po), which was used previously to model hydrodynamics and sediment transport in Suisun Bay (Warner et al., 2004) will be refined and tested for sediment supply and redistribution simulations, and long-term geomorphic evolution simulations. Presently, the refined model is being developed for Suisun Bay in collaboration with UC Davis through a University of California Water Resources Center Grant. A combination of the Delft 2DH (Roelvink et al. 2001) and 3D (Winterwerp 2001) coupled hydrodynamic, sand and mud transport models and morphology models within the Delft3D system (http://www.netcoast.nl/tools/rikz/delft3d.htm and http://www.wldelft.nl/soft/d3d/intro/) will be used in San Pablo Bay. Delft models are currently being used by Dan Hanes and Patrick Barnard, USGS, to model sediment exchange between the estuary and ocean. The knowledge gained from the ROMS and Delft models will be used to formulate a simplified model of geomorphic response to scenarios. Once the models are crosschecked and validated for benchmark cases, use of these two models optimizes existing collaborations and resources and improves confidence in the models by allowing comparison of results. (4) Future geomorphology of San Francisco Bay– the geomorphic model will compute tidal and wind wave redistribution of sediments and the subsequent evolution of shallow-water habitat, mudflats, and tidal wetlands. Geomorphic modeling techniques, including input filtering, empirical relations, and process-based modeling will be implemented and compared.

Required Inputs – For model calibration and validation, we will use the large database compiled by USGS and other agencies on bathymetry (Jaffe et al., in press; Jaffe et al. 1998; Capiella et al. 1999; Foxgrover et al. 2004), suspended-sediment concentration (Buchanan and Ganju 2004), and tributary inflow. Flow from the Delta and east side-rivers will be provided by the watershed modeling element②**a**, in the varying scenarios created by the climate modeling team. Inputs to the Delta sedimentation model will be water discharge and a sediment rating curve developed by extrapolating data presented by Wright and Schoellhamer (2004). Inputs to the sediment delivery model will be water and sediment yield from the Delta sedimentation model, rate of sea-level rise from the GCMs①, and the Delta structural configurations prescribed above (in ③). Inputs to the geomorphic evolution model will be output from the sediment delivery model, sediment delivery from local tributaries (estimated by regression of historical sediment loads on flow rates), and sea level rise and wind climatology from the GCMs①. Historical Suisun Bay (Capiella et al. 1999) and San Pablo Bay (Jaffe et al., in press; Jaffe et al. 1998) bathymetric analyses of the past century will be used to test the Bay geomorphology model.

Outputs – We will estimate changes in Delta sedimentation for each climate change scenario. The sediment supply model will route sediment from the Delta to the subembayments of the estuary. The geomorphic evolution models will determine altered bathymetry in San Pablo and Suisun Bays, which will be applied in the UP model②**b** to estimate resulting changes in salt transport into the Delta. In addition, geomorphic evolution models will simulate long-term changes in depth, and therefore habitat evolution within San Francisco Bay, which will be used by the invasives⑥ and fish⑦ studies in this project.

Fate and Effects of Selenium, Mercury, and Cadmium ⑤

Investigator – Robin Stewart

Problem – Pollutant effects in San Francisco Bay are tied in complex and interactive ways to hydrology, hydrodynamics, sediment transport, ecological processes and food web structure. Three metals have been shown specifically to have adverse effects: selenium has disrupted food webs in the Central Valley (Luoma and Presser 2000); health advisories constrain human consumption of Bay-Delta fish because of mercury contamination and cadmium has historically impaired invertebrate growth in South San Francisco Bay (Hornberger et al. 2000; Brown et al. 2003). These metals have distinct origins and delivery pathways: Se from the San Joaquin Valley and refineries, Hg from the Sacramento River, and Cd from mining in the Shasta district (Cain et al. 2000). The concentrations of these toxicants in the Delta and Bay vary with loadings from the source, amount of runoff, changes in sediment load, chemistry of the runoff, and the source of runoff. The effects of the contaminants are determined by their concentration, chemistry and bioavailability in the Bay or Delta. The goal here is to contrast how future hydrologic scenarios might alter concentrations of three of these contaminants— selenium, mercury, and cadmium— and the implications of those changes for bioavailability and potential adverse effects.

Tools/Analyses – We will extend to the three contaminants the approach used to compute selenium effects in San Francisco Bay for varying scenarios of altered loadings, developed by Luoma and Presser (2000). The approach establishes metal loadings scenarios from source-specific information. Inflows to the Bay (including source and chemistry) are used to determine concentrations. Partitioning coefficients and speciation are used to differentiate particulate and dissolved concentrations; a dynamic bioaccumulation model (DYMBAM, Schlekat et al. 2001) calculates uptake by the first trophic level; then empirically derived trophic-partitioning constants are used to calculate trophic transfer through the foodweb. For example, Luoma and Presser (2000) used this approach to propagate Se transfer through a bivalve-based food web to compute bioaccumulation in sturgeon and scaup. The approach will be applied to assess bioaccumulation, trophic transfer, and potential effects of three metals on predators⑦ from different food webs: invasive predators that feed from the water column (e.g. striped bass for mercury and selenium) and native predators (e.g. Sacramento splittail and/or sturgeon, which feed on bivalves⑥).

Required Inputs – Loading data for mercury and cadmium are available from the existing literature, and will be assembled for this study. Model bioaccumulation coefficients for mercury and cadmium are being developed for invertebrate species and for fish (Croteau, in preparation; Fisher, N. SUNY, CALFED ERP-02 P40). Input from other project elements will be used to define different scenarios of source loading and/or runoff influences. For example, if inflows from the SJR increase relative to Sacramento R. inflows (from ②**a**), Se loads to and concentrations in the Bay-Delta will increase. The timing of such increases is crucial to determine Se exposures of migratory predators (information from fish element⑦). Similarly, if Sacramento R. inflows increase relative to the SJR, mercury and cadmium loads and concentrations could increase.

Outputs – For each scenario, we will compare projected monthly inflows, sources, sediment loads and either metal loadings or metal concentrations using flow outputs from BDWM② and transports computed by Delta TRIM③. The bioavailability/effects model will then be used to constrain influences of these changes on upper trophic level animals. The output will be a comparison, under different Delta scenarios, of potential stresses to selected invasive and native predators from different food webs. This stress can be one of the considerations in determining the suitability of ecological conditions in both the fish⑦ and invertebrate⑥ elements of the project.

Invasive Species– ***Potamocorbula*****,** ***Corbicula*****, and** ***Egeria*** **⑥**

Investigator – Janet Thompson

Problem – One of the ERP goals is to "reduce the negative impacts of invasive species". We will look at three species that have displayed significant ecosystem effects and that have been sufficiently studied to allow us to project their distribution in response to the scenarios described in this project. Two of these species, the filter-feeding bivalves Potamocorbula amurensis (PA) and Corbicula fluminea (CF), have previously been shown to change the food web by controlling the biomass of phytoplankton at the base of the food web (Alpine and Cloern 1992, Lucas et al. 2002). These alien bivalves have the potential to impede progress of CALFED's ERP by consuming zooplankton, outcompeting native zooplankton, shrimp, and larval fish for food (Kimmerer 2002), and increasing the trophic transfer of contaminants (Stewart et al. 2004, Linville et al. 2002). The third exotic species, Egeria densa (ED), is a perennial freshwater submerged macrophyte that occupies about 8% of the surface area of the Delta and has transformed the shallow water habitat in the Delta to one that is now dominated by a denser (leaves and plants), more widely distributed, less seasonally variable, and more shade-tolerant species than was there before. As summarized by Brown (2003), the fish community in ED tends to be dominated by alien species and the edge of the ED beds dominated by alien piscivorous fish, so the few natives that appear to benefit from the food and refuge available in the ED are potentially more likely to be preyed upon. Areas such as Suisun Marsh, which presently has no beds of ED, may be prime restoration areas (Brown 2003) and it is important that we be able to understand conditions which may encourage ED's spread. Thus, we will assess potential changes in the distribution, biomass, and food consumption of PA and CF, and in the distribution and relative density of ED, for each scenario.

Tools/Analyses – We will construct several statistical models (e.g., GAM, logistic regression and CART) of the three species to estimate their potential distribution in the Bay and Delta for each scenario based on their known physiological tolerances and field distribution data. Validity of all models will be determined by comparison to the following field data: (1) Potamocorbula's population structure and distribution since 1986 (Thompson 2004 and unpublished data); (2) Corbicula's present distribution (Parchaso and Thompson 2004), growth rates (USGS unpublished data, Foe and Knight 1985), and its population structure and recruitment history as reported by the CA Dept. of Water Resources Environmental Monitoring Program since 1977; and (3) Egeria distribution as reported by the CA Dept. of Boating and Waterways (2001) and the Egeria Project at the Romberg Tiburon Center (http://romberg.sfsu.edu/~egeria/). In addition, we will estimate biomass distribution for specified habitats in the Bay/Delta for CF and PA using a relatively inexpensive, "off the shelf" modeling program, STELLA (Ruth and Lindholm 2002). Both of these species dominate the community when they are present, recover quickly from disturbance, and interspecific competition does not appear to be a limiting factor for either species (Nichols et al. 1990, Thompson 2004, McMahon 1999). Thus we believe there is potential for successful multi-dimensional landscape models of these species that dynamically link to hydrographic and phytoplankton models at some time in the future. We expect the STELLA models to give us order-of-magnitude estimates of biomass (and thus of grazing rate), and to highlight the life history parameters most in need of study before larger modeling efforts are attempted. Data will be reported by habitat type which will be defined by the environmental factors determined to limit the distribution of each species, based on the statistical modeling effort.

Two types of errors will be reported for predicted distributions based on statistical tools. The first type of error, that associated with the statistical method, is easiest to calculate. The second type of error is that in which the presence of an organism is predicted at a location where they are not present, or conversely, due to some unmeasured environmental factor. This type of error is more difficult to assess. Therefore we will establish that the predictions are potential distributions within the statistical error limits. Errors associated with rate parameters (e.g., growth), environmental variables (e.g. temperature), and model numerics (reviewed in Ruth and Lindholm 2002) will be assessed by running STELLA in Monte Carlo fashion with random sampling from parameter and input variable distributions. Overall error will be determined by sampling from all input and parameter distributions simultaneously, and the sensitivity of the species density and biomass to the model parameters will be established by applying this error propagation approach to each parameter separately. This sensitivity analysis will increase our understanding of the species and also help establish which errors are most important in our predictions. We will use this knowledge to reduce the error where possible, or at a minimum know which parameters are most important in our error propagation analyses. Model results for present-day conditions will be compared against known distributions and biomass values for the species during wet, dry and average hydrologic years to demonstrate the ramifications of these errors.

Required Inputs – Distribution models will require future scenarios values for seasonal streamflow, water temperature and salinity, phytoplankton biomass, current velocity, flood frequency, turbidity, and habitat evolution produced from the modeling elements described above (②**a,b**, ③, and ④). STELLA will require some of these same environmental variables in addition to biological estimates of rate of cohort (age)-specific growth and mortality, fecundity, recruitment, immigration, and emigration at a minimum. The Bay/Delta is in the mid-latitudinal range for both of these exotic bivalves and preliminary work by the USGS and others has shown that growth rate, reproductive rate, fecundity, and recruitment are most closely related to food and temperature in this system. Therefore these rates will be estimated through a combination of published rates and analysis of local field data. Phytoplankton biomass will thus be required to run STELLA. Unfortunately, neither the time step or the sophistication of the population models can match with those of the TRIM ③ phytoplankton module at this time, and we will need to develop a submodel to estimate phytoplankton biomass assuming a local balance between phytoplankton growth rate and bivalve grazing rate (phytoplankton biomass will change as function of ③ and ④ model-derived values of temperature and turbidity, and published estimates of zooplankton grazing and irradiance). Phytoplankton biomass in this simple model will be reduced by a parameter derived from phytoplankton growth rate (from TRIM③) and clam grazing rate during each month, if needed (e.g., if depth-normalized grazing rate is twice the growth rate of phytoplankton, the biomass level will be reduced by half as a first estimate). Seasonal phytoplankton biomass will be compared to that predicted by TRIM (using the newly derived benthic grazing rates) and will be adjusted if needed. If necessary, we will iteratively run the STELLA models with TRIM to ensure the correct benthic grazing rate is being applied for the appropriate phytoplankton biomass levels in TRIM. Initial conditions in the model will assume population structure and species distributions that are consistent with what we find today. A short "conditioning" period will be used to stabilize the phytoplankton submodel and clam growth model at the beginning of the model runs.

Outputs – will include, for each scenario: (1) Seasonal estimates of the distribution for *Egeria, Corbicula* and *Potamocorbula* based on habitat type, throughout Suisun Bay and the Delta; (2) Spatial distribution of the seasonal biomass levels and grazing rates for *Potamocorbula* (annual distributions for *Corbicula*) based on habitat type; monthly data will be available when possible for critical periods in the TRIM phytoplankton module and contaminant metals models. Grazing rates will be estimated as described in Lucas et al. (2002) and Thompson (2004).

Native and Alien Fish Population Trends ⑦

Investigator – Larry R. Brown

Problem – Restoration of native fish populations is a significant goal of CALFED's Ecosystem Restoration Program (ERP). Various management strategies are presently being considered or implemented to accomplish such restoration; however, it is unclear if the benefits of such strategies would be maintained in response to the hydrologic and physical changes in ecosystems that could occur in response to changes in climate, water use, and physical configuration. Fish species of the BDRW system are affected by many environmental factors (Bennett and Moyle 1996), including those responsive to climatic-hydrologic change: salinity distribution as indexed by "X2" (Jassby et al. 1995, Kimmerer 2002); timing and duration of floodplain inundation (Sommer et al. 2001); flow and temperature as they affect spawning and growth (Feyrer and Healey 2003); the balance between native and alien fishes (Brown and Ford 2002); habitat quality as influenced by the distribution of *Egeria densa* (Brown 2003); stream temperature as it affects anadromous salmonids during upstream migration, spawning, and rearing (Moyle 2002); and high flow events that mobilize streambeds resulting in the loss of incubating eggs, or move larvae into unsuitable areas. The objective of this element is to determine if populations of selected native and alien fish species are likely to increase, decrease, or remain constant in response to environmental changes expected based on the scenarios defined above.

Tools/Analyses – This project element will include two tasks. The first task will be to maintain communication with fisheries resource managers. Communication is needed so that the project team can remain informed about the critical information needs of managers, managers can remain informed about the progress of other project elements, and managers can remain informed about the degree to which the project team will be able to meet their needs. The PI will convene a committee of agency and academic scientists to fulfill this task. The group will meet face-to-face at least once a year with additional communications by e-mail and other methods as warranted.

The second task will be to assess potential population responses through integration of quantitative depictions of future environments with species-specific ecophysiological and life-history information for target species. Assessments will comprise a series of subtasks:

- Construct a qualitative life-history model based on existing information for each species of interest. For some species, models already exist (e.g., striped bass, splittail, anadromous salmonids). For others, models will have to be constructed from the literature and local information. The models will identify the periods in the life cycle when each species would be most vulnerable to changes in temperature, salinity, flow, and habitat changes.
- Assess the likely population effects of the scenarios by comparing outputs of salinity and temperature distributions with salinity and temperature preferences/tolerances of native and alien fishes.
- Assess the likely population effects of the scenarios by comparing outputs of flow patterns

with available information on the responses of native and alien fishes to flow regime.

- Assess the likely population effects of the scenarios regarding the fate and effects of selenium, mercury, silver and cadmium for the species modeled.
- Assess the likely population effects of changes in the distribution and density of *Egeria densa* to the extent possible given values and confidence in predicted salinity field, water temperatures and bathymetry from the Delta models.
- Predict overall responses (positive, negative, neutral) of fish populations to changes in temperature, salinity, flow, and habitat predicted by the scenarios.
- Summarize the predictions for the individual species into an integrated prediction for the fish community as a whole.

It is likely that sufficient information is available to construct life-history models for most of the common native and alien species. Evaluations of individual species responses will likely progress from professional judgment and simple conceptual models to predictions from simple qualitative models, such as loop analysis (Puccia and Levins 1985). The qualitative approach is necessary because actual population sizes of most fish species in the Delta are unknown, making quantitative evaluations impossible.

Required Inputs – For Task 2, assessments of population responses will begin with outputs from GCMs①, BDWM②**a**, Delta TRIM③, UP②**b**, and the geomorphic models④ as future scenarios of air and water temperature, seasonal streamflow and salinity distributions, Bay-Delta circulation patterns, flood frequency and floodplain inundation, and habitat mosaics. Assessments of the effects of changes in contaminants will be limited to the species modeled by Stewart⑤. Presently, such models are planned for striped bass, Sacramento splittail, and white sturgeon. Assessments of the distribution and relative density of the alien macrophyte *Egeria densa*⑥ will also be incorporated to the extent possible. Salinity, temperature and habitat preferences/tolerances of native and alien fishes will be determined from the literature. Responses of various species to changes in flow regime, such as severity and frequency of flood events and inundation of floodplain will also be assessed from the literature. Data collected by the Interagency Ecological Program and other local programs will be evaluated including fall mid-water trawl, summer townet, 20-mm survey, and Delta resident shoreline fish monitoring. Sufficient literature or local information must be available to construct a life-cycle model for each species to be assessed. Existing, locally derived life-cycle models will be utilized if available.

Outputs – Task 1 will inform all the project elements about the information needs of managers. Outputs of Task 2 will include: (1) a simple life-cycle model for each alien and native species considered; (2) an assessment of the likely population effects for those species of changes in temperature, salinity, habitat, and flow regime; and (3) an integrated community assessment of such changes representing visions of trends of fish community responses to a range of future conditions in the BDRW system.

Project Administration ⑧

Investigators – James E. Cloern, Noah Knowles

Coordinate information exchange between Tasks 1-7. Coordinate product dissemination, budget reporting, and delivery of progress reports.

Task Table: task summary, schedule and list of deliverables

task ID	task name	start month	end month	personnel involved	description	deliverables
1	Climate Modeling	1	36	Dettinger, Michael D., PhD. Cayan, Daniel R., PhD. Peterson, David H., PhD. Knowles, Noah, PhD. *Postdoc Task 1 Operations Modeler	Use outputs of selected GCM models and Operations Models to develop detailed scenarios of climate change in California through the 21st century.	Daily weather series at 200 stations for the 20th and 21st centuries with concurrent sets of sea temperature and sea level variability and trends.
2	Watershed -Estuary Modeling	1	36	Dettinger, Michael D., PhD. Cayan, Daniel R., PhD. Peterson, David H., PhD. Knowles, Noah, PhD.	Apply the watershed model BDWM to compute runoff and inflows to the Delta under scenarios prescribed in Task 1. Apply the model UP to compute currents, salinity and temperature in San Francisco Bay under these scenarios.	Computed salinity and currents in San Francisco Bay, Delta inflows from its tributary rivers, flow rates, salinities and temperatures in the rivers.
3	Delta Modeling	1	36	Cloern, James E., PhD. Lucas, Lisa L., PhD. Monsen, Nancy E., PhD. *Postdoc Task 3	Apply the model DeltaTRIM to compute tidal currents/stage, water temperature and phytoplankton biomass and primary production in the Delta under scenarios prescribed in Task1.	Computed tidal current speeds and direction, stage, salinity, source water mixture and residence time in the Delta. Computed directional changes in phytoplankton biomass and primary production in the Delta.
4	Sediment, Geomorphology and Tidal habitat Modeling	1	36	Ganju, Neil K., PhD. Schoellhamer, David, PhD. Jaffe, Bruce., PhD. *Postdoc Task 4	Construct and link models to compute sediment inputs to the Delta and downstream embayments of San Francisco Bay, patterns of sediment deposition and redistributions, and future geomorphology of San Francisco Bay.	Computed changes in sediment supply and deposition in the Delta and San Francisco Bay. Computed changes in geomorphology of San Francisco Bay including long-term changes in habitats.

5	Fate and Effects of Se, Hg, and Cd	1	36	Stewart, A. Robin, PhD. *Postdoc Task 5	Project changes in the loadings and bioaccumulation of toxic contaminants in the Delta and San Francisco Bay.	Projected riverine loadings of selenium, mercury, and cadmium to the central Delta and Suisun Bay. Projected trends of change in bioaccumulation of these elements within Bay-Delta food webs.
6	Invasive Species Potamocorbula, Corbicula and Egeria	1	36	Thompson, Janet K., PhD. *Biologist 1 Task 6 *Biologist 2 Task 6	Use outputs from Tasks 1-4 to assess the potential spread and population growth of these key alien species in the Delta under prescribed scenarios of future change.	Seasonal estimates of the biomass distribution for Potamocorbula, annual estimates for Corbicula, and qualitative distributions of Egeria density throughout Suisun Bay and the Delta.
7	Native and Alien Fish Population Trends	1	36	Brown, Larry R., PhD. *Postdoc Task 7	Use outputs from Tasks 1-6 to assess potential population responses of native and alien fishes in the Delta under prescribed scenarios of change.	A suite of simple life cycle models for alien and native fishes in the Delta. Assessments of likely population responses of these species to projected changes in salinity, temperature and flow.
8	Project Administration	1	36	Cloern, James E., PhD. Knowles, Noah, PhD.	Coordinate information exchange between Tasks 1-7. Coordinate product dissemination, budget reporting, and delivery of progress reports.	Progress reports, budget reports, and communications to collaborators and interested stakeholders

General deliverables involving all tasks:

- Presentation of results at CALFED Science Conferences, State of the Estuary Conferences, IEP Annual Meetings, as briefings before CALFED science boards and the BDPAC;
- Publish results will appear in the IEP Newsletter, San Francisco Estuary Project's Estuary, USGS Fact Sheets, and peer reviewed journals such as San Francisco Estuary and Watershed Science, and the website Access USGS — San Francisco Bay and Delta (http://sfbay.wr.usgs.gov/)
- Semi-annual reports will be submitted every 6 months following the project start date;
- Final report will be submitted 36 months from the project start date;
- Draft manuscript(s) will be substituted for a project closure summary report and submitted 36 months from the project start date;
- Final manuscripts will be submitted after publication.

3. Selection Panel Compliance

A. To reduce the budget by 10 percent with minimal impact on the project as a whole, the following changes have been made, and are reflected in the Statement of Work as presented above:

1) The Delta hydrodynamics component will model temperature in two dimensions instead of three.

2) The contaminants component cut silver and will evaluate mercury, cadmium, and selenium.

3) The invasives component will provide annual estimates of Corbicula biomass distributions rather than seasonal.

B. To meet the selection panel's requirement of integrating this effort with other efforts: We will exchange results and elements of study design with projects at the U.S. Forest Service, U.C. Davis, U.C. Berkeley, and California Department of Water Resources. This integration with other projects will take the form of communication and meetings with members of these projects, sharing of data, and such general collaboration as is beneficial to our projects. In response to reviewers' comments, we have also contacted members of the Delta Risk Management Study and made plans to coordinate our efforts if the DRMS goes forward. Further, we will hold another workshop to which other agencies will be invited to hear and discuss the findings of CaSCADE and to help shape the final products to be produced in the project's third year.